Grant County
PUBLIC UTILITY DISTRICT
Excellence in Service and Leadership

Priest Rapids Fish Forum
Meeting

Wednesday, 4 March 2015
9:00 a.m. – 12:00 p.m.
Grant PUD, 11 Spokane St., Suite 205B, Wenatchee, WA
Call-In Number: 1-800-977-8002, Bridge: 7422882

AGENDA

- I. Welcome and Introductions (9:00 to 9:05)
- II. Agenda Review (9:05 to 9:10)
  - A. Additional Agenda Items (All)
- III. Approve February Meeting Notes (9:10 to 9:20)
  - A. Review Action Items from February meeting (All)
- IV. Update on Wanapum Dam (9:20-9:30)
- V. Update on WSMP (9:30-10:30)
  - A. Update on Juvenile Rearing (Rose and Miller)
  - B. Phase 2 Sturgeon Conservation Program (Ecopath/Ecosim) (Mott)
  - C. Decision: Release Strategy for 2015 (Jackson)
  - D. WSMP Annual Report (Mott)
  - E. Presentation on WSMP 2014 and 2015 Work (Golder/CCT)
  - F. Other White Sturgeon Items (All)
- VI. Update on PLMP (10:30-11:00)
  - A. NNI Update (Hillman)
  - B. PLMP Annual Report (Clement)
  - C. Report on the 20 Feb. fishway tour (Clement)
  - D. Other Lamprey Items (All)
- VII. Benthic Community Survey Report (11:00-11:55)
  - A. Benthic Community Presentation (EAS)
- VIII. Next Meeting: 1 April 2015 – Grant PUD Natural Resources Wenatchee Office

Grant County
PUBLIC UTILITY DISTRICT

Priest Rapids Fish Forum

Wednesday, 4 March 2015
Grant PUD Wenatchee Office

PRFF Representatives

Stephen Lewis, USFWS
Bob Rose, YN
Doris Squeochs, Wanapum
Jason McLellan, CCT
Mike Clement, GCPUD
Debbie Williams, GCPUD
Patrick Verhey, Chad Jackson, WDFW
Pat McGuire, WDOE
Aaron Jackson, Carl Merkle, CTUIR
Keith Hatch, BIA
Chris Mott, GCPUD
Tracy Hillman, Facilitator

Attendees

Kirk Truscott, CCT
Pat McGuire, WDOE
Patrick Verhey, WDFW
Paul Grutter, Golder Assoc.
Jason McLellan, CCT
Jim Powell, BCAHS (Via phone)
Donella Miller, YN
Chris Mott, Grant PUD
Brett Tiller, EAS
Tom Skiles, CRITFC (Via phone)
RD Nelle, USFWS
Chad Jackson, WDFW (Via phone)
Aaron Jackson, CTUIR
Matt Howell, CCT
Larry Hildebrand, Golder Assoc.
Mike Clement, Grant PUD
Debbie Williams, Grant PUD
Tracy Hillman, Facilitator

Distributed Items:

1. 04 March 2015 Meeting Agenda
2. 2014 White Sturgeon Management Plan
3. 2014 White Sturgeon Management Plan Annual Data Report
4. Aquatic Invasive Species Control and Prevention Plan: 2014 Annual Report
5. Relationships Between Anadromous Lampreys and Their Host Fishes in the Eastern Bering Sea
6. Assessment of the Stranding of Benthic Fauna in the Wanapum Reservoir due to Water Level Reduction - 2014

Action Items:

1. Tracy Hillman will try to secure a vote from the Yakama Nation on the juvenile sturgeon SOA.

2. PRFF will provide comments on the White Sturgeon Management Plan Annual Report to Chris Mott by Friday, 20 March 2015.

3. The Pacific Lamprey Subgroup will meet on Thursday, 19 March from 10:00 am to 4:00 pm at Grant PUD in Ephrata, WA.

Final Meeting Minutes

I. Welcome and Introductions

II. Agenda Review – No additions were made to the agenda.

   A. Meeting Minutes Approval – 04 February 2014 – Approved.

   B. Action Items from Last Meeting:

      1. Chris Mott will work with Chelan PUD to set up a conference call with Blue Leaf Environmental to discuss the use of the Ecopath with Ecosim model to estimate project area carrying capacities. **Complete.**

      2. Chad Jackson will send the revised white sturgeon release strategy SOA to Tracy Hillman for distribution to the PRFF. The PRFF will review the revised SOA and let Tracy know by Friday, 20 February if they approve the SOA. **Complete – Tracy Hillman received the revised SOA and sent it to the PRFF. Colville Tribes, Grant PUD, WDFW, USFWS, and Wanapum voted yes on the SOA. The Yakama Nation asked for more time to consider the SOA.**

      3. The PRFF can send follow-up questions to Rob O'Connor on his presentation on adult lamprey passage at Priest Rapids and Wanapum dams. **Complete.**

      4. Comments on the draft 2014 Pacific Lamprey Management Plan Comprehensive Annual Report are due to Mike Clement on Monday, 2 March. **Complete.**

      5. Tracy Hillman will send a Doodle Poll to the Pacific Lamprey Subgroup in order to identify addition meeting dates. Up to three meeting dates will be selected for the Subgroup. **Complete. The next meeting will be held on 19 March from 10:00-4:00 at Grant PUD, Ephrata, WA.**

      6. Grant PUD has scheduled a tour of the fish ladders at Wanapum and Priest Rapids dams on Friday, 20 February. Participants are to let Mike Clement know by 17 February if they intend to join the tour. **Complete – Patrick Verhey was the only attendant. Potential modifications to the OLAFT were identified. Gaps below the picketed lead need to be large enough to allow lamprey to pass the picketed leads and bypass the deneil. Mike Clement will discuss this with Tom Dresser, who will inform the PRCC of modifications being made to the OLAFT.**

III. Update on Wanapum Dam and Fish Passage – Mike Clement gave an update on the status of Wanapum Dam. Three of the 39 tendons remain to be installed. Engineers estimate that Wanapum Pool can be raised to 571.5 feet by 1 April. Grant PUD will seek approval from the Board of Consultants and FERC. Modifications to the trash rack have worked well. It is undecided if the temporary metal screen will be removed in the dry before the pool raise, or after, by divers.

IV. Update on White Sturgeon Management Plan (WSMP)

   A. Update on Juvenile Rearing (Rose and Miller) – February update was distributed to the PRFF by Tracy Hillman. In summary, juvenile sturgeon rearing at Marion Drain are doing well. Growth of juvenile sturgeon in 2014-2015 is similar to growth of juveniles in previous years.

   B. Phase 2 Sturgeon Conservation Program (Ecopath/Ecosim) – Chris Mott reported that he met with Cory Wright from Blue Leaf Environmental. Chris noted that Cory is concerned with the carrying capacity component of the model and is not sure the model will do what the PRFF wants it to do. Tracy Hillman noted that the PRFF will likely be the first to use the model with white sturgeon. Chris and Mike Clement will continue to look into the Ecopath with Ecosim model with help from Blue Leaf Environmental.

C. **SOA on Juvenile White Sturgeon Release Strategy for 2016** – Tracy Hillman reported that he received affirmative votes from the Colville Tribes, Grant PUD, WDFW, USFWS, and Wanapum on the juvenile sturgeon SOA. He said that the Yakama Nation asked for more time to consider the SOA. Tracy asked Donella Miller if the Yakama Nation was prepared to provide their vote. She indicated that she would speak with Bob Rose about the SOA. Tracy will continue to seek a vote from the Yakama Nation on the SOA.

D. **WSMP Annual Report** – Tracy Hillman reported that comments on the White Sturgeon Management Plan Annual Report are due on Friday, 20 March 2015.

E. **Presentation on WSMP 2014 and 2015 Work** – Paul Grutter with Golder and Jason McLellan with the Colville Tribes gave presentations on sturgeon monitoring within the Priest Rapids Project Area (see Attachment 1). Paul noted that the highest catch rates for sturgeon broodstock were recorded during the first four days of the sample program; thereafter catch rates declined sharply coinciding with a rapid decrease in total river discharge. Paul said that in the first four days of broodstock fishing, they caught four ripe fish (two females and two males). Because Marion Drain had so many fish on station, the females were released. Only one ripe male was transported to Marion Drain. Enough milt was taken from the males for the rest of the season. Larry Hildebrand commented that male CRITFC sturgeon are getting large enough to enter the window of breeding. Paul reported that less fin deformities were seen in the CRITFC fish this season. Paul recommended that future broodstock capture efforts should focus on providing support for the broodstock capture program downstream from McNary Dam.

When asked about the lack of growth and the increased fin deformities of juvenile sturgeon held at Marion Drain during the period of dispute resolution last summer, Larry Hildebrand said he had no explanation. He noted that because deformities increased and size didn't, a lack of food could have been a cause. He explained that after the initial release of the largest fish, densities of the smaller fish in the second release would have been lower, which would lead one to believe that fin deformities would have decreased, not increased.

Jason McLellan reported that although juvenile sturgeon catch rates within the project area were relatively low, hatchery sturgeon were distributed widely throughout both reservoirs. He recommended that the PRFF consider releasing juvenile hatchery sturgeon in downstream, deep-water sites to limit possible density-dependent effects in upstream reaches.

Paul Grutter concluded the presentation by reviewing and describing the objectives and tasks of the 2015 sturgeon study plan. Mike Clement said that on 16 March, a conference call will be held to discuss broodstock collection logistics. Everyone is invited to participate.

V. Update on PLMP

A. **NNI Update from the Pacific Lamprey Subgroup** – Tracy Hillman reported that the Pacific Lamprey Subgroup met on 29 January to discuss how the PRFF should address NNI for Pacific lamprey. The Subgroup discussed a seven-step process for establishing an NNI Agreement. As part of the seven-step process, they began discussing possible draft recommendations for an NNI Agreement. Those included possibly setting up a Pacific Lamprey NNI Fund. The draft proposal envisions that annual contributions by Grant PUD would provide funds for use by the PRFF to implement Pacific Lamprey NNI measures in order to satisfy Section 4.1 (*Objective 1: No Net Impact (NNI). Identify, address, and fully mitigate Project effects to the extent reasonable and feasible*) and Section 4.2 (*Objective 2: Provide safe, effective, and timely volitional passage for* *adult upstream and downstream migration*) of the PLMP. The NNI Account would be an adaptive compromise measure to achieve NNI where the PRFF is unable to determine Project effects on the downstream passage of juvenile lamprey and upstream passage of adults. This Fund would be an interest-bearing account that would be under the control of the PRFF, similar to the PRCC Habitat Account, if approved. Money from this fund could be used to address translocation and monitoring of translocation activities, tracking adults to spawning areas in tributaries, reducing juvenile entrainment into irrigation facilities, and propagation of juvenile lamprey into tributaries. Other activities identified in the PLMP and License would continue as planned.

The next Subgroup meeting will be on Thursday, 19 March from 10:00 am to 4:00 pm at Grant PUD in Ephrata, WA.

B. **PLMP Annual Report** – Mike Clement reported that he received comments from Tom Skiles on the Pacific Lamprey Management Plan Annual Report. Mike is in the process of addressing those comments.

C. **Other Lamprey Items** – Mike Clement received the Rock Island data files from Steve Hemstrom, Chelan PUD. Mike noted that passage of adult lamprey at Rock Island was not able to be discerned because only one of three ladders at Rock Island had detection last summer. A 2015 study plan related to adult trapping, tagging, and release at Priest Rapids will be distributed to the PRFF by Grant PUD.

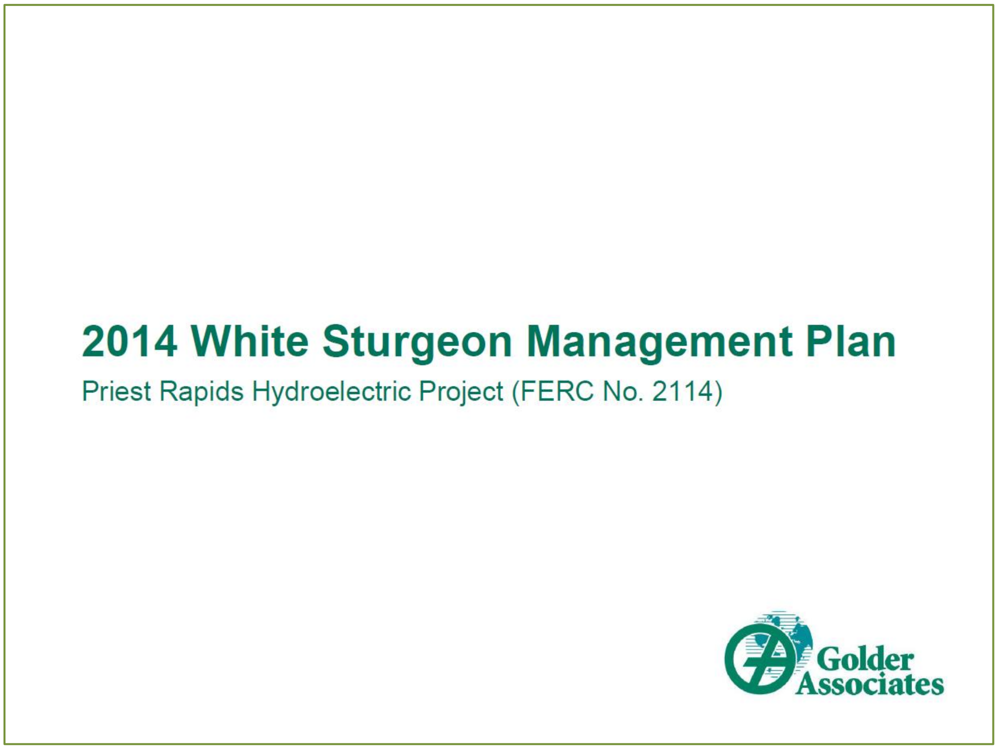
VI. **Benthic Community Survey Report** – Brett Tiller, Environment Assessment Services, gave a presentation on benthic organisms stranded during the Wanapum pool drawdown due to the fracture discovered in February 2014 (see Attachment 2). Brett identified the freshwater mollusk species composition and densities in areas that were dewatered and he described the potential effects of the reduced water level on those organisms. In addition, he estimated freshwater mussel densities in areas unaffected by the water-level reduction (unexposed regions remaining and within shoreline areas where water levels fluctuate during routine hydropower operations). Finally, he identified fish and other organisms found in areas that were dewatered.

Brett indicated that about 14.7 km^2 of riverbed area was dewatered in 2014. These dewatered regions contained relatively high densities of native freshwater mussels and upriver segments contained several relatively rare or uncommon Molluscan taxa. His studies also demonstrated that native freshwater mussels persisted in non-dewatered areas. In addition, dewatered regions contained roughly 10 km^2 of Type I and II lamprey habitat. Finally, he indicated that he is uncertain about the rate at which rare or uncommon Molluscan taxa will recolonize dewatered regions.

VII. **Next Meeting** – 1 April 2015 at Grant PUD in Wenatchee, WA.

Attachment 1

Presentation by Paul Grutter and Jason McLellan on the 2014 White Sturgeon Management Plan



2014 White Sturgeon Management Plan

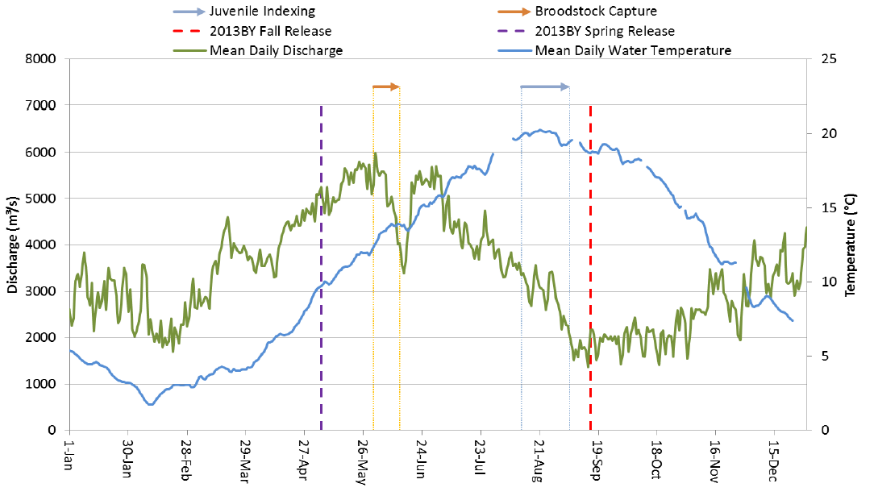
Priest Rapids Hydroelectric Project (FERC No. 2114)

Golder Associates

Methods

- Discharge and Temperature
- 2013BY Marking and Release
  - Two release dates May 6, 2014 and mid-September, 2014
- Broodstock Capture
  - Angling – Focused on the 5 km section of river below Rock Island Dam in Wanapum Reservoir. May 31, 2014 to June 13, 2014
  - Fish Handling, Processing and Transport
- VR2W Telemetry Array Download and Maintenance
  - Wanapum Reservoir – 2 VR2W stations lost, 1 station removed
  - Priest Rapids Reservoir – 3 VR2W stations lost
- Juvenile Movement

Results – Discharge and Temperature



Mean daily discharge and mean hourly water temperature, as measured below Wanapum Dam.

Results – 2013BY Mark and Release

Release number and mean fork length and weight of the 2013BY juvenile White Sturgeon released in the PRPA, 2014.

	May 2014 Release			September 2014 Release			PRPA 2014 Total		
Release Location Reservoir (River Mile)	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**
Wanapum (421.5)	3331(32)	266 (40)	118 (53)	1762(20)	291 (44)	151 (75)	5093 (52)	275 (43)	129 (63)
Priest Rapids (415.6)	997(9)	272 (42)	131 (56)	504(5)	281 (43)	135 (73)	1501(14)	275 (42)	132 (63)
Total	**4328(41)**	268(41)	121(54)	**2266(25)**	289 (44)	147(75)	**6594(66)**	275 (43)	130 (63)

- All fish produced, tagged and processed at Marion Drain Hatchery
- 66 of the 2013BY release implanted with acoustic telemetry tags (52 in Wanapum reservoir and 14 in Priest Rapids reservoir)
- 2013BY juveniles exhibited a high incidence of fin deformities, with deformities recorded for approximately 51% of the May release and 90% of the September release

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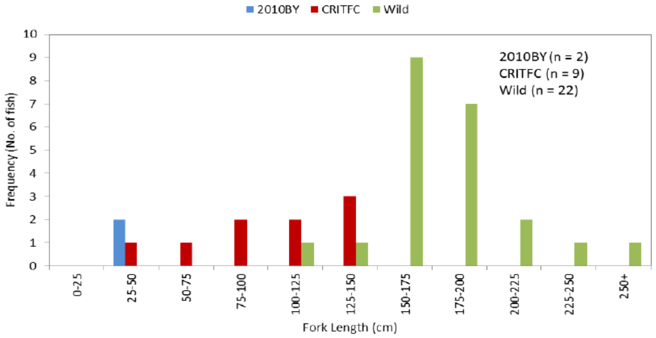
Results – Broodstock Capture



Length–frequency of wild and hatchery (2010BY and CRITFC)

- 33 White Sturgeon angled below Rock Island Dam in 2014 (22 wild, 11 hatchery, CPUE = 0.03 fish/hook-hours)
- Annual growth rates of recaptured fish were consistent with previous findings that White Sturgeon in the PRPA were growing and smaller fish generally grow at a faster rate than larger fish
- 1 of 33 wild fish captured in Wanapum Reservoir warranted transport to MDH to supplement the broodstock

Results – Broodstock Capture

Acoustic Telemetry Tagging

- 6 adult White Sturgeon captured during the Broodstock collection program were tagged with acoustic telemetry transmitters

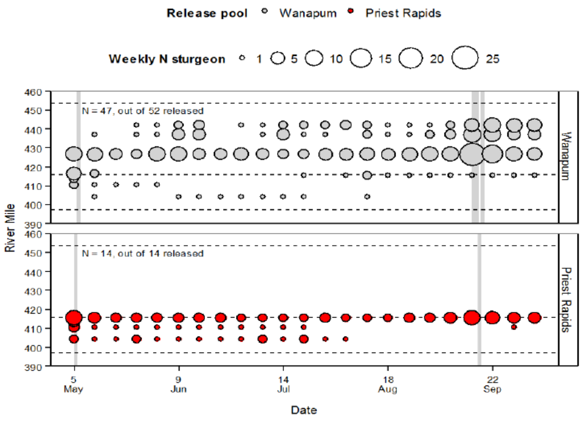
White Sturgeon Diet Assessment

- During the 2014 program three 2003BY CRITFC White Sturgeon were sacrificed to examine stomach contents.
- Crayfish, crayfish claws, carapace fragments and a complete unidentified salmonid found in one White Sturgeon.

Avian Predation

- 143 PIT-tags from 2010BY and 2012BY were detected and identified at a known bird colony in the forebay of Rock Island Dam. PIT-tags from 2013BY were not detected as of October 9, 2014.

Results – 2013BY Juvenile White Sturgeon Movement



Weekly counts of acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014.

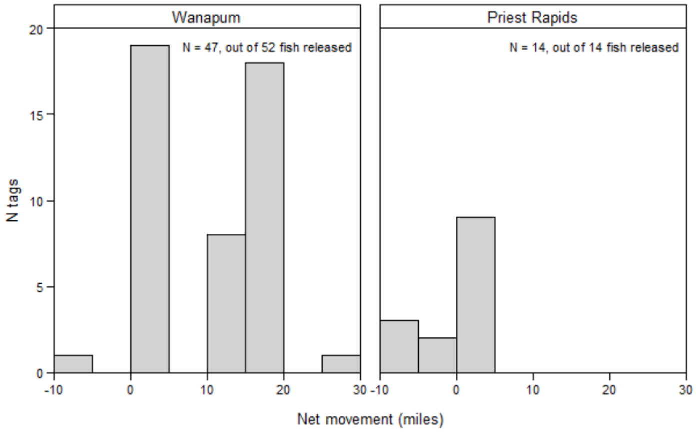
Wanapum Reservoir

- Fish initially moved both up- and downstream from the RM 421.5 release location after May 6 release date.
- By mid summer most fish were upstream of release location.
- 3 of the 52 acoustic-tagged fish released in Wanapum were entrained into Priest Rapids Reservoir. Entrained fish were from May release

Preist Rapids Reservoir

- Fish dispersing downstream from release site (RM 416.5) were recorded throughout May to early August and late September.

Results – 2013BY Juvenile White Sturgeon Movement



Histograms of net movement (sum of all RM changes) of 2013BY fishfor acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014. Negative values represent downstream movements.

Discussion – Juvenile White Sturgeon Release

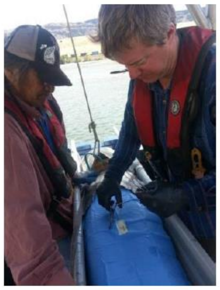
- All future Wanapum Reservoir releases should occur at Rocky Coulee launch (RM 421.5) due to reduced transport time, ease of access and likely reduced avian predation pressure on juvenile compared to upstream release locations.
- Two separate release events provide an opportunity to examine the effect of seasonal release timing and the effect of size at release on aspects of juvenile White Sturgeon dispersal, survival and downstream entrainment.

Discussion – Broodstock Capture

- In 2014, highest catch rates were recorded in the initial four days of the sample program; thereafter catch rates declined sharply coinciding with a rapid decrease in total river discharge.
- Future Grant PUD broodstock capture efforts may be better spent on providing support for the capture program below McNary Dam.

Discussion – Movement of Acoustic Tagged Juveniles

- Consistent with other juvenile broodyear releases, the 2013BY were more frequently detected by receivers located at RM442.0 and RM426.5 in Wanapum Reservoir and at RM415.5 in Priest Rapid Reservoir
- Restoration of the VR2W stations lost in 2014 is a priority. A revised anchoring system will be implemented in 2015 in the hopes of improving station longevity.



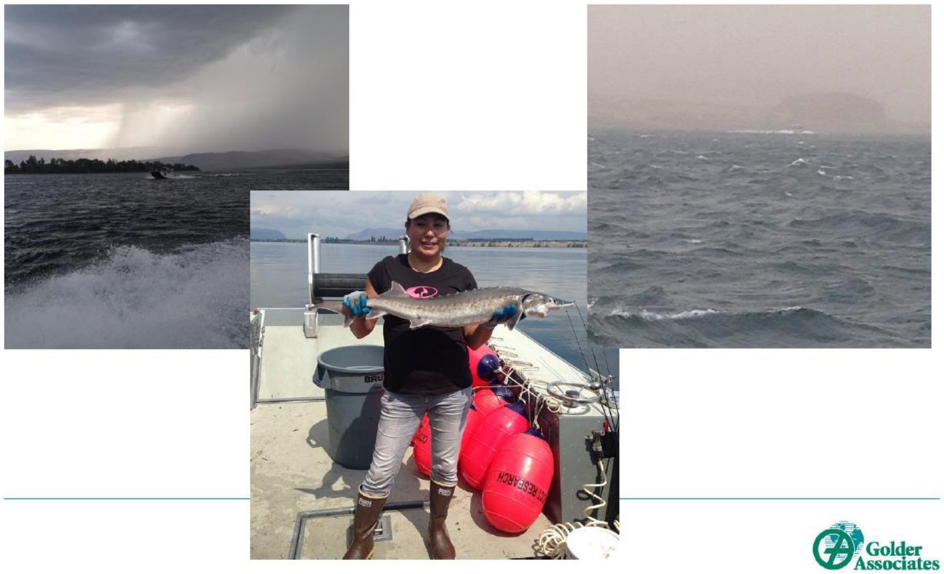
Discussion – Juvenile Entrainment

- Entrainment rate of 2013BY release was 5.8% (October 8 2014); this was likely an underestimate

Entrainment rate for acoustic tagged juvenile White Sturgeon

Release Details				Entraining Dam (RM)	Number Entrained	Percent Entrainment (%)
Pool	Year	N	Release RM			
Priest Rapids	2011	21	415.6	Priest Rapids (397.1)	2	9.5
Priest Rapids	2013	6	415.6	Priest Rapids (397.1)	0	0.0
Priest Rapids	2014	14	415.6	Priest Rapids (397.1)	0	0.0
Subtotal		**41**			**2**	**4.9**
Wanapum	2011	70	450.6	Wanapum (415.6)	9	12.9
Wanapum	2013	24	450.6/442.0	Wanapum (415.6)	0	0.0
Wanapum	2014	52	421.5	Wanapum (415.6)	3	5.8
Subtotal		**146**			**12**	**8.2**

2014 Juvenile Indexing

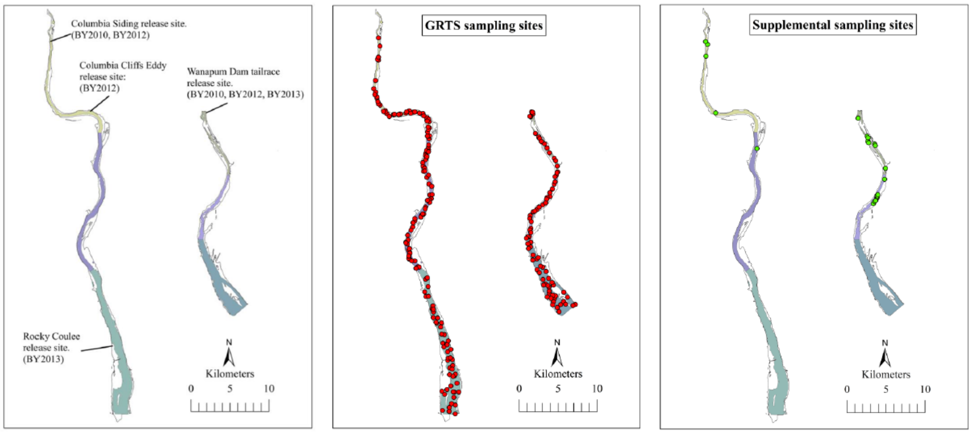


Setline Gear

- 183 m (600 ft) setlines (1/4” three strand nylon, tarred)
- 40 gangions per line
- Dacron line (80lb and 130lb test) with airline tubing sheath
- Gamakatsu Octopus circle hooks (2/0, 4/0, 6/0, 8/0)
- Pickled squid as bait

Unequal probability GRTS Design

	Reservoir and section							
	Wanapum (25-29 August and 2-5 September)				Priest Rapids (12-14 and 18-22 August)			
	Lower	Middle	Upper	All	Lower	Middle	Upper	All
Number of sample sites								
Specified spsurvey draw	50	50	50	150	40	20	20	80
Actual sample	51	55	44	150	39	24	17	80
Sampling area (Ha)	2,185	941	551	3,677	1,369	346	213	1,928
Samples/100Ha	2.3	5.8	8.0	4.1	2.9	6.9	8.0	4.2

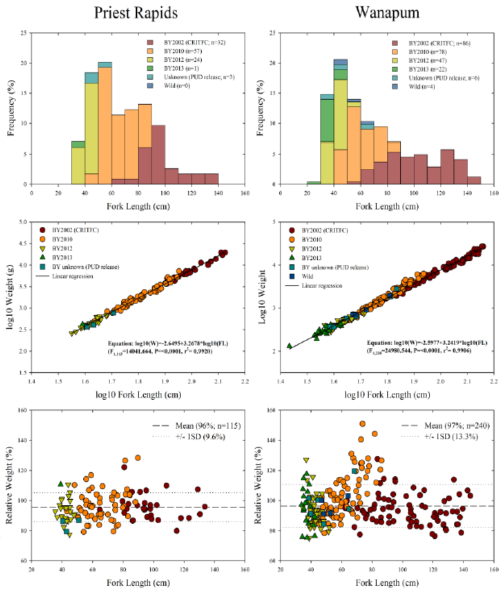


Catch

Brood Year	Release reservoir	# released	Capture reservoir and sampling type						Total
			Wanapum			Priest Rapids			
			GRTS	Supp.	Total	GRTS	Supp.	Total	
2002	Rock Island	≈20,600	78	11	89	24	9	33	122
2010	Rocky Reach	6,376	18	--	18	2	--	2	20
	Wanapum	7,016	57	4	61	4	3	7	68
	Priest Rapids	2,101	--	--	--	39	9	48	48
2012	Wanapum	2,264	48		48	--	--	--	48
	Priest Rapids	1,717	--	--	--	17	7	24	24
2013	Wanapum	3,331	22	--	22	--	--	--	22
	Priest Rapids	997	--	--	--	--	1	1	1
Unknown (Hatchery)	Unknown (PUD)	NA	6	--	6	3	--	3	9
Unknown (Wild)	NA	NA	4	1	5	--	--	--	5
All sturgeon	NA	NA	233	16	249	89	29	118	367

- Five sturgeon were captured twice (i.e., 362 individuals were handled during study)
- An additional 16 sturgeon were lost at boat
- Bycatch: 381 Nothern Pikeminnow, seven Largescale Sucker, one Carp, one Channel Catfish.

Size and Condition



BY (program)	Fork Length (cm)				
	n	mean	SD	min	max
2002 (CRITFC)	118	101.6	22.0	58.3	145.8
2010 (CPUD)	20	65.0	8.8	51.0	85.5
2010 (GPUD)	115	62.1	11.8	41.8	89.7
2012 (GPUD)	71	42.4	3.6	34.3	52.0
2013 (GPUD)	23	37.2	3.4	27.1	42.4
Unknown (Hatchery)	9	48.7	10.9	38.5	68.4
2010-2013 (All PUD)	238	53.6	13.9	27.1	89.7
Wild	5	82.4	66.0	46.9	199.8
All sturgeon	361	69.6	29.0	27.1	199.8

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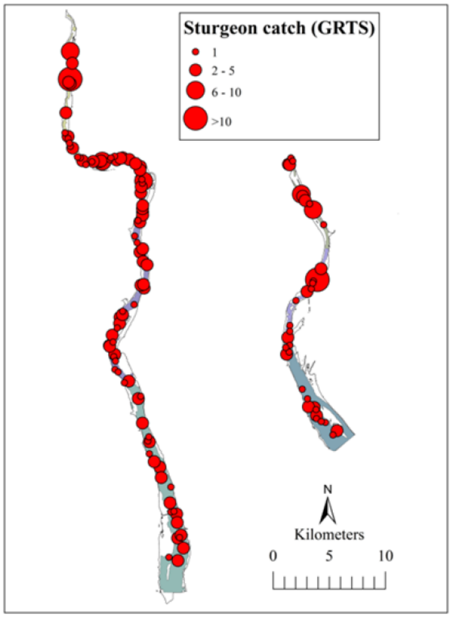
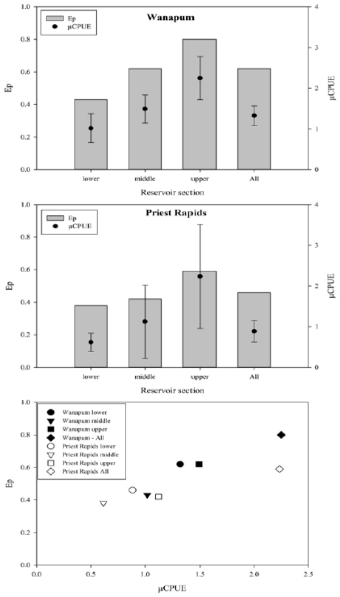
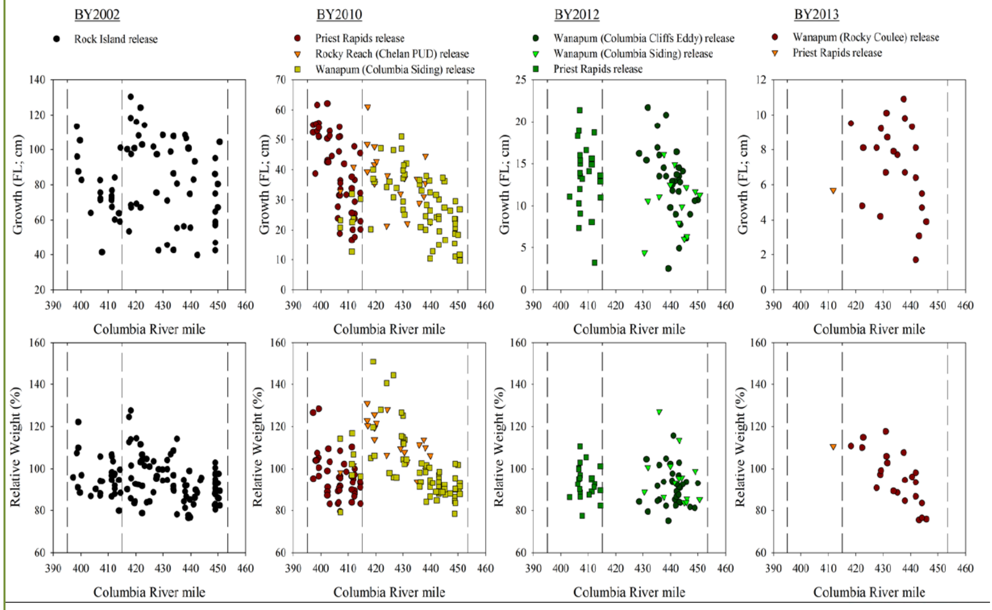
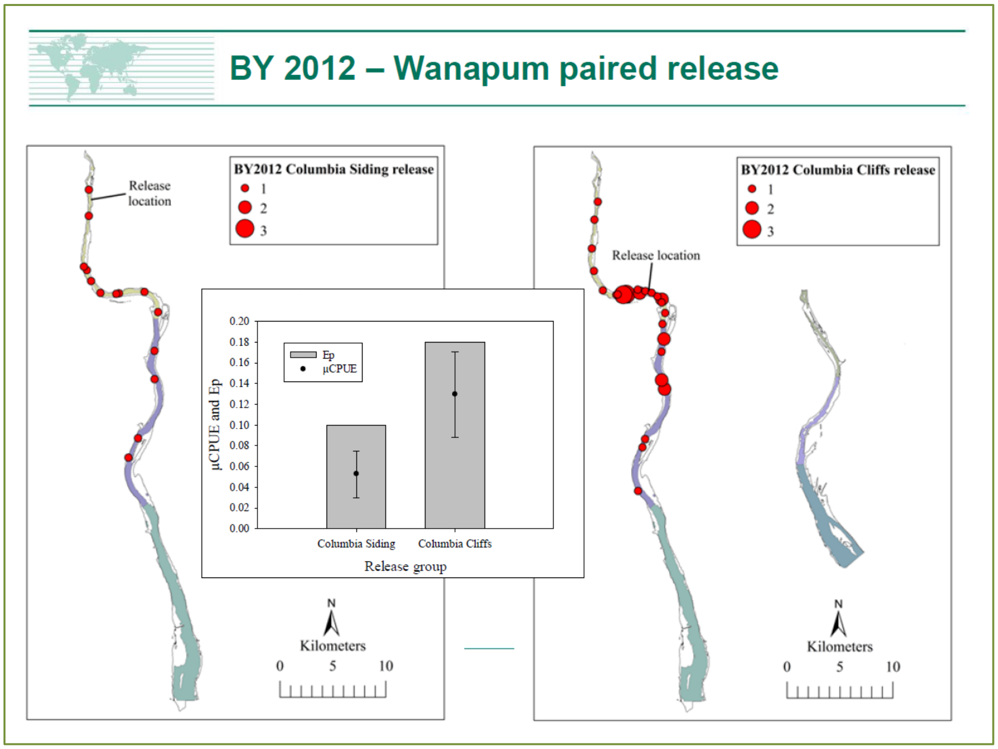
Catch Distribution (GRTS samples)



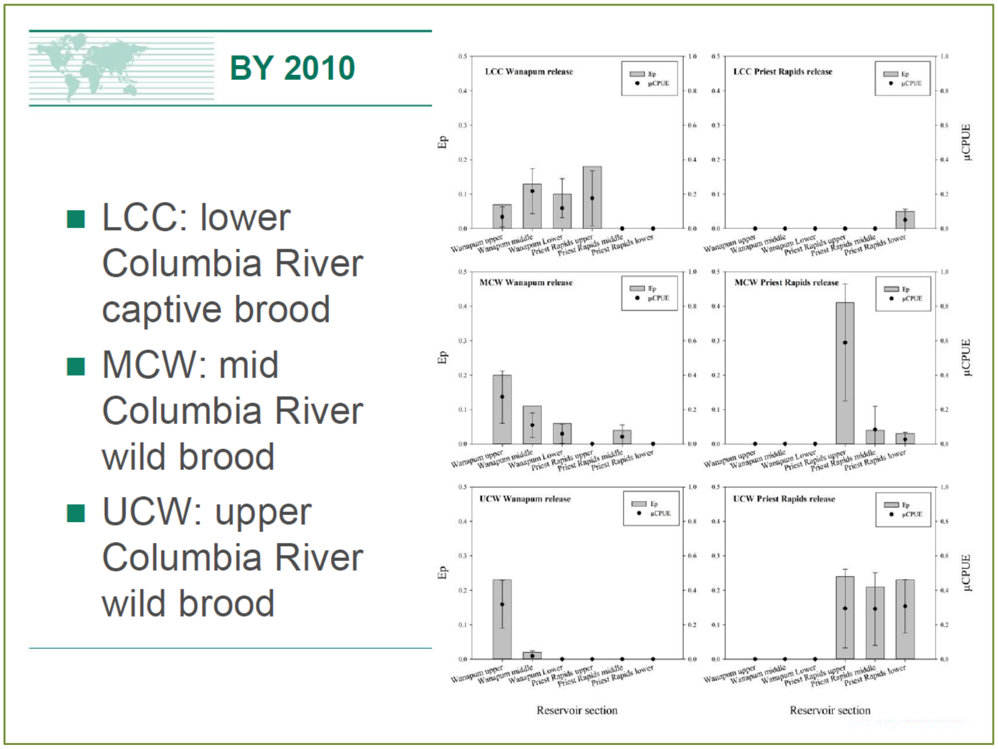


Growth





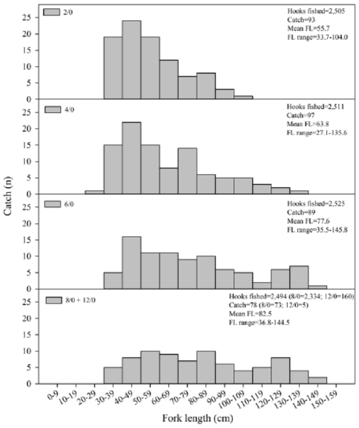
BY 2012 – Wanapum paired release

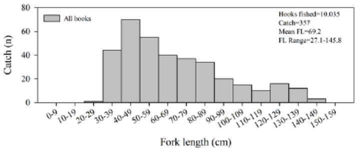


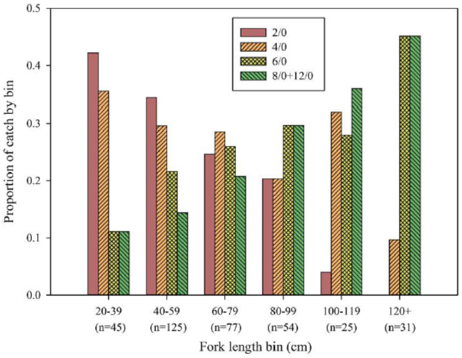
BY 2010

- LCC: lower Columbia River captive brood
- MCW: mid Columbia River wild brood
- UCW: upper Columbia River wild brood

Setline gear performance







- 3.7% (367 of 10,035) of all overnight hook sets resulted in a sturgeon capture (i.e., a sturgeon that was successfully landed and processed).
- An additional 4.6% (n=457) of hook sets were lost due to gangion line breakage (2.8%; n=285) or were bent or broken (1.7%; n=172) at retrieval.

Golder Associates

Conclusions

- Hatchery sturgeon are distributed widely throughout both reservoirs
- Catch rates were relatively low:
  - Improve retention rates
    - Use stronger gangion line (e.g., wire leader)
    - Use same hook sizes but more robust hooks
  - Maintain similar level of effort (# of overnight sets) in future surveys
- Consider downstream, deep water sites for future hathery releases (esp. Wanapum) to limit possible density dependent effects in upstream reaches.

Golder Associates

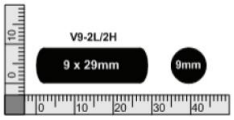
2015 WSMP Study Plan

Table 3. The 2015 WSMP Study Objectives and Tasks

WSMP Objective	WSMP Task No.	Task
1	2	Conservation Aquaculture and PRFF Support
1	3.1	Juvenile Marking
1	3.2	Juvenile Transport
2	1	Juvenile Movement Assessment
2	3	Adult Indexing (Capture-Recapture)
4	1	Evaluation of Existing Spawning Use
4	2	Hatchery White Sturgeon Growth, Survival, and Stocking Rate Adjustment
4	3	Database Management and Development Requirements
4	4	Annual WSMP Report

Objective 1 Task 3.1 – Juvenile Marking (2015)

- Processing and tagging of the 2014BY will be conducted by LGL staff based out of Sidney BC, with the support of BLE staff based in Ellensburg, WA.
- All fish to be released will be tagged with glass 12.5 mm, 134 kHz ISO PIT tags. 1% of fish to be released will also be tagged with a Vemco V9-2L hydroacoustic tag.
- Tags will be implanted using standard surgical procedures and prior to release, all fish will be held for up to two weeks to allow for healing.



Objective 1 Task 3.2 – Juvenile Transport (2015)

- 2014BY release scheduled for first or second week of May, 2015
- BLE staff will coordinate and transport juvenile White Sturgeon from MDH to release locations in Wanapum and Priest Rapids reservoirs (77% of juveniles in Wanapum and 23% in Priest Rapids).
- Chelan PUD will provide fish transport truck, driver and all necessary equipment to safely release the juvenile White Sturgeon.

Objective 2 Task 1 – Juvenile White Sturgeon Movement Assessment (2015)

- Due to the loss of 6 VR2W stations in 2014, future monitoring programs will require that all stations are removed and fully serviced every 3 years.
- In April 2015 the 6 monitoring stations lost in 2014 will be redeployed.
    - Relocated the PRTR station back to RM396.1.
    - Forebay stations relocated to safety booms.
    - Metal frame bottom deployments at select locations.
- Remaining 6 monitoring stations retrieved and weak materials or connections replaced.

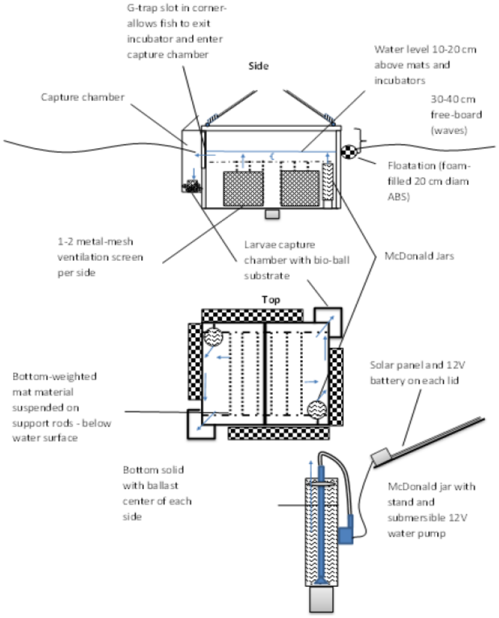
Objective 2 Task 3 – Adult Indexing (2015)

- Capture/re-capture study in fall 2015 to obtain population data on adult and sub-adult White Sturgeon in Wanapum and Priest Rapids reservoirs.
- 182 individual set line sample sets deployed over two 14-day sample sessions in fall 2015. Setline deployment locations determined using GRTS design.
- Setline will use baited barbed hooks of three different sizes: 12/0, 14/0, 16/0.
- Captured adults will be scanned for PIT tags, checked for marks of previous capture, and PIT tagged. Life history attributes including fork length, weight, sex and reproductive status. Soft tissue will be collected for DNA analysis.
- Up to 10 Vemco V16 -6H acoustic tags will be implanted in adult White Sturgeon.

Objective 4 Task 1 – Evaluation of Existing Spawning Use (2015)

- Egg collection mats deployed below Rock Island Dam to capture wild spawned White Sturgeon eggs to determine spawn timing and number of events.
- 11 to 15 paired egg collection mat sites inspected daily.
- Eggs will be enumerated and a sub-sample will be preserved and/or photographed for developmental stage identification.

Objective 4 Task 1 – Evaluation of Existing Spawning Use (2015)

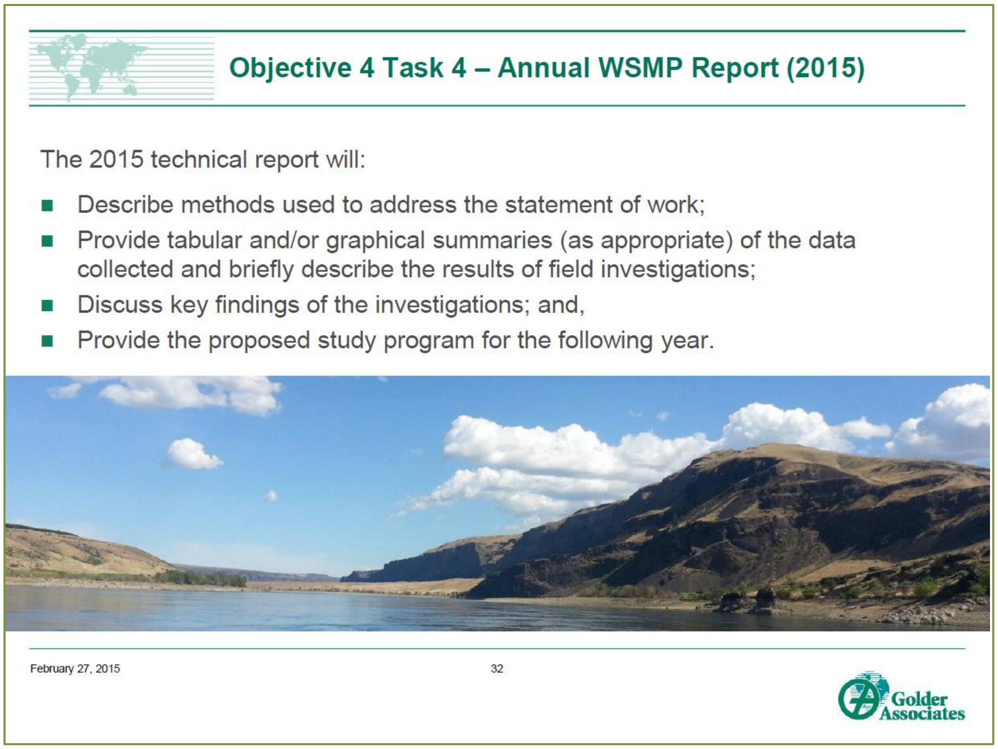


- Redesigned floating *in situ* incubator for 2015
- Incubator moored in eddy approx. 3.5 km downstream of Rock Island Dam.
- Egg-laden mat material will be removed from metal mat frame and suspended within incubator.
- Larvae transferred to MDH.

Objective 4 Task 3 – Database Management and Development Requirements

All indexing databases will be updated with the following variables:

- Annual stocking data (fish lengths, weights, deformities, scute marks, PIT tag number)
- Annual index monitoring results (lengths, weights, deformities, capture location, scute marks, PIT or sonic tag number)
- Annual results obtained from tracking actively tagged juveniles (location records)



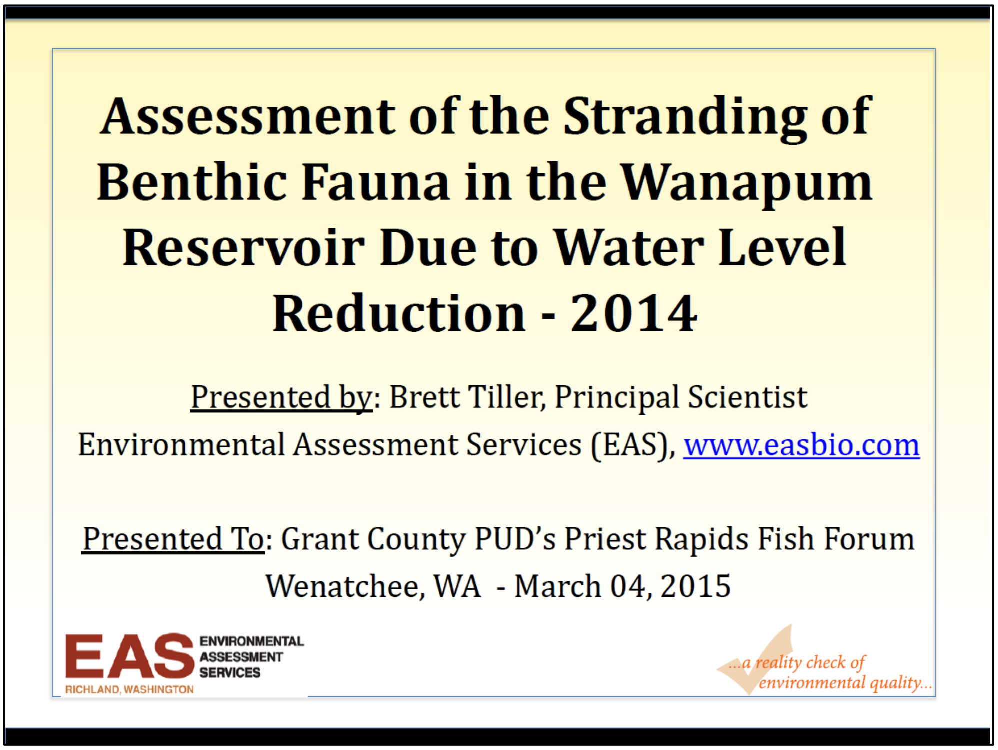
Objective 4 Task 4 – Annual WSMP Report (2015)

The 2015 technical report will:

- Describe methods used to address the statement of work;
- Provide tabular and/or graphical summaries (as appropriate) of the data collected and briefly describe the results of field investigations;
- Discuss key findings of the investigations; and,
- Provide the proposed study program for the following year.

Attachment 2

Presentation by Brett Tiller on Stranding of Benthic Fauna in the Wanapum Reservoir in 2014



Assessment of the Stranding of Benthic Fauna in the Wanapum Reservoir Due to Water Level Reduction - 2014

Presented by: Brett Tiller, Principal Scientist
Environmental Assessment Services (EAS), www.easbio.com

Presented To: Grant County PUD's Priest Rapids Fish Forum
Wenatchee, WA - March 04, 2015

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Acknowledgments

Mike Clement and Tom Dresser — Grant County PUBLIC UTILITY DISTRICT *Excellence in Service and Leadership*

Mark Timko & Co. — BLUE LEAF ENVIRONMENTAL

Ed Johannes — Deixis Consultants

Jeff Korth, Chad Jackson, Bruce Baker, Peter Vernie, Anita Victory — Washington Department of FISH and WILDLIFE

Objectives

1) Characterize freshwater mollusk species composition and densities in areas that were dewatered as a result of the 2014 water-level reduction and describe potential effects of the reduced water level on these organisms.

2) Assess freshwater mussel densities in areas unaffected by the water-level reduction (unexposed regions remaining and within shoreline areas where water levels fluctuate during routine hydropower operations).

3) Document fishes and other organisms present in areas that were dewatered.

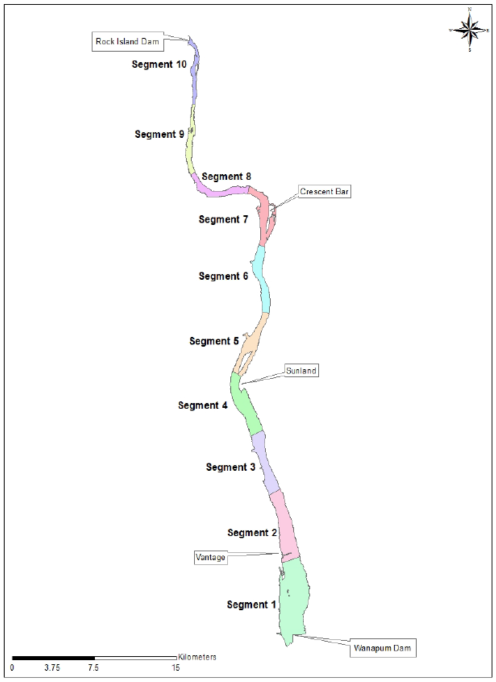
Overview

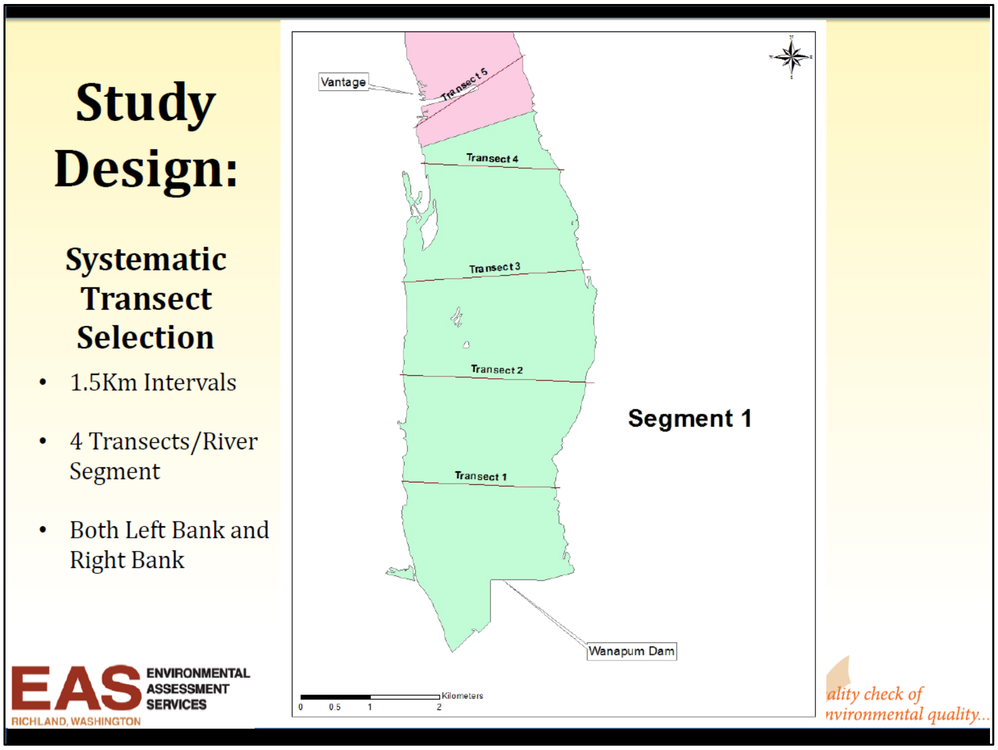
- Study Designs / Methods
- Results
    - Native Freshwater Mussels
    - Snails and Peaclams
- Other Observations
- Recovery Perspectives
- Summary
- Questions / Comments

Study Design:

Hydro-Geomorphic Stratification

- 60Km Long Study Area
- 10 River Segments
- 6Km per Segment





Study Design:

Systematic Transect Selection

- 1.5Km Intervals
- 4 Transects/River Segment
- Both Left Bank and Right Bank

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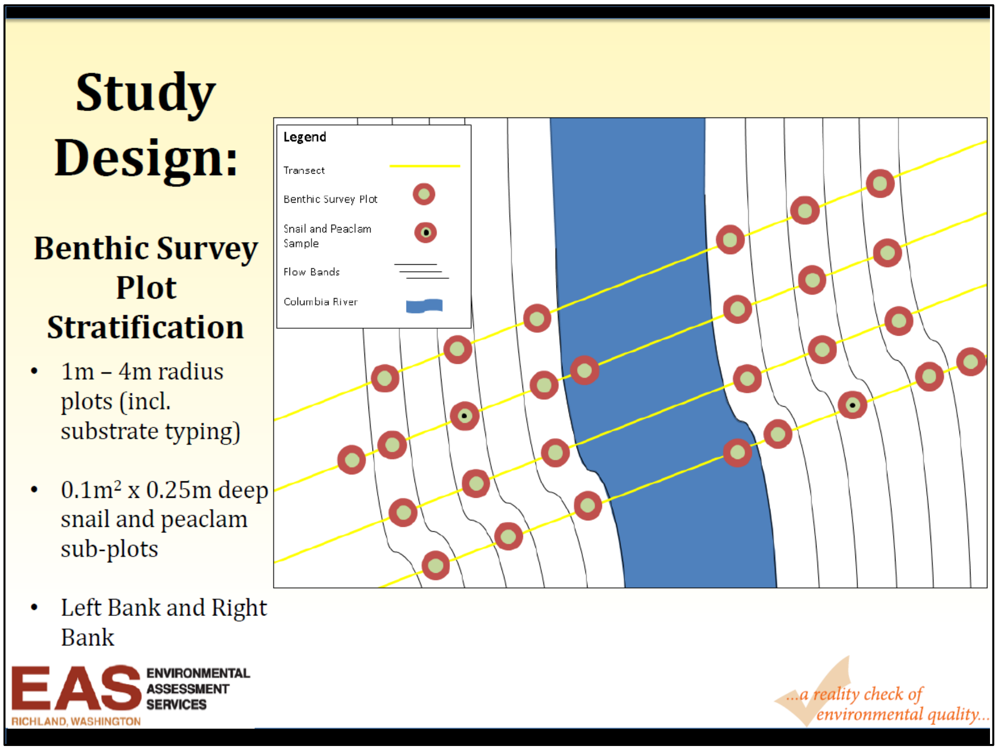

Study Design:

Benthic Survey Plot Stratification

- 1m – 4m radius plots (incl. substrate typing)
- 0.1m² x 0.25m deep snail and peaclam sub-plots
- Left Bank and Right Bank

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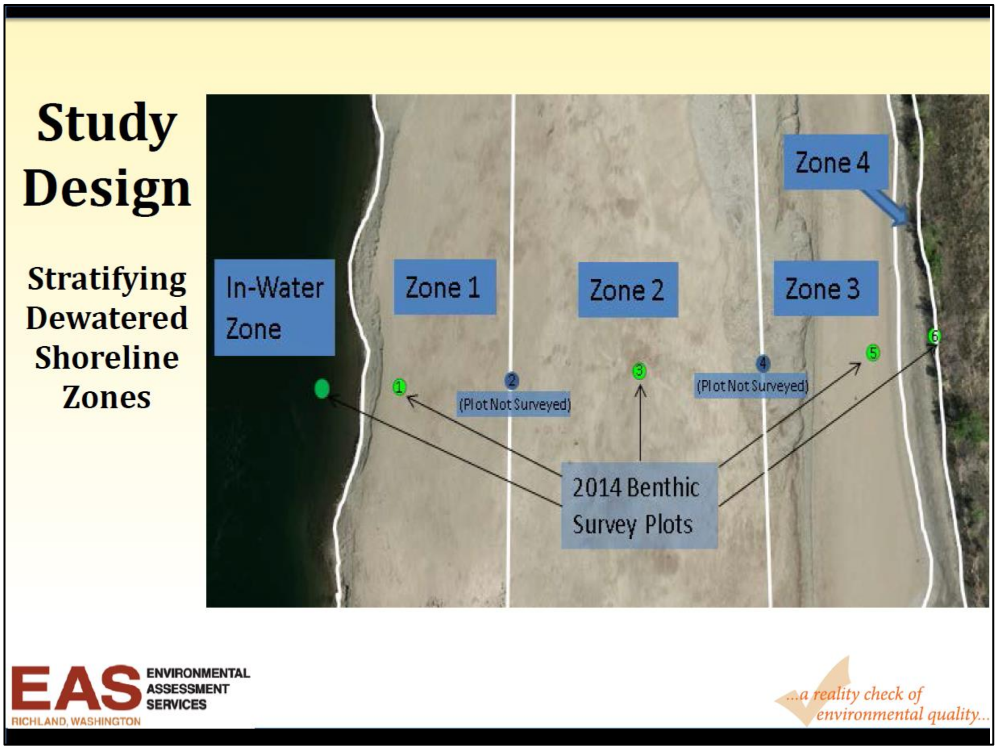

Study Design

Stratifying Dewatered Shoreline Zones

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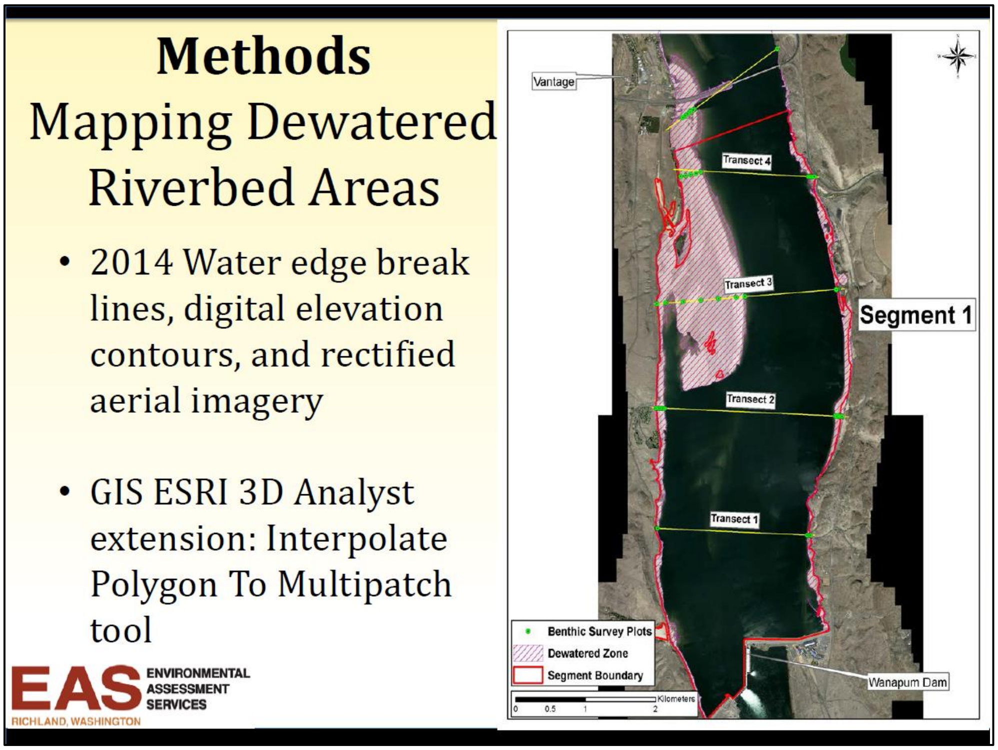

Methods

Mapping Dewatered Riverbed Areas

- 2014 Water edge break lines, digital elevation contours, and rectified aerial imagery
- GIS ESRI 3D Analyst extension: Interpolate Polygon To Multipatch tool

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Sample Sizes

	River Segment										
	1	2	3	4	5	6	7	8	9	10	Total
Snails and fingernail clam Plots	6	0	3	1	4	2	4	3	3	2	28
Mussels Survey Plots	26	15	22	17	20	26	28	26	27	26	233

Zone	# Plots	Sum of Plot Area (m^2)
1	79	2499
2	68	2533
3	67	2714
4	19	314
Total	233	8060

Depth (ft) below Water Line	# Plots	Sum of Plot Area (m^2)
10	19	955
15	5	63
20	5	63
25	5	63
30	5	63
Total	39	1206

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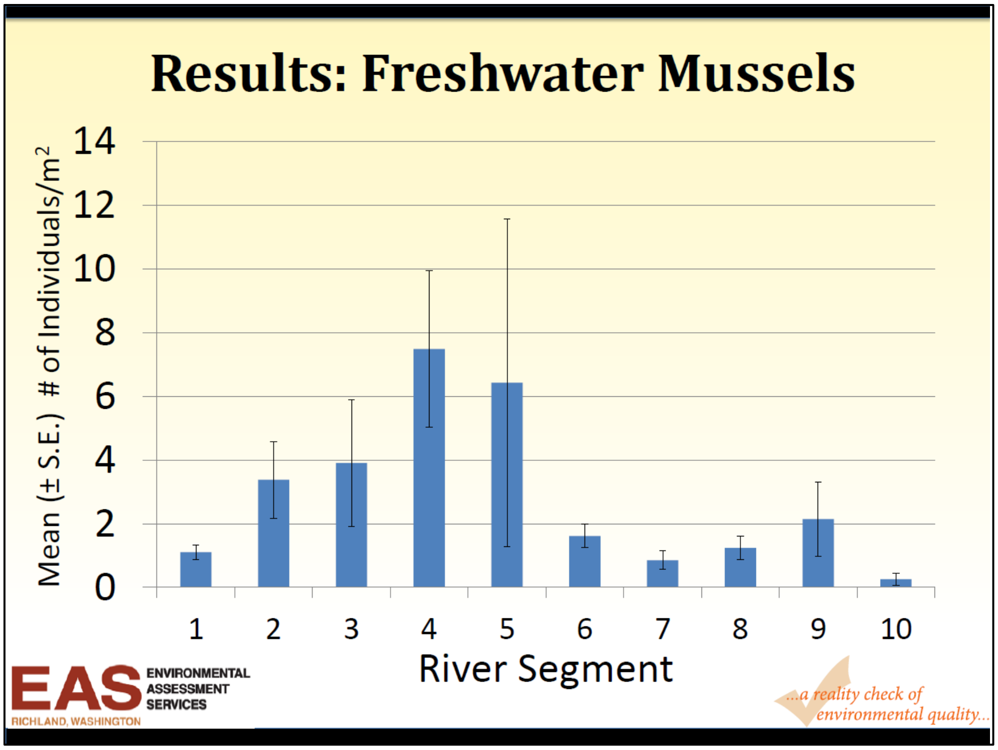

Results: Freshwater Mussels

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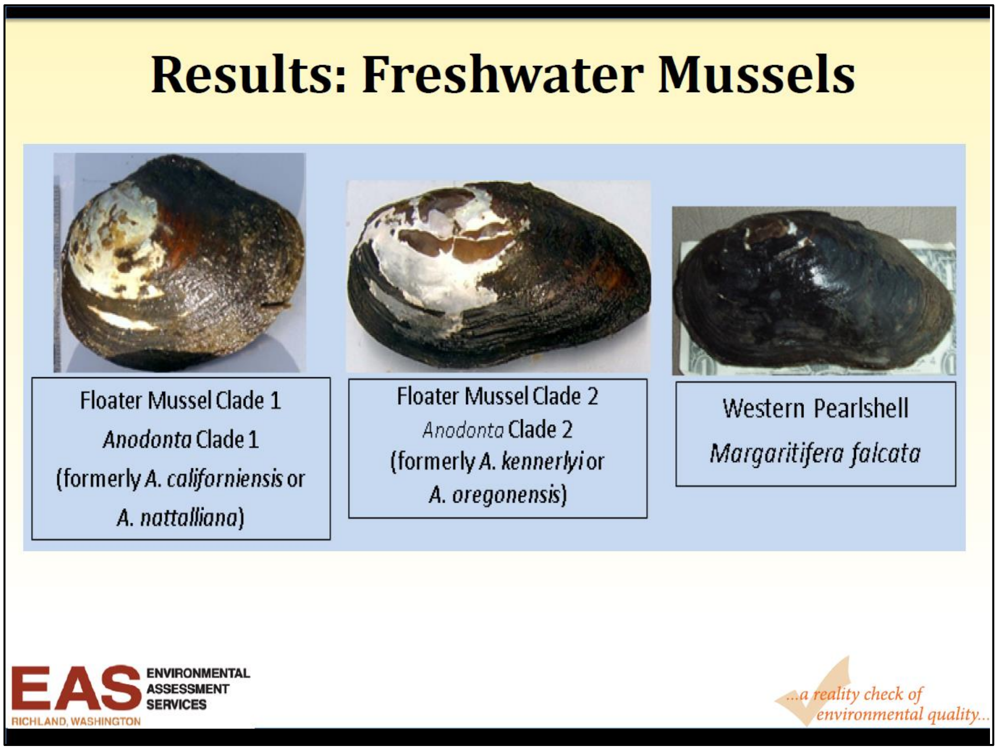

Results: Freshwater Mussels

Floater Mussel Clade 1
Anodonta Clade 1
(formerly *A. californiensis* or *A. nattalliana*)

Floater Mussel Clade 2
Anodonta Clade 2
(formerly *A. kennerlyi* or *A. oregonensis*)

Western Pearlshell
Margaritifera falcata

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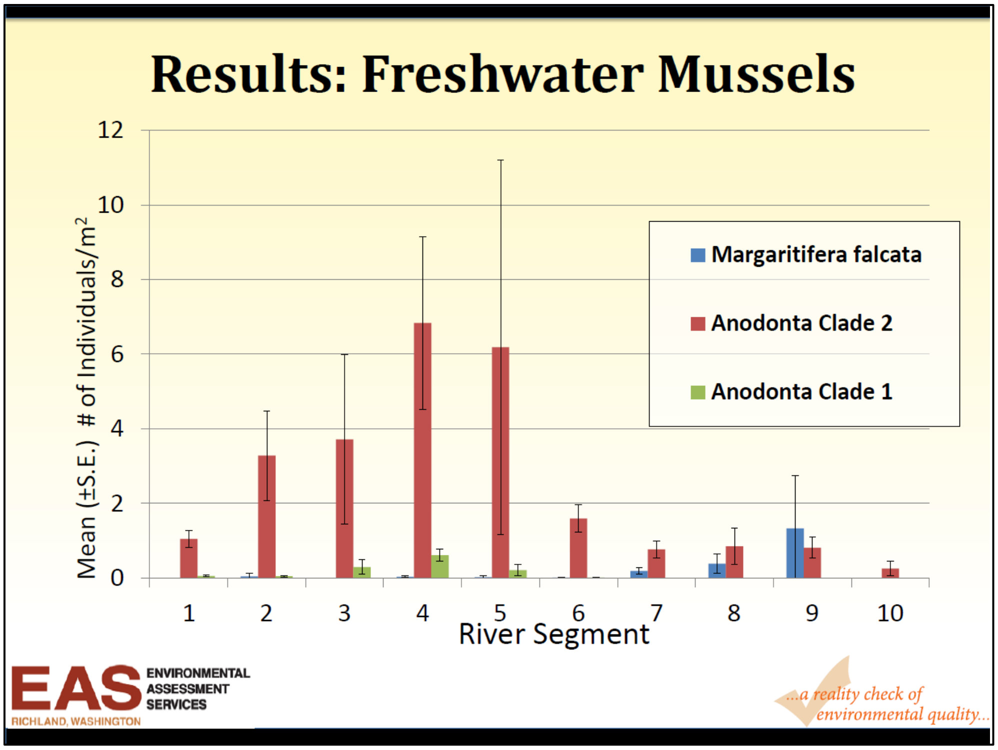
Results: Freshwater Mussels



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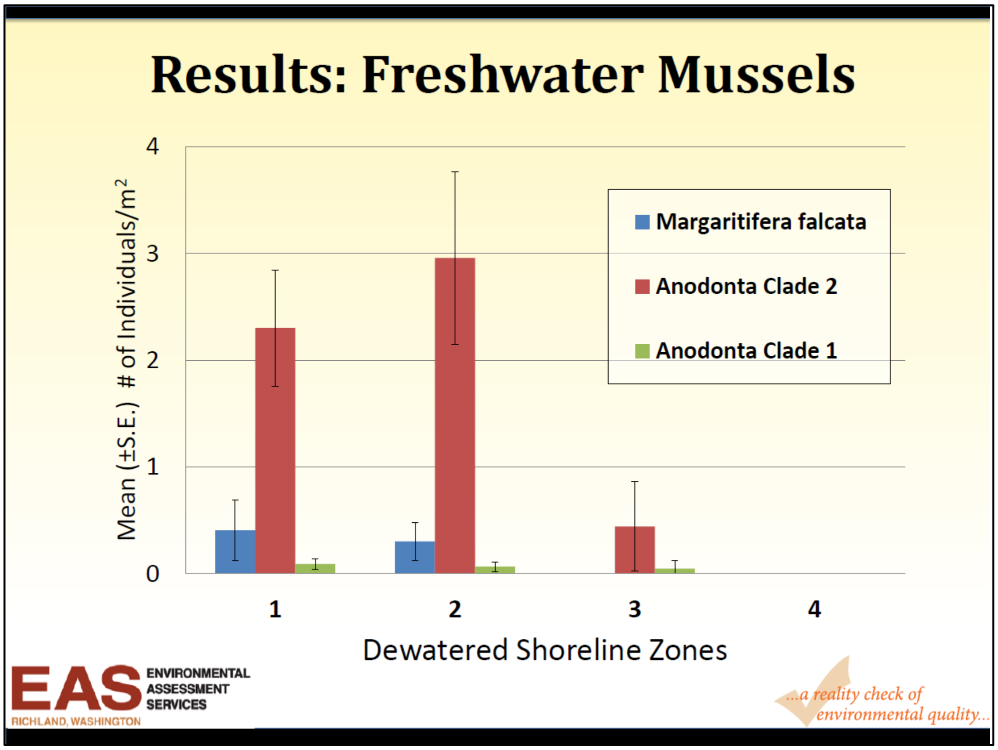
Results: Freshwater Mussels



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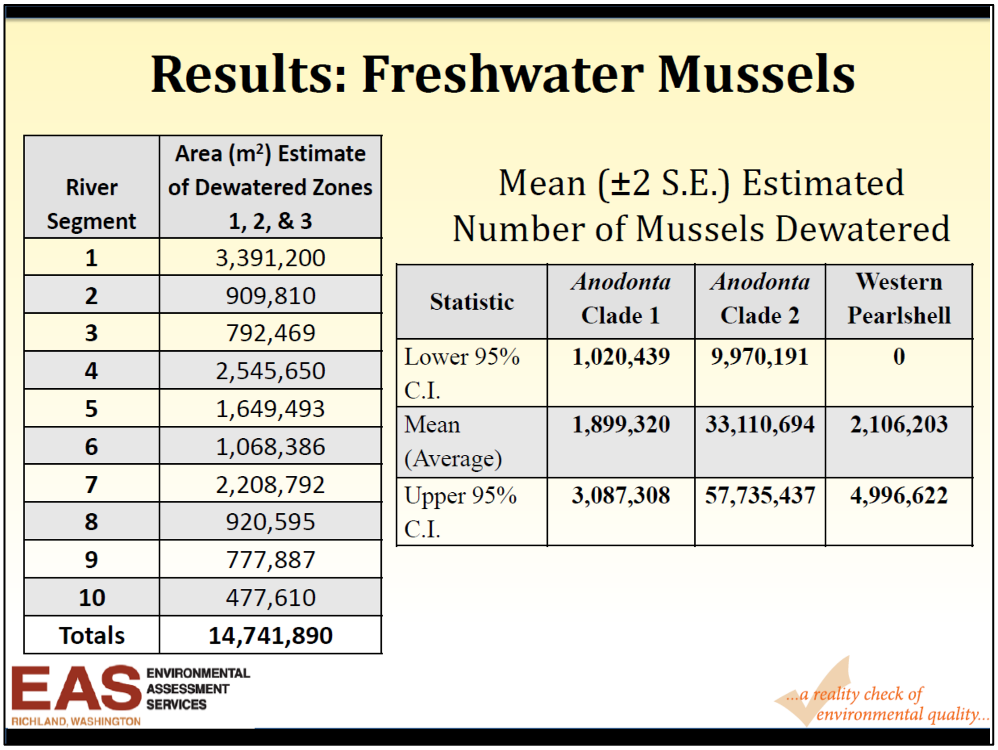

Results: Freshwater Mussels

River Segment	Area (m^2) Estimate of Dewatered Zones 1, 2, & 3
1	3,391,200
2	909,810
3	792,469
4	2,545,650
5	1,649,493
6	1,068,386
7	2,208,792
8	920,595
9	777,887
10	477,610
Totals	**14,741,890**

Mean (±2 S.E.) Estimated Number of Mussels Dewatered

Statistic	*Anodonta* Clade 1	*Anodonta* Clade 2	Western Pearlshell
Lower 95% C.I.	**1,020,439**	**9,970,191**	**0**
Mean (Average)	**1,899,320**	**33,110,694**	**2,106,203**
Upper 95% C.I.	**3,087,308**	**57,735,437**	**4,996,622**

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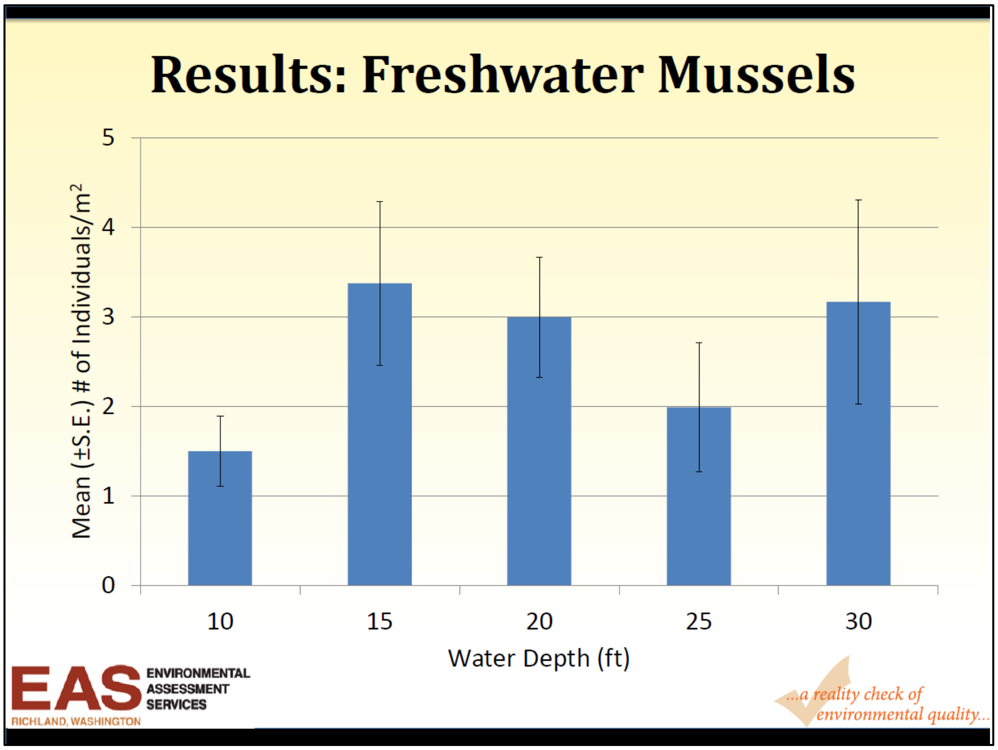

Results: Freshwater Mussels

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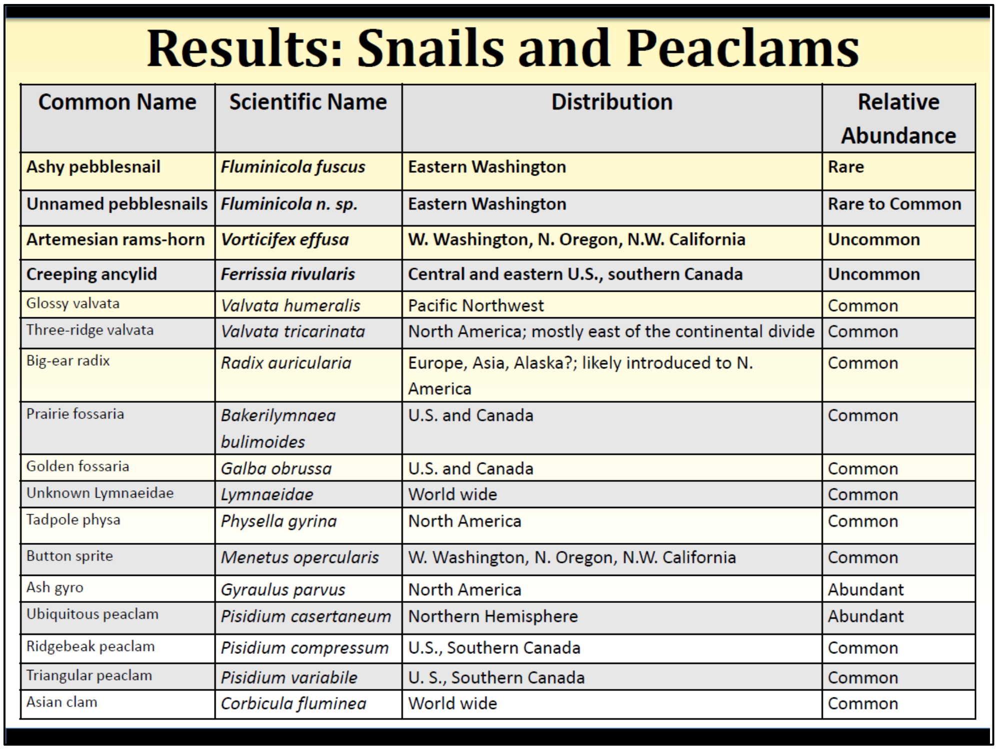
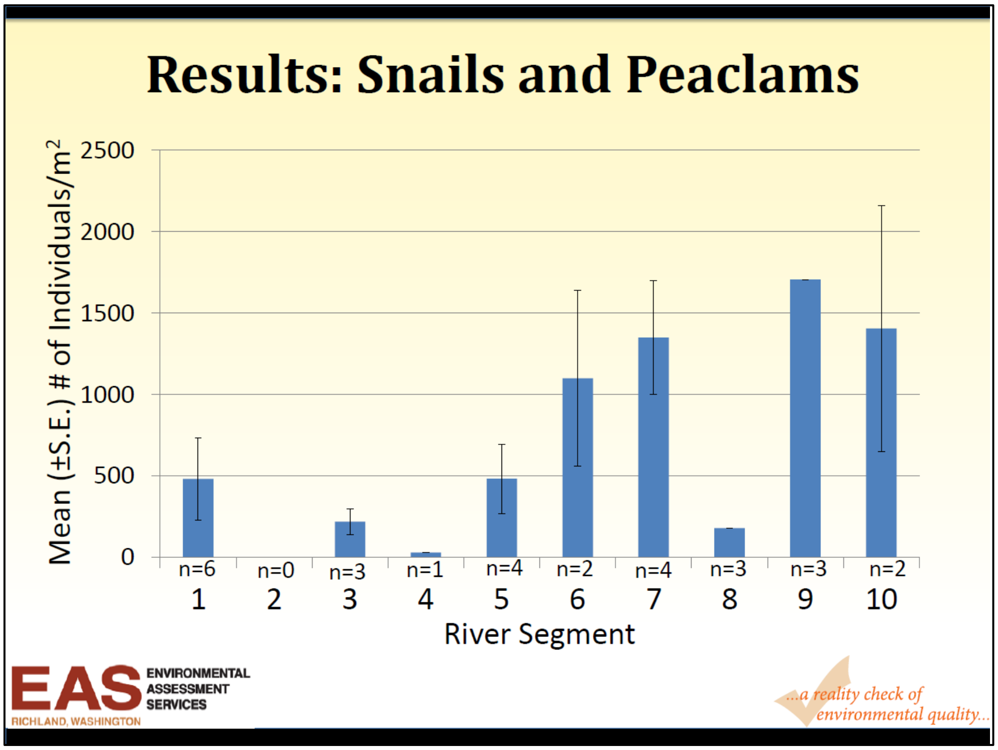


Results: Snails and Peaclams

Common Name	Scientific Name	Distribution	Relative Abundance
Ashy pebblesnail	***Fluminicola fuscus***	**Eastern Washington**	**Rare**
Unnamed pebblesnails	***Fluminicola n. sp.***	**Eastern Washington**	**Rare to Common**
Artemesian rams-horn	***Vorticifex effusa***	**W. Washington, N. Oregon, N.W. California**	**Uncommon**
Creeping ancylid	***Ferrissia rivularis***	**Central and eastern U.S., southern Canada**	**Uncommon**
Glossy valvata	*Valvata humeralis*	Pacific Northwest	Common
Three-ridge valvata	*Valvata tricarinata*	North America; mostly east of the continental divide	Common
Big-ear radix	*Radix auricularia*	Europe, Asia, Alaska?; likely introduced to N. America	Common
Prairie fossaria	*Bakerilymnaea bulimoides*	U.S. and Canada	Common
Golden fossaria	*Galba obrussa*	U.S. and Canada	Common
Unknown Lymnaeidae	*Lymnaeidae*	World wide	Common
Tadpole physa	*Physella gyrina*	North America	Common
Button sprite	*Menetus opercularis*	W. Washington, N. Oregon, N.W. California	Common
Ash gyro	*Gyraulus parvus*	North America	Abundant
Ubiquitous peaclam	*Pisidium casertaneum*	Northern Hemisphere	Abundant
Ridgebeak peaclam	*Pisidium compressum*	U.S., Southern Canada	Common
Triangular peaclam	*Pisidium variabile*	U. S., Southern Canada	Common
Asian clam	*Corbicula fluminea*	World wide	Common



Results: Snails and Peaclams

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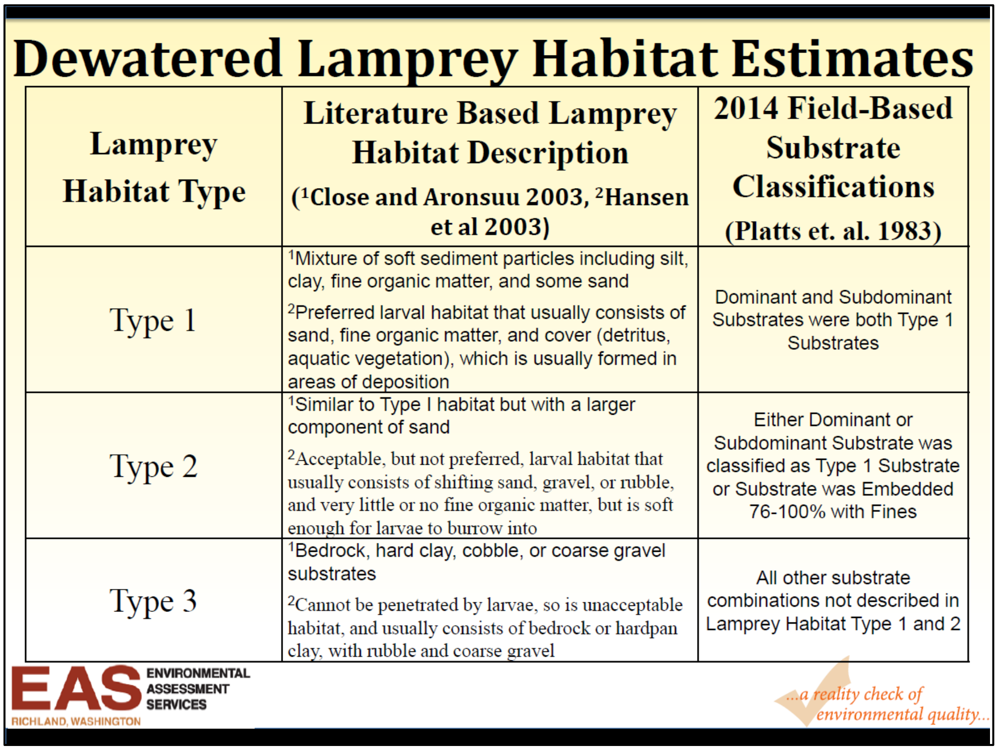
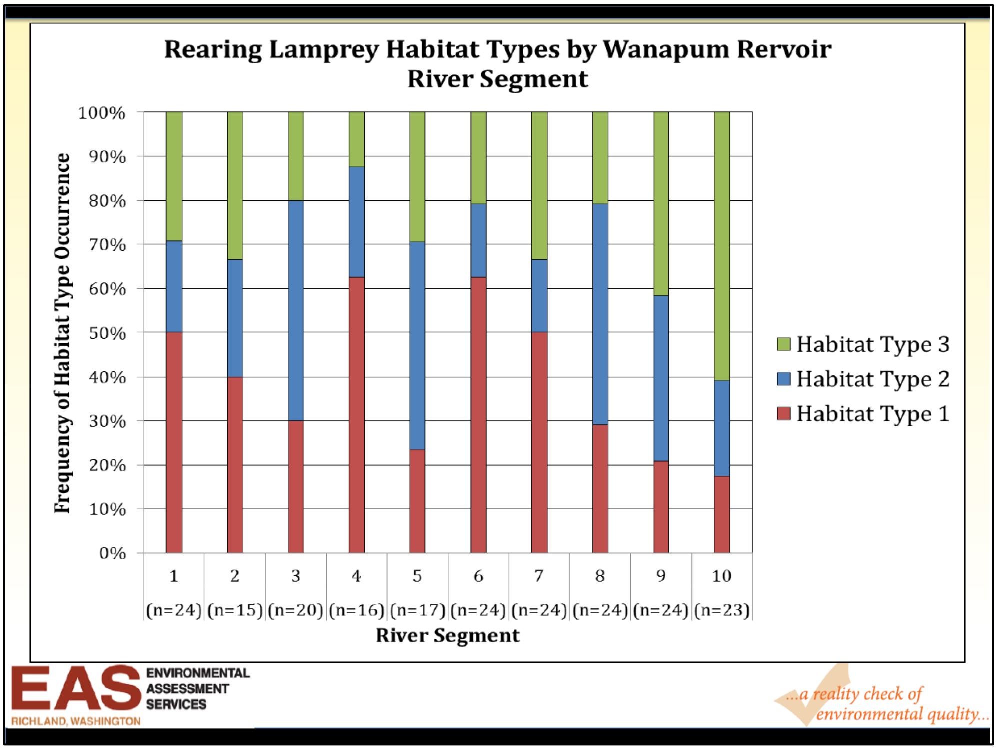
Results: Fish and Other Organisms

- crayfish
- lamprey
- redside shiner
- three-spine stickleback
- sculpin



Dewatered Lamprey Habitat Estimates

Lamprey Habitat Type	Literature Based Lamprey Habitat Description ([1]Close and Aronsuu 2003, [2]Hansen et al 2003)	2014 Field-Based Substrate Classifications (Platts et. al. 1983)
Type 1	[1]Mixture of soft sediment particles including silt, clay, fine organic matter, and some sand [2]Preferred larval habitat that usually consists of sand, fine organic matter, and cover (detritus, aquatic vegetation), which is usually formed in areas of deposition	Dominant and Subdominant Substrates were both Type 1 Substrates
Type 2	[1]Similar to Type I habitat but with a larger component of sand [2]Acceptable, but not preferred, larval habitat that usually consists of shifting sand, gravel, or rubble, and very little or no fine organic matter, but is soft enough for larvae to burrow into	Either Dominant or Subdominant Substrate was classified as Type 1 Substrate or Substrate was Embedded 76-100% with Fines
Type 3	[1]Bedrock, hard clay, cobble, or coarse gravel substrates [2]Cannot be penetrated by larvae, so is unacceptable habitat, and usually consists of bedrock or hardpan clay, with rubble and coarse gravel	All other substrate combinations not described in Lamprey Habitat Type 1 and 2



Rearing Lamprey Habitat Types by Wanapum Rervoir River Segment

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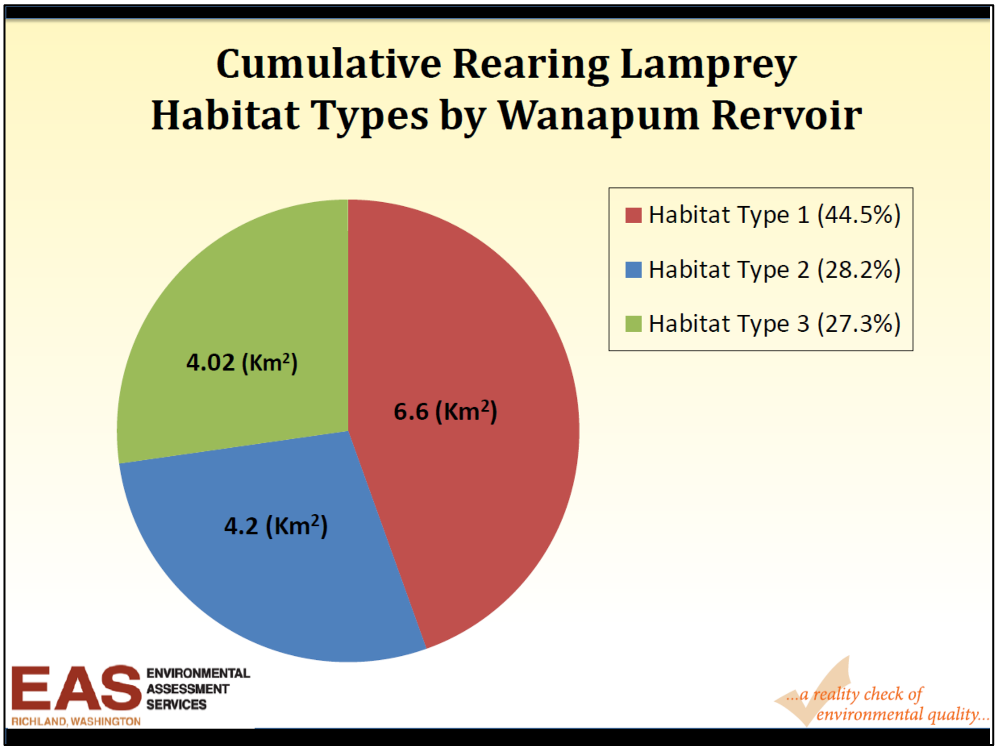

Cumulative Rearing Lamprey Habitat Types by Wanapum Rervoir

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Recovery Perspectives

Paucity of Molluscan Recolonization Rate Information Exists in the Pacific Northwest

However..,
~37 million mussels colonized Wanapum Project Area within 50 year period,

Thus, we might expect ~750,000/yr for ~14.7Km^2 Wanapum Project Area Dewatered (~0.05 individuals/m^2/yr)

Molluscan Recovery Perspect-ives

Taxon	Slow Recovery Rate	Interm. Recovery Rate	Fast Recovery Rate
PROSOBRANCH GASTROPODS			
Fluminicola	x		
Valvata		x	
PULMONATE GASTROPODS			
Bakerilymnaea			x
Galba			x
Stagnicola			x
Physella			x
Gyraulus			x
Menetus			x
Vorticifex		x	
Ferrissia		x	
UNIONIDS			
Anodonta	x		
Margaritifera	x		
Gonidea	x		
SPHAERIIDS			
Pisidium			x

Summary

- ~14.7Km^2 of Riverbed Area was Dewatered in 2014
- Dewatered Regions Contained Relatively High Densities of Native Freshwater Mussels
- Up-river Segments Possessed a Several Relatively Rare or Uncommon Molluscan Taxa

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Summary (cont'd)

- Dewatered Regions ~10Km^2 of Lamprey Types I and II Habitat
- Native Freshwater Mussels Persisted in Non-Dewatered Regions
- Recolonization Rates of Rare or Uncommon Molluscan Taxa in Dewatered Regions Uncertain

2014 White Sturgeon Management Plan

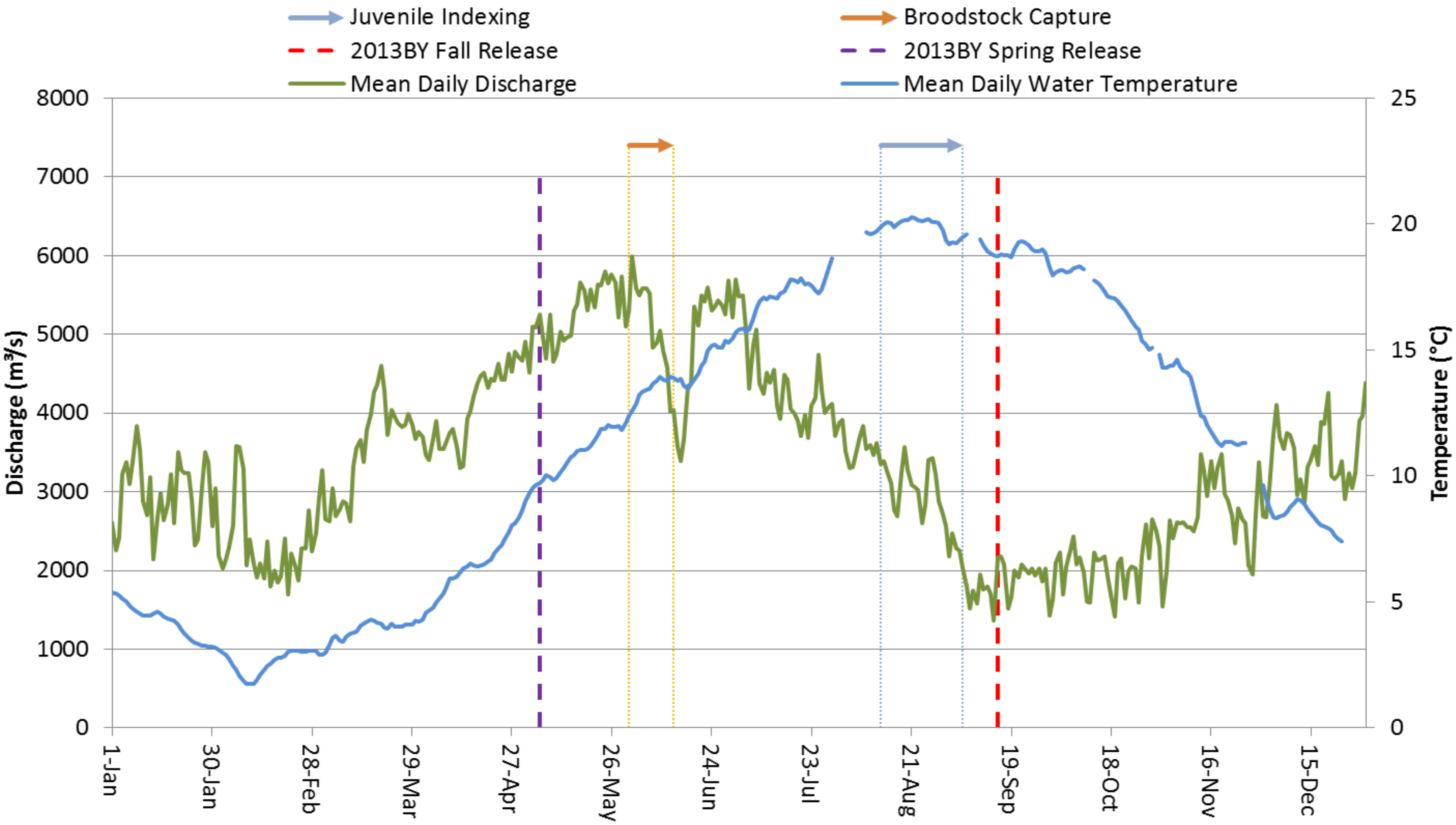
Priest Rapids Hydroelectric Project (FERC No. 2114)

Golder Associates

Methods

- Discharge and Temperature
- 2013BY Marking and Release
  - Two release dates May 6, 2014 and mid-September, 2014
- Broodstock Capture
  - Angling – Focused on the 5 km section of river below Rock Island Dam in Wanapum Reservoir. May 31, 2014 to June 13, 2014
  - Fish Handling, Processing and Transport
- VR2W Telemetry Array Download and Maintenance
  - Wanapum Reservoir – 2 VR2W stations lost, 1 station removed
  - Priest Rapids Reservoir – 3 VR2W stations lost
- Juvenile Movement

Results – Discharge and Temperature



Mean daily discharge and mean hourly water temperature, as measured below Wanapum Dam.

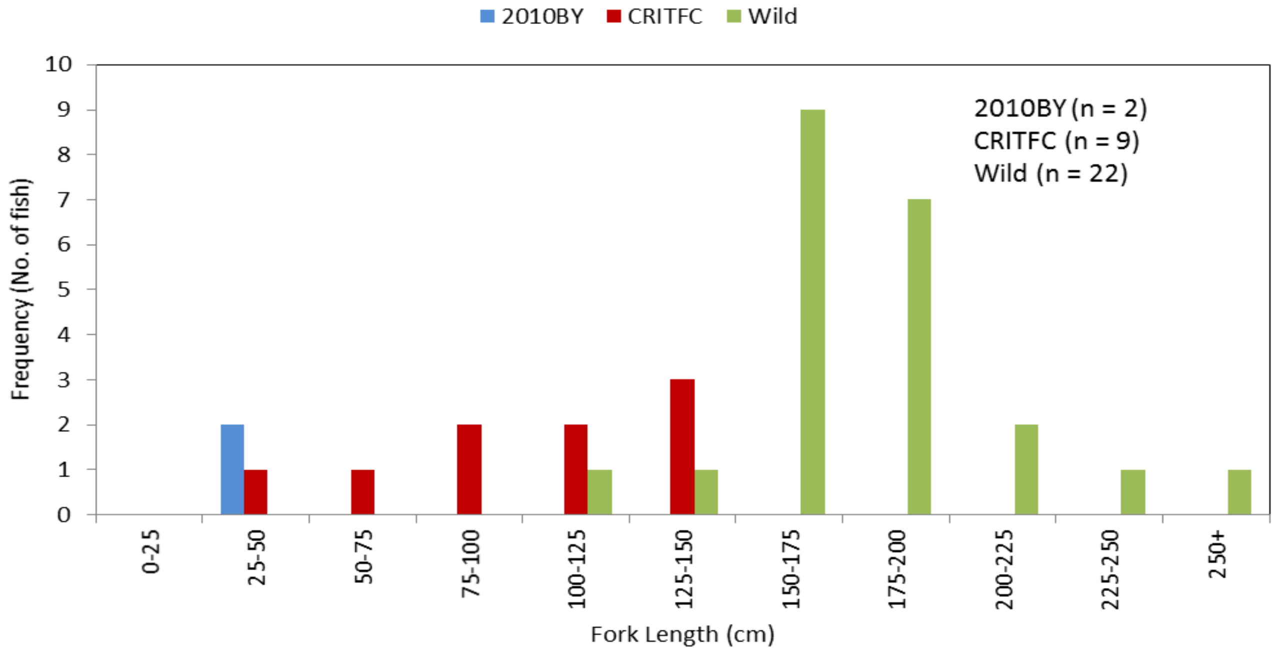
Results – 2013BY Mark and Release

Release number and mean fork length and weight of the 2013BY juvenile White Sturgeon released in the PRPA, 2014.

	May 2014 Release			September 2014 Release			PRPA 2014 Total		
Release Location Reservoir (River Mile)	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**
Wanapum (421.5)	3331(32)	266 (40)	118 (53)	1762(20)	291 (44)	151 (75)	5093 (52)	275 (43)	129 (63)
Priest Rapids (415.6)	997(9)	272 (42)	131 (56)	504(5)	281 (43)	135 (73)	1501(14)	275 (42)	132 (63)
Total	**4328(41)**	268(41)	121(54)	**2266(25)**	289 (44)	147(75)	**6594(66)**	275 (43)	130 (63)

- All fish produced, tagged and processed at Marion Drain Hatchery
- 66 of the 2013BY release implanted with acoustic telemetry tags (52 in Wanapum reservoir and 14 in Priest Rapids reservoir)
- 2013BY juveniles exhibited a high incidence of fin deformities, with deformities recorded for approximately 51% of the May release and 90% of the September release

Results – Broodstock Capture



Length–frequency of wild and hatchery (2010BY and CRITFC)

- 33 White Sturgeon angled below Rock Island Dam in 2014 (22 wild, 11 hatchery, CPUE = 0.03 fish/hook-hours)
- Annual growth rates of recaptured fish were consistent with previous findings that White Sturgeon in the PRPA were growing and smaller fish generally grow at a faster rate than larger fish
- 1 of 33 wild fish captured in Wanapum Reservoir warranted transport to MDH to supplement the broodstock

Results – Broodstock Capture

Acoustic Telemetry Tagging

- 6 adult White Sturgeon captured during the Broodstock collection program were tagged with acoustic telemetry transmitters

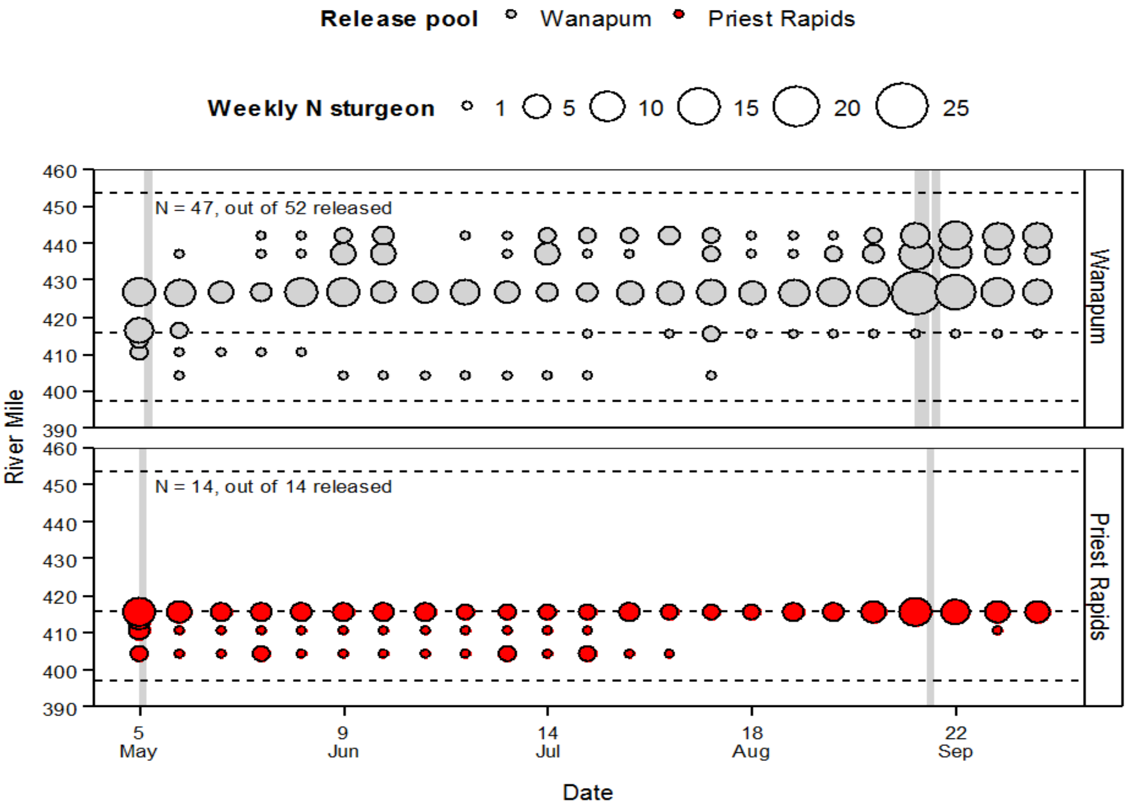
White Sturgeon Diet Assessment

- During the 2014 program three 2003BY CRITFC White Sturgeon were sacrificed to examine stomach contents.
- Crayfish, crayfish claws, carapace fragments and a complete unidentified salmonid found in one White Sturgeon.

Avian Predation

- 143 PIT-tags from 2010BY and 2012BY were detected and identified at a known bird colony in the forebay of Rock Island Dam. PIT-tags from 2013BY were not detected as of October 9, 2014.

Results – 2013BY Juvenile White Sturgeon Movement



Weekly counts of acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014.

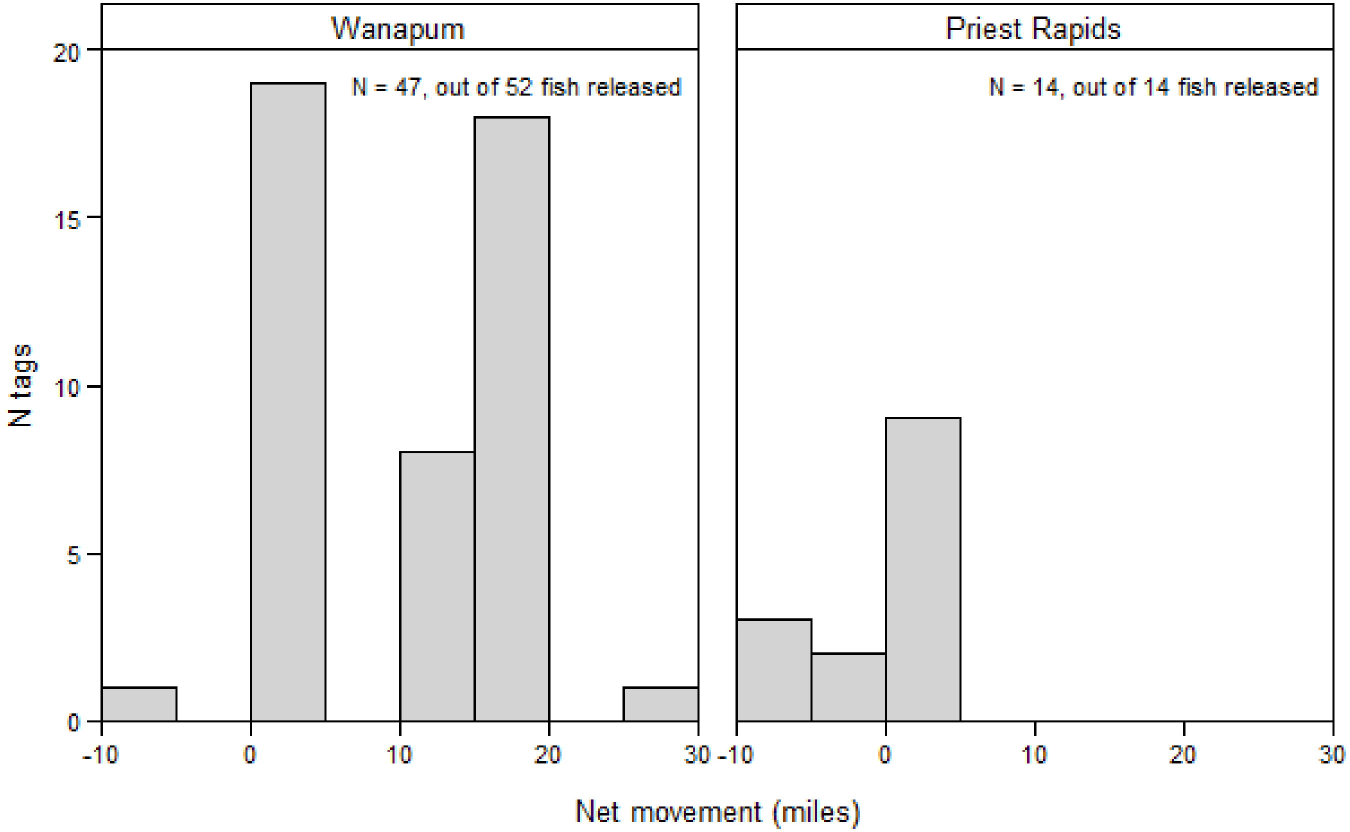
Wanapum Reservoir

- Fish initially moved both up- and downstream from the RM 421.5 release location after May 6 release date.
- By mid summer most fish were upstream of release location.
- 3 of the 52 acoustic-tagged fish released in Wanapum were entrained into Priest Rapids Reservoir. Entrained fish were from May release

Preist Rapids Reservoir

- Fish dispersing downstream from release site (RM 416.5) were recorded throughout May to early August and late September.

Results – 2013BY Juvenile White Sturgeon Movement



Histograms of net movement (sum of all RM changes) of 2013BY fishfor acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014. Negative values represent downstream movements.

Discussion – Juvenile White Sturgeon Release

- All future Wanapum Reservoir releases should occur at Rocky Coulee launch (RM 421.5) due to reduced transport time, ease of access and likely reduced avian predation pressure on juvenile compared to upstream release locations.

- Two separate release events provide an opportunity to examine the effect of seasonal release timing and the effect of size at release on aspects of juvenile White Sturgeon dispersal, survival and downstream entrainment.

Discussion – Broodstock Capture

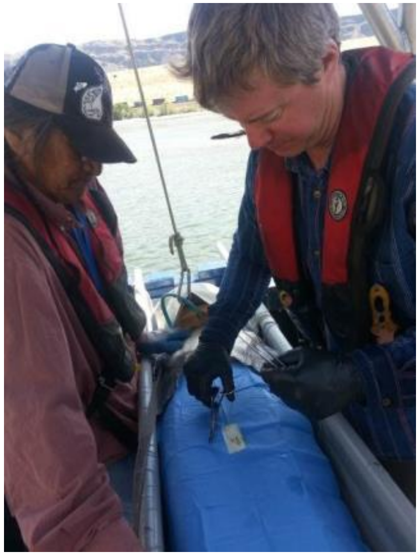
- In 2014, highest catch rates were recorded in the initial four days of the sample program; thereafter catch rates declined sharply coinciding with a rapid decrease in total river discharge.

- Future Grant PUD broodstock capture efforts may be better spent on providing support for the capture program below McNary Dam.

Discussion – Movement of Acoustic Tagged Juveniles

- Consistent with other juvenile broodyear releases, the 2013BY were more frequently detected by receivers located at RM442.0 and RM426.5 in Wanapum Reservoir and at RM415.5 in Priest Rapid Reservoir

- Restoration of the VR2W stations lost in 2014 is a priority. A revised anchoring system will be implemented in 2015 in the hopes of improving station longevity.



Discussion – Juvenile Entrainment

- Entrainment rate of 2013BY release was 5.8% (October 8 2014); this was likely an underestimate

Entrainment rate for acoustic tagged juvenile White Sturgeon

Release Details				Entraining Dam (RM)	Number Entrained	Percent Entrainment (%)
Pool	Year	N	Release RM			
Priest Rapids	2011	21	415.6	Priest Rapids (397.1)	2	9.5
Priest Rapids	2013	6	415.6	Priest Rapids (397.1)	0	0.0
Priest Rapids	2014	14	415.6	Priest Rapids (397.1)	0	0.0
Subtotal		**41**			**2**	**4.9**
Wanapum	2011	70	450.6	Wanapum (415.6)	9	12.9
Wanapum	2013	24	450.6/442.0	Wanapum (415.6)	0	0.0
Wanapum	2014	52	421.5	Wanapum (415.6)	3	5.8
Subtotal		**146**			**12**	**8.2**

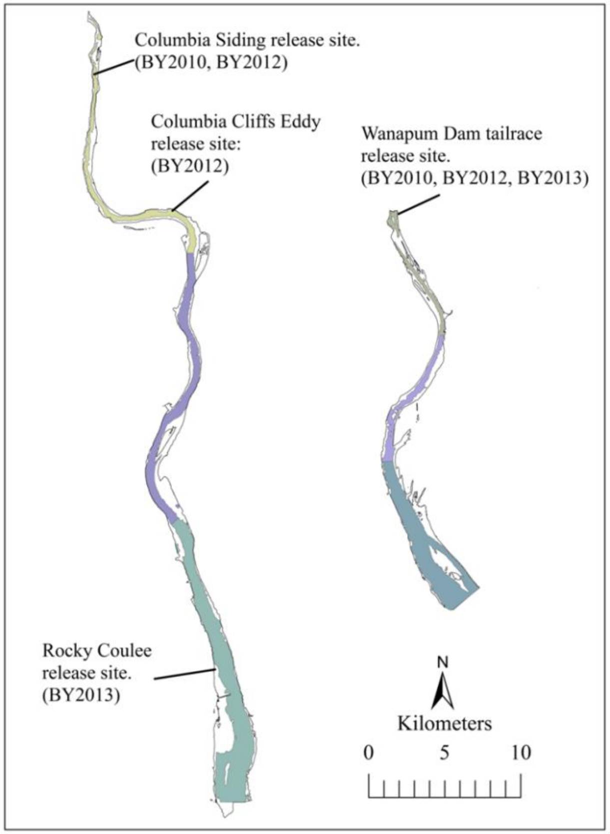
2014 Juvenile Indexing

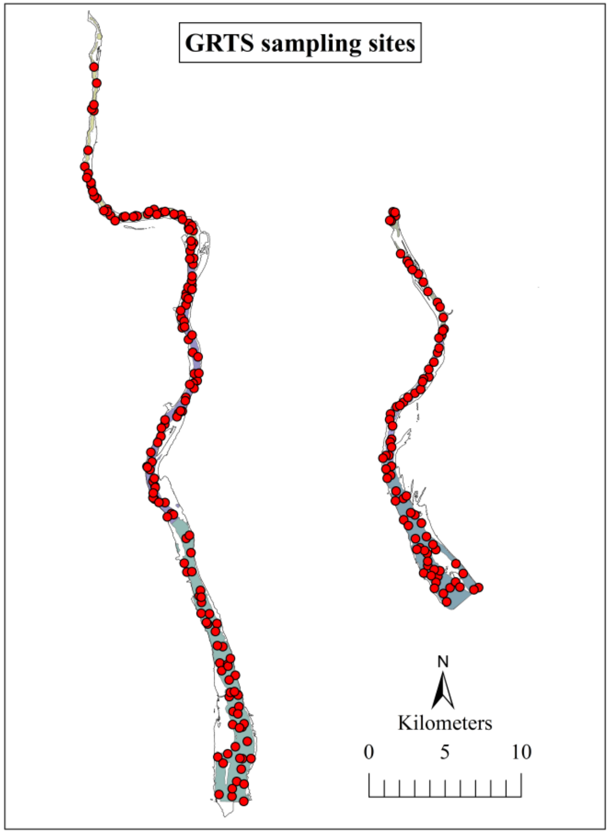
Setline Gear

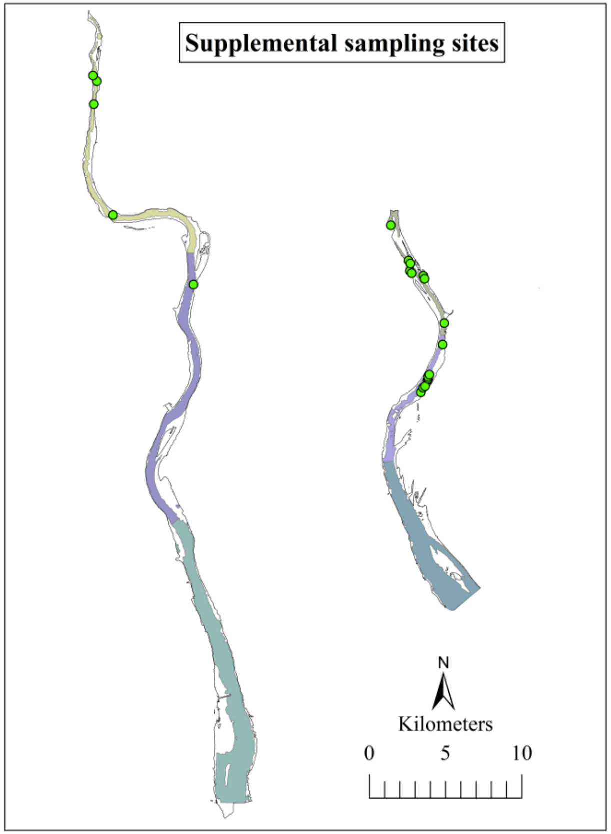
- 183 m (600 ft) setlines (1/4” three strand nylon, tarred)
- 40 gangions per line
- Dacron line (80lb and 130lb test) with airline tubing sheath
- Gamakatsu Octopus circle hooks (2/0, 4/0, 6/0, 8/0)
- Pickled squid as bait

Unequal probability GRTS Design

	Reservoir and section							
	Wanapum (25-29 August and 2-5 September)				Priest Rapids (12-14 and 18-22 August)			
	Lower	Middle	Upper	All	Lower	Middle	Upper	All
Number of sample sites								
Specified spsurvey draw	50	50	50	150	40	20	20	80
Actual sample	51	55	44	150	39	24	17	80
Sampling area (Ha)	2,185	941	551	3,677	1,369	346	213	1,928
Samples/100Ha	2.3	5.8	8.0	4.1	2.9	6.9	8.0	4.2





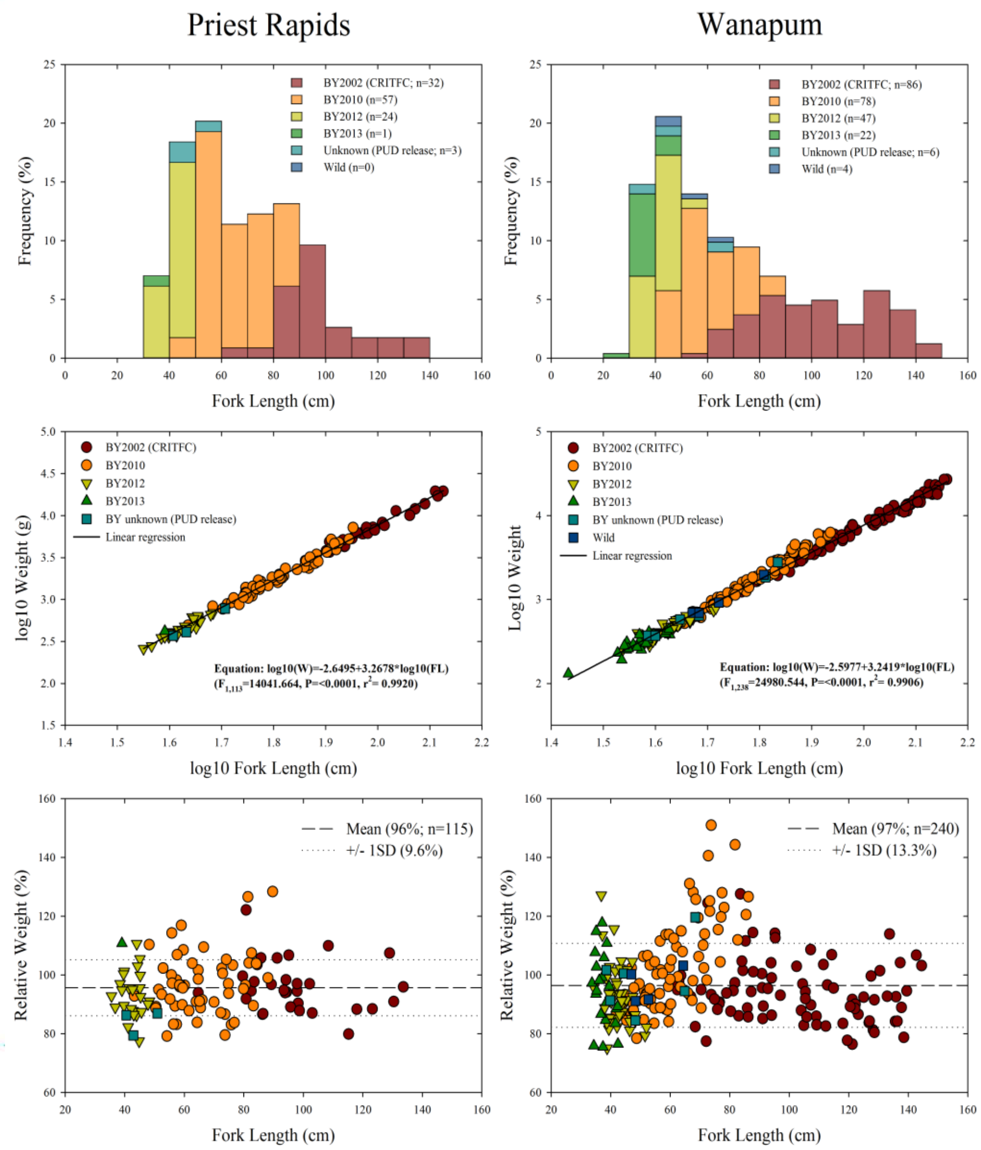


Catch

Brood Year	Release reservoir	# released	Capture reservoir and sampling type								
			Wanapum				Priest Rapids				Total
			GRTS	Supp.	Total		GRTS	Supp.	Total		
2002	Rock Island	≈20,600	78	11	89		24	9	33		122
2010	Rocky Reach	6,376	18	--	18		2	--	2		20
	Wanapum	7,016	57	4	61		4	3	7		68
	Priest Rapids	2,101	--	--	--		39	9	48		48
2012	Wanapum	2,264	48		48		--	--	--		48
	Priest Rapids	1,717	--	--	--		17	7	24		24
2013	Wanapum	3,331	22	--	22		--	--	--		22
	Priest Rapids	997	--	--	--		--	1	1		1
Unknown (Hatchery)	Unknown (PUD)	NA	6	--	6		3	--	3		9
Unknown (Wild)	NA	NA	4	1	5		--	--	--		5
All sturgeon	NA	NA	233	16	249		89	29	118		367

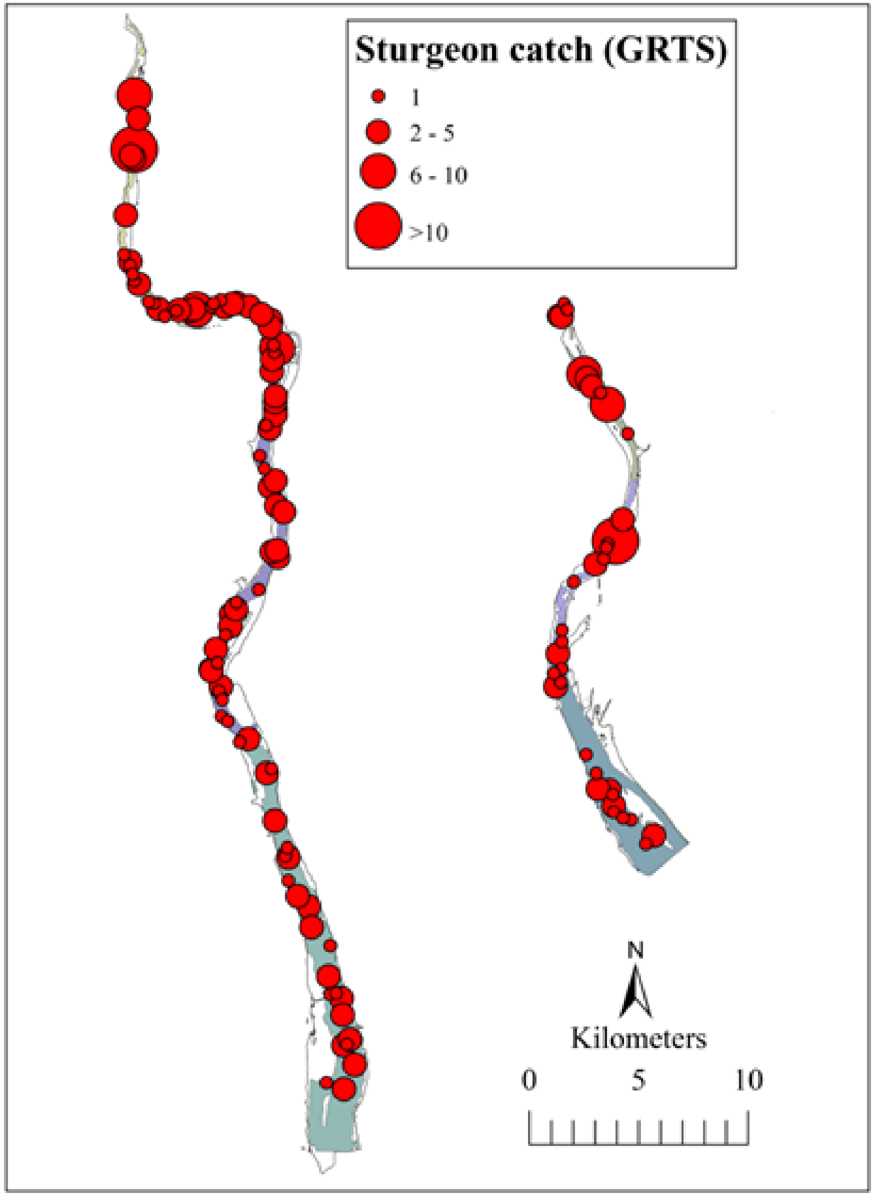
- Five sturgeon were captured twice (i.e., 362 individuals were handled during study)
- An additional 16 sturgeon were lost at boat
- Bycatch: 381 Nothern Pikeminnow, seven Largescale Sucker, one Carp, one Channel Catfish.

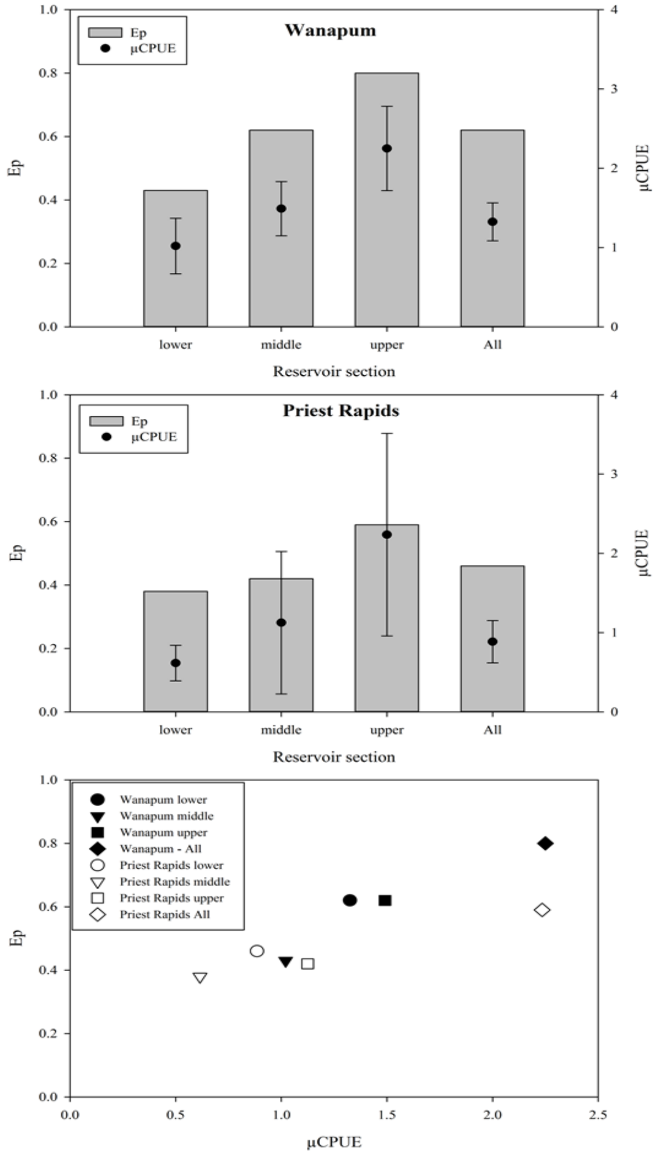
Size and Condition



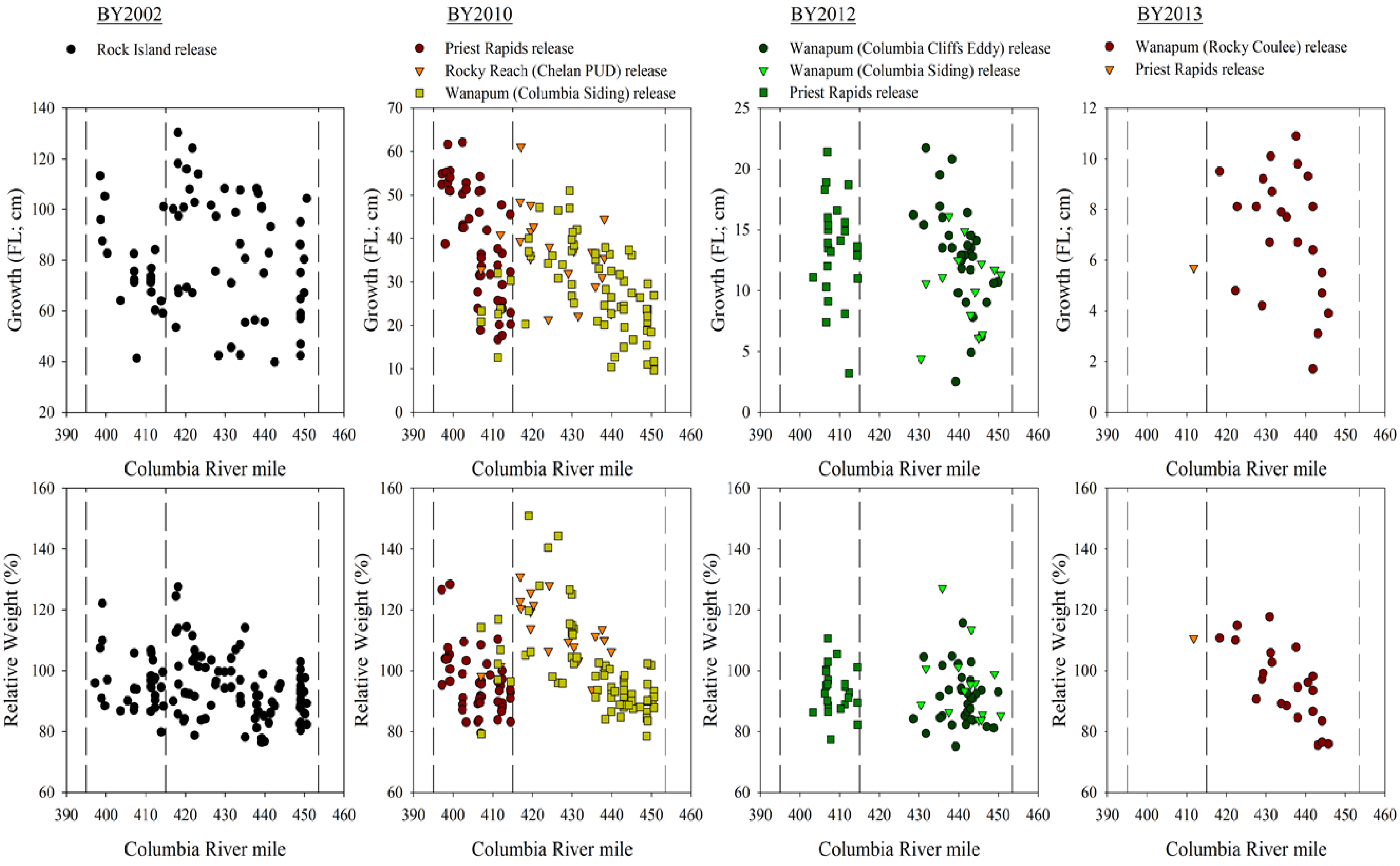
BY (program)	Fork Length (cm)				
	n	mean	SD	min	max
2002 (CRITFC)	118	101.6	22.0	58.3	145.8
2010 (CPUD)	20	65.0	8.8	51.0	85.5
2010 (GPUD)	115	62.1	11.8	41.8	89.7
2012 (GPUD)	71	42.4	3.6	34.3	52.0
2013 (GPUD)	23	37.2	3.4	27.1	42.4
Unknown (Hatchery)	9	48.7	10.9	38.5	68.4
2010-2013 (All PUD)	238	53.6	13.9	27.1	89.7
Wild	5	82.4	66.0	46.9	199.8
All sturgeon	361	69.6	29.0	27.1	199.8

Catch Distribution (GRTS samples)

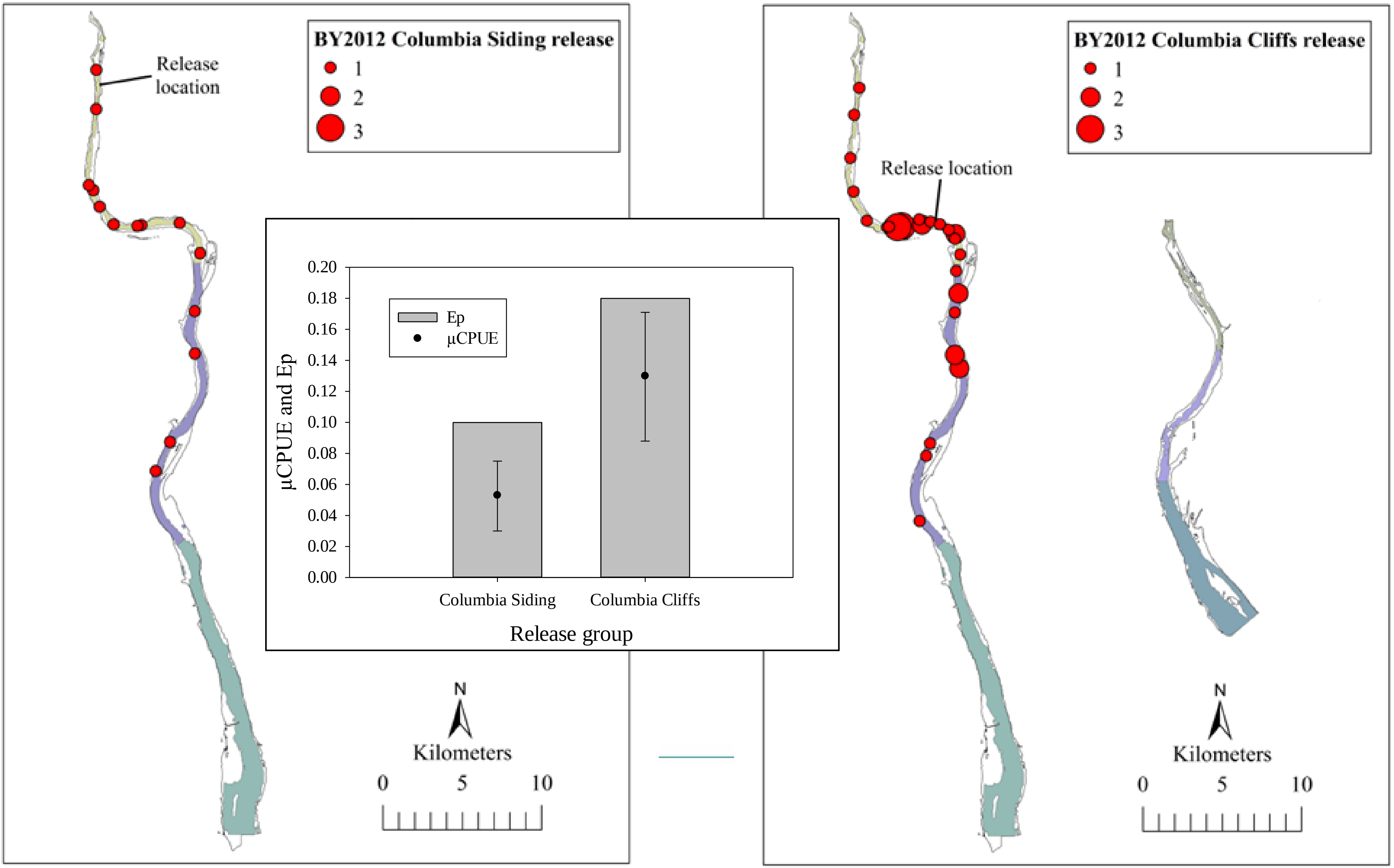




Growth

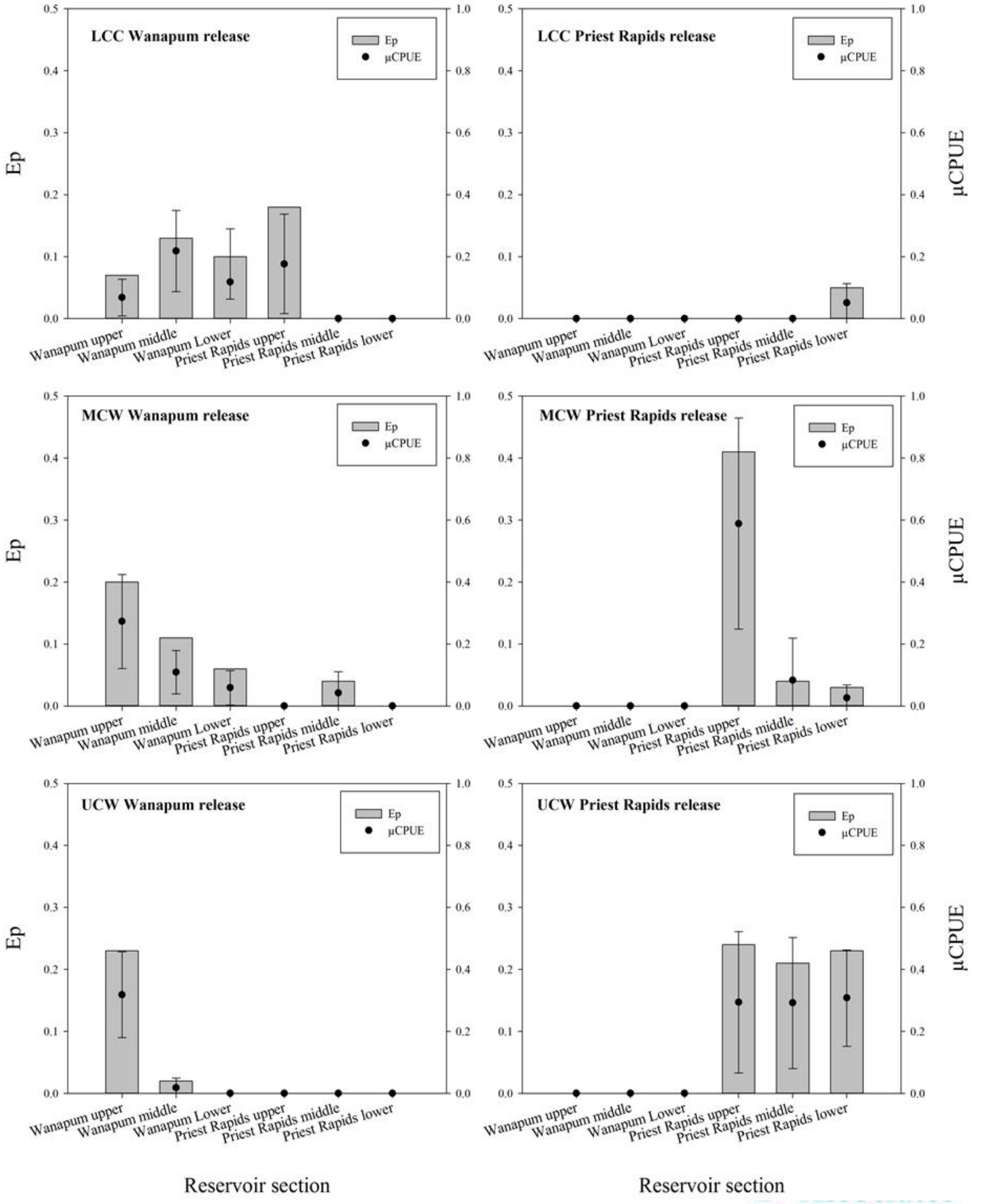

BY2002
● Rock Island release
BY2010
● Priest Rapids release
▼ Rocky Reach (Chelan PUD) release
■ Wanapum (Columbia Siding) release
BY2012
● Wanapum (Columbia Cliffs Eddy) release
▼ Wanapum (Columbia Siding) release
■ Priest Rapids release
BY2013
● Wanapum (Rocky Coulee) release
▼ Priest Rapids release
Growth (FL; cm)
Relative Weight (%)
Columbia River mile
390 400 410 420 430 440 450 460
BY2002: 20 40 60 80 100 120 140
BY2010: 0 10 20 30 40 50 60 70
BY2012: 0 5 10 15 20 25
BY2013: 0 2 4 6 8 10 12
60 80 100 120 140 160

BY 2012 – Wanapum paired release

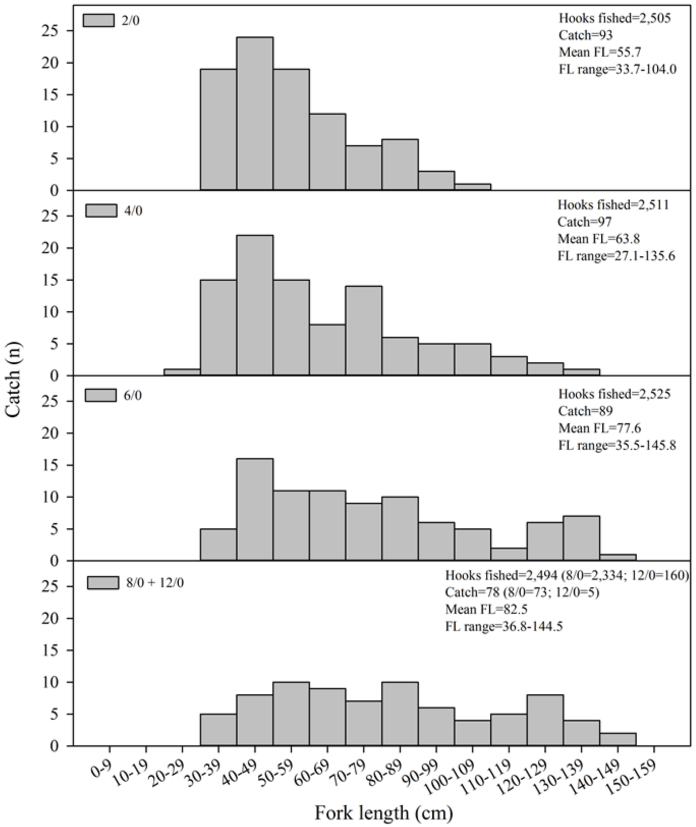


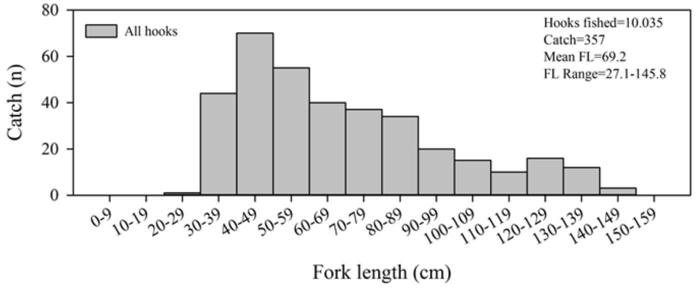
BY 2010

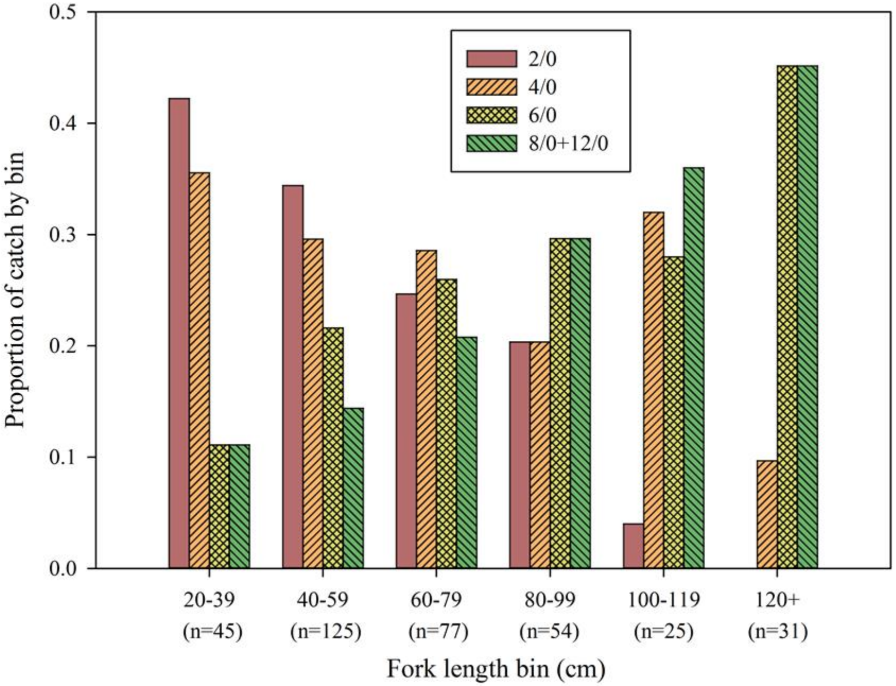
- LCC: lower Columbia River captive brood
- MCW: mid Columbia River wild brood
- UCW: upper Columbia River wild brood



Setline gear performance







- 3.7% (367 of 10,035) of all overnight hook sets resulted in a sturgeon capture (i.e., a sturgeon that was successfully landed and processed).
- An additional 4.6% (n=457) of hook sets were lost due to gangion line breakage (2.8%; n=285) or were bent or broken (1.7%; n=172) at retrieval.

Conclusions

- Hatchery sturgeon are distributed widely throughout both reservoirs
- Catch rates were relatively low:
  - Improve retention rates
    - Use stronger gangion line (e.g., wire leader)
    - Use same hook sizes but more robust hooks
  - Maintain similar level of effort (# of overnight sets) in future surveys
- Consider downstream, deep water sites for future hathery releases (esp. Wanapum) to limit possible density dependent effects in upstream reaches.

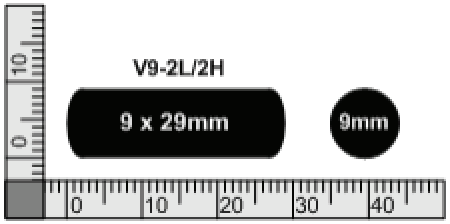
2015 WSMP Study Plan

Table 3. The 2015 WSMP Study Objectives and Tasks

WSMP Objective	WSMP Task No.	Task
1	2	Conservation Aquaculture and PRFF Support
1	3.1	Juvenile Marking
1	3.2	Juvenile Transport
2	1	Juvenile Movement Assessment
2	3	Adult Indexing (Capture-Recapture)
4	1	Evaluation of Existing Spawning Use
4	2	Hatchery White Sturgeon Growth, Survival, and Stocking Rate Adjustment
4	3	Database Management and Development Requirements
4	4	Annual WSMP Report

Objective 1 Task 3.1 – Juvenile Marking (2015)

- Processing and tagging of the 2014BY will be conducted by LGL staff based out of Sidney BC, with the support of BLE staff based in Ellensburg, WA.
- All fish to be released will be tagged with glass 12.5 mm, 134 kHz ISO PIT tags. 1% of fish to be released will also be tagged with a Vemco V9-2L hydroacoustic tag.
- Tags will be implanted using standard surgical procedures and prior to release, all fish will be held for up to two weeks to allow for healing.



Objective 1 Task 3.2 – Juvenile Transport (2015)

- 2014BY release scheduled for first or second week of May, 2015

- BLE staff will coordinate and transport juvenile White Sturgeon from MDH to release locations in Wanapum and Priest Rapids reservoirs (77% of juveniles in Wanapum and 23% in Priest Rapids).

- Chelan PUD will provide fish transport truck, driver and all necessary equipment to safely release the juvenile White Sturgeon.

Objective 2 Task 1 – Juvenile White Sturgeon Movement Assessment (2015)

- Due to the loss of 6 VR2W stations in 2014, future monitoring programs will require that all stations are removed and fully serviced every 3 years.
- In April 2015 the 6 monitoring stations lost in 2014 will be redeployed.
    - Relocated the PRTR station back to RM396.1.
    - Forebay stations relocated to safety booms.
    - Metal frame bottom deployments at select locations.
- Remaining 6 monitoring stations retrieved and weak materials or connections replaced.

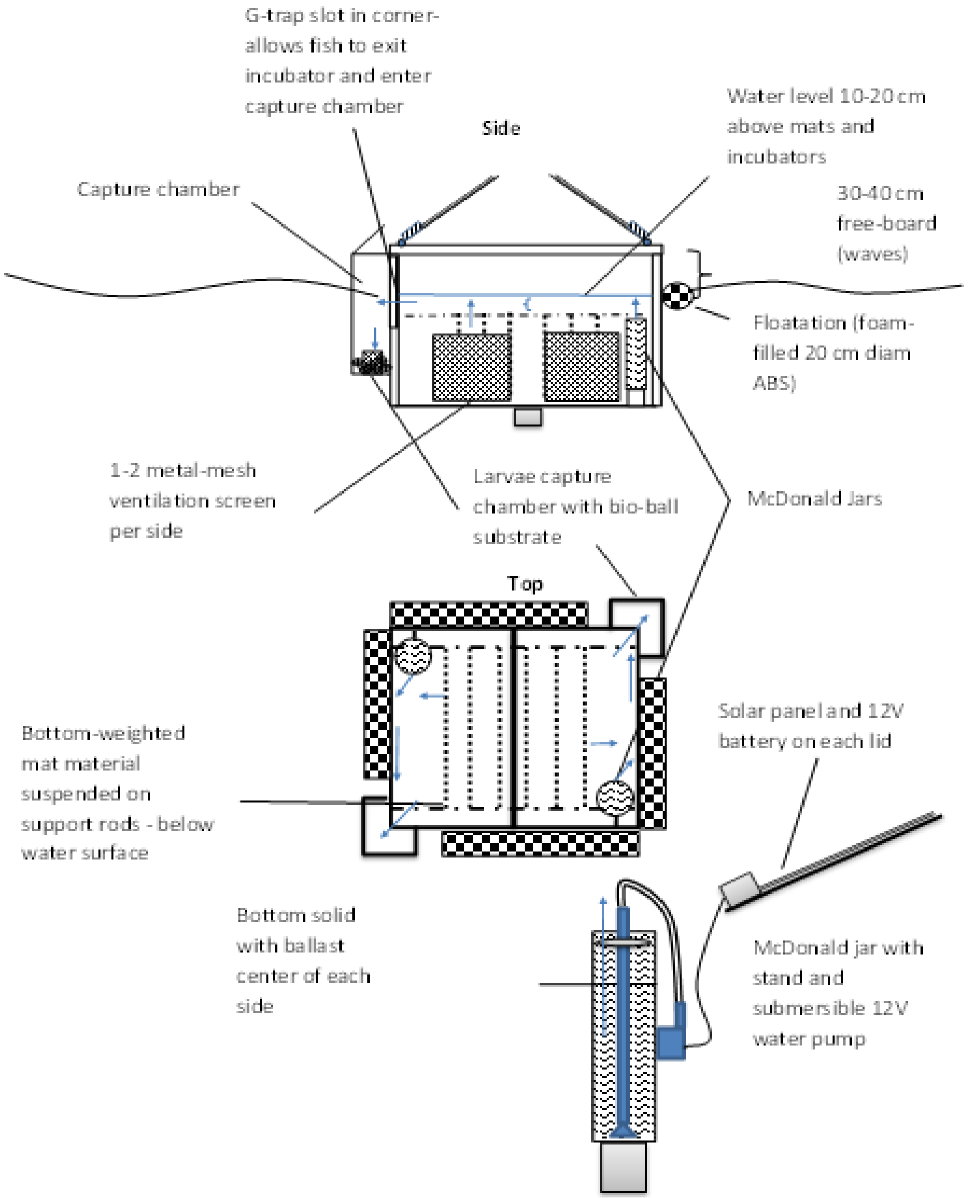
Objective 2 Task 3 – Adult Indexing (2015)

- Capture/re-capture study in fall 2015 to obtain population data on adult and sub-adult White Sturgeon in Wanapum and Priest Rapids reservoirs.
- 182 individual set line sample sets deployed over two 14-day sample sessions in fall 2015. Setline deployment locations determined using GRTS design.
- Setline will use baited barbed hooks of three different sizes: 12/0, 14/0, 16/0.
- Captured adults will be scanned for PIT tags, checked for marks of previous capture, and PIT tagged. Life history attributes including fork length, weight, sex and reproductive status. Soft tissue will be collected for DNA analysis.
- Up to 10 Vemco V16 -6H acoustic tags will be implanted in adult White Sturgeon.

Objective 4 Task 1 – Evaluation of Existing Spawning Use (2015)

- Egg collection mats deployed below Rock Island Dam to capture wild spawned White Sturgeon eggs to determine spawn timing and number of events.
- 11 to 15 paired egg collection mat sites inspected daily.
- Eggs will be enumerated and a sub-sample will be preserved and/or photographed for developmental stage identification.

Objective 4 Task 1 – Evaluation of Existing Spawning Use (2015)



- Redesigned floating *in situ* incubator for 2015
- Incubator moored in eddy approx. 3.5 km downstream of Rock Island Dam.
- Egg-laden mat material will be removed from metal mat frame and suspended within incubator.
- Larvae transferred to MDH.

Objective 4 Task 3 – Database Management and Development Requirements

All indexing databases will be updated with the following variables:

- Annual stocking data (fish lengths, weights, deformities, scute marks, PIT tag number)
- Annual index monitoring results (lengths, weights, deformities, capture location, scute marks, PIT or sonic tag number)
- Annual results obtained from tracking actively tagged juveniles (location records)

Objective 4 Task 4 – Annual WSMP Report (2015)

The 2015 technical report will:

- Describe methods used to address the statement of work;
- Provide tabular and/or graphical summaries (as appropriate) of the data collected and briefly describe the results of field investigations;
- Discuss key findings of the investigations; and,
- Provide the proposed study program for the following year.

2014
White Sturgeon Management Plan Annual Data Report

Priest Rapids Hydroelectric Project (FERC No. 2114)

Prepared for:

Public Utility District No.2 of Grant County
P.O. Box 878
Ephrata, WA 98823

Prepared by:

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March 2015

Golder Associates Ltd. would like to acknowledge and thank our partners in this research project as follow:

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Matt Howell	Colville Confederate Tribes
Lucia Ferreira	LGL Environmental Ltd.
Anita Blakley	LGL Environmental Ltd.
Corey Wright	Blue Leaf Environmental
Stuart Hurd	Hurd’s Guide Services
Jim Powell	Fidelis Aquaculture Management

List of Abbreviations

401 Certification	Washington Department of Ecology Section 401 Water Quality Certification for the Priest Rapids Project
BY	Brood Year
CPUE	Catch-Per-Unit-Effort
CRITFC	Columbia River Intertribal Fisheries Commission
CBH	Columbia Basin Hatchery
FERC	Federal Energy Regulatory Commission
FL	Fork Length
Grant PUD	Public Utility District No. 2 of Grant County, Washington
GRTS	Generalized Random-Tessellation Stratified
MDH	Marion Drain Hatchery
M&E	Monitoring and Evaluation
PIT	Passive Integrated Transponder
Project	Priest Rapids Project
PRFF	Priest Rapids Fish Forum
PRPA	Priest Rapids Project Area
RM	River Mile
UCWSRI	Upper Columbia White Sturgeon Recovery Initiative
UTM	Universal Transverse Mercator
WSMP	White Sturgeon Management Plan

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1.0 Introduction

On April 17, 2008, the Federal Energy Regulatory Commission (FERC) issued Public Utility District No. 2 of Grant County, Washington (Grant PUD) a 44-year license to operate the Priest Rapids Hydroelectric Project (FERC No. 2114), hereafter referred to as the Priest Rapids Project area (PRPA), located in the mid-Columbia River (Figure 1). Article 401 of the FERC license, consistent with the provisions of the Washington Department of Ecology Section 401 Water Quality Certification for the Priest Rapids Project (401 Certification), requires that Grant PUD develop a White Sturgeon Management Plan (WSMP) and conduct an on-going Monitoring and Evaluation (M&E) program to evaluate the effects of the Project on White Sturgeon (*Acipenser transmontanus*) populations within the PRPA. The 2014 M&E program was developed in context with Grant PUD's WSMP, with the overall goal to restore populations of White Sturgeon in the PRPA to levels commensurate with the carrying capacity of available habitats. In 2014, the following tasks were completed under the M&E program:

- Develop and implement a tagging, marking and release plan for the 2013 Brood Year (2013BY) juvenile White Sturgeon based on the annual release target objectives as determined by the Priest Rapids Fish Forum (PRFF) co-managers.
- Conduct broodstock sampling using guide-assisted angling for 14 days in late May and early June 2014. Specific sample locations accessible by angling were selected to increase the probability of capturing larger brood candidate and reduce capture of smaller fish. Transport viable broodstock candidates to the Yakama Nation's Marion Drain Hatchery (MDH).
- Determine the distribution and relative abundance of the hatchery juvenile White Sturgeon.
- Monitor dispersal of the 2013BY juvenile White Sturgeon, based on the movement of acoustic-tagged fish within each release group and determine the extent of outmigration from the Wanapum and Priest Rapids reservoirs.

In alignment with White Sturgeon supplementation programs developed for the Upper Columbia River, the Grant PUD M&E program includes the development of a juvenile population indexing program. The objectives of this program are to monitor the effectiveness of the PRPA juvenile White Sturgeon supplementation program by evaluating juvenile emigration rates, survival rates, growth rates, distribution, habitat selection, habitat use, habitat availability, and habitat suitability. As outlined in the WSMP, monitoring efforts to determine program effectiveness were scheduled for implementation in Years 4, 5, 6, 8, and then every 3rd year for the term of the New License. However, this schedule was contingent upon the success of broodstock aquaculture component of the M&E program and assumed an annual release of up to 6,500 hatchery brood in Years 1 through 4.

Juvenile population indexing was initiated as a pilot program in 2012 (Year 5) and used small-mesh gill nets (79 overnight gill net sets) to target juvenile sturgeon. To reduce the risk of encountering salmonids protected under the U.S. Endangered Species Act, sampling was restricted to late August, at depths >10 m, with nets oriented parallel to flow. Despite the relatively intensive survey effort, only one hatchery origin juvenile White Sturgeon was captured. As a result, for the second juvenile indexing survey in 2014 (Year 7), gill net gear was abandoned in favor of baited setlines. Given the lack of information gained in 2012, and the need to switch gear type, the 2014 survey represented an extension of the exploratory, or pilot, phase of the M&E program with the objective of providing general information on juvenile sturgeon distribution, catch rates, and growth, as well as gear efficacy, with which to inform the development and implementation of a full juvenile indexing program.

Prior to the 2014 juvenile indexing survey, the PRPA juvenile White Sturgeon supplementation program released a total of 15,709 hatchery-raised juvenile sturgeon from three brood years (2010, 2012, and 2013) into the PRPA. Release numbers varied from year to year as did release strategies (Table 1).

The 2010BY releases were composed of the progeny of broodstock originating from three widely separated areas of the Columbia Basin:

- Upper Columbia Wild (UCW) - the progeny of broodstock captured in the Upper Columbia River in Canada and reared by the Freshwater Fisheries Society at Kootenay Sturgeon Hatchery in British Columbia;
- Mid-Columbia Wild (MCW) - the progeny of broodstock captured in the PRPA reared at the Yakama Nation Marion Drain Hatchery (MDH), and
- Lower Columbia Cultured (LCC) - the progeny of captive broodstock originally captured below Bonneville Dam in the lower Columbia River and reared at the Yakama Nation MDH.

Broodstock from widely separated geographic areas may express locally adaptive traits and therefore their progeny could exhibit varying degrees of success following release into the PRPA. The purpose of these experimental releases was to explore the relative suitability of the three stocks for achieving the goals of the PRPA supplementation program via assessments of differences in post-release movement patterns, growth, and survival.

The 2010BYsturgeon were released in 2011 at the Columbia Siding location (RM450.6) situated in the upper reach of Wanapum Reservoir, and in Wanapum Dam tailrace (RM415.6) in Priest Rapids Reservoir (Table 1). The Columbia Siding release was achieved by backing the transport trailer to the river’s edge and releasing the fish into the nearshore portion of a large eddy at a depth of approximately 2 m. Following release, numerous fish could be seen holding on the river bottom at the site. Subsequent PIT-tag detection surveys conducted by Chelan PUD at a known bird colony located in the forebay of Rock Island Dam recorded numerous PIT-tags from the 2010BY Columbia Siding release group (Golder 2013). The eddy at Columbia Siding is relatively large and shallow; these conditions could potentially expose juveniles to avian predation, which might explain the relatively high incidence of PIT-tags observed at the bird colony.

In response, a release experiment was developed for 2012BY juveniles destined for release into Wanapum Reservoir in 2013. The purpose of this experiment was to assess the effects of release location on subsequent juvenile dispersal and survival. The 2012BY Wanapum release (n = 2,264) was split in half with one half released at Columbia Siding - the same site used for the 2010BY releases - and the other half released at Columbia Cliffs Eddy (RM442.0), a deep water area with documented high use by adult and older juvenile sturgeon. Fish were released into the Columbia Siding area in the same manner as in 2011 (Table 1). Fish scheduled for release at the Columbia Cliffs Eddy were dip-netted into a holding tank onboard a Colville Confederated Tribes (CCT) research boat, transported to the site, and released in an area with a maximum depth of approximately 40 m. Observations indicated that fish descended rapidly to depth immediately following release.

In February 2014, prior to the scheduled release of 2013BY sturgeon, a crack was discovered in the spillway of Wanapum Dam which precipitated an immediate drawdown of Wanapum Reservoir to protect the structure from failure. The drawdown limited access to areas in the upper reservoir and so the 2013BY Wanapum release was conducted from the shore at Rocky Coulee boat launch located in the lower reservoir at RM 421.5 near Vantage, WA. Priest Rapids Reservoir levels were relatively unaffected by Wanapum Dam operations and the 2013BY release was conducted from the boat launch located in the Wanapum Dam tailrace as in previous years.

Table 1. Summary of PRPA hatchery sturgeon releases 2011-2014.

							FL (cm)	
BY	Reservoir	Location	RM	Brood source	Date	#Released	Mean	SD
2010	Wanapum	Columbia Siding	450.6	UCW	26 April 2011	2,020	24.6	3.0
				MCW	29 April 2011	2,996	28.8	3.6
				LCC	27-29 April 2011	2,000	34.7	3.6
				All	--	7,016	29.3	5.1
	Priest Rapids	Wanapum tailrace	415.6	UCW	26 April 2011	900	24.8	2.8
				MCW	28 April 2011	601	29.0	3.6
				LCC	28 April 2011	600	35.9	2.9
				All	--	2,101	29.8	5.3
2012	Wanapum	Columbia Siding	450.6	MCW	14 May 2012	1,135	29.2	2.7
		Columbia Cliffs	442.0	MCW	14 May 2012	1,129	29.8	2.6
		All	--	MCW	--	2,264	29.5	2.6
	Priest Rapids	Wanapum tailrace	415.6	MCW	14-15May 2013	1,717	28.5	2.4
2013	Wanapum	Rocky Coulee	421.5	MCW	6 May 2014	3,331	26.6	4.0
	Priest Rapids	Wanapum tailrace	415.6	MCW	5 May 2014	997	27.2	41.7

1.1 Consultation

Pursuant to the reporting requirements, Grant PUD provided a complete draft of the WSMP Annual Report to the PRFF on February XX, 2015 for review. Written comments were received from XXXXX on XXXX, 2015. A summary of comments by the PRFF as received by Grant PUD on the draft PLMP Comprehensive Annual and Biological Objectives Status Report have been compiled along with responses from Grant PUD (Appendix X). The summary is based on written (Appendix X) comments.

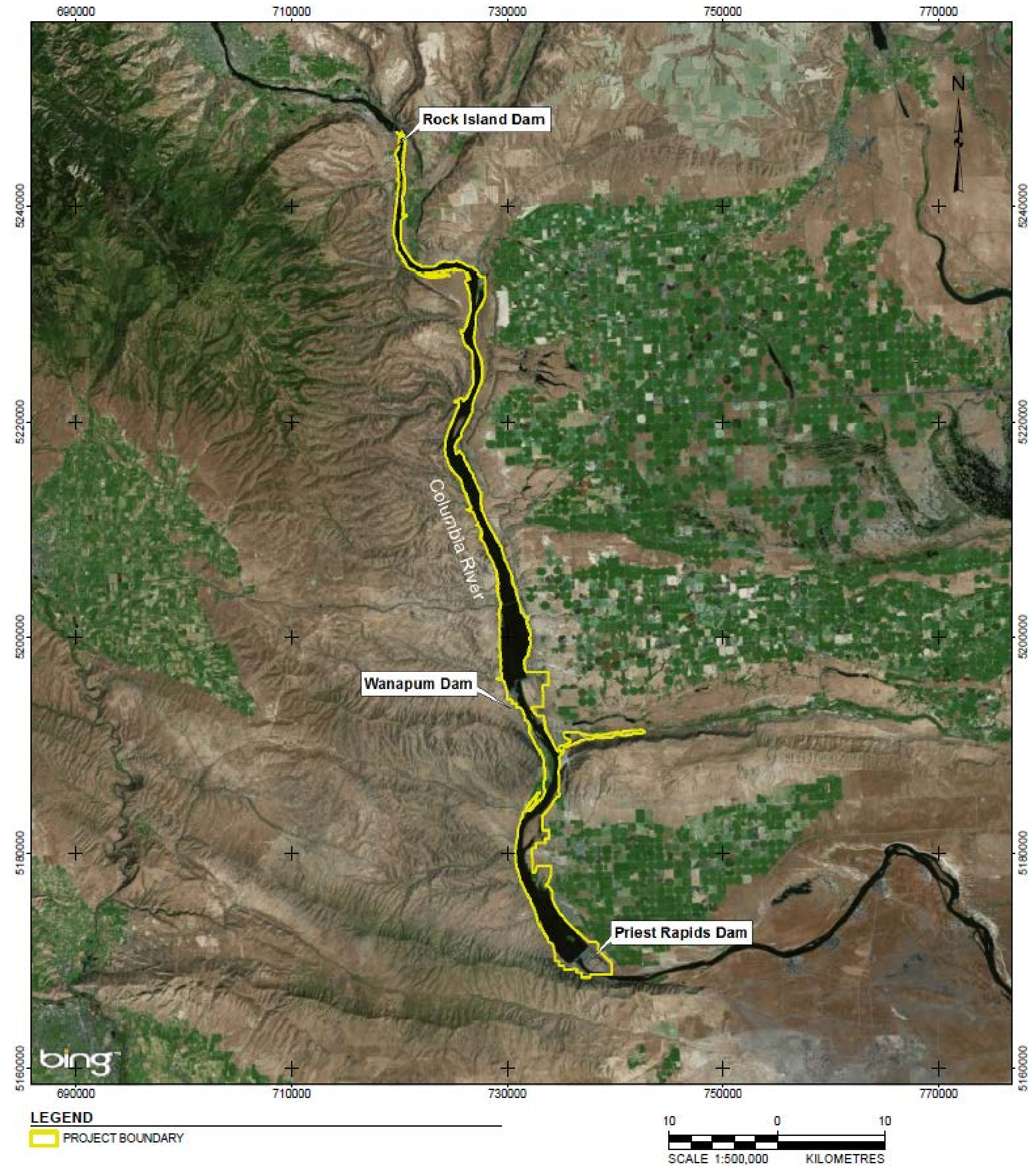

Figure 1 **The Priest Rapids Project Area.**

2.0 Methods

The methods used in the present study closely followed those used in previous studies conducted in the PRPA; these methods are described in detail in the previous studies (Golder 2013, 2014). The following sections provide general descriptions of methods used; more detail is provided for new methods or methods modified from previous studies.

2.1 Environmental Variables

2.1.1 Discharge and Temperature

Most aspects of White Sturgeon life history, as well as the sampling methodologies applied to assess them, are affected by temporal changes in discharge and water temperature. Previous studies have used total river discharge and temperature data as recorded in the tailwater of Rock Island Dam to represent these environmental variables within the PRPA (Golder 2014). Changes in discharge and water temperature below Rock Island Dam were especially relevant to the study efforts, such as brood stock capture, that are conducted within a few kilometers of the dam. Due to the emergency reduction of Wanapum Reservoir in February 2014, temperature and discharge monitoring equipment at Rock Island Dam were at times affected due to the large reduction in tailwater elevation. For the purpose of this study, mean hourly and mean daily total discharge and water temperature as measured in the Wanapum Dam tailwater were considered more reliable and were used in all analyses to represent these environmental variables in the PRPA. Mean hourly total river discharge and water temperature data from January 1 to December 31, 2014 were obtained from the Columbia River Data Access in Real Time webpage (DART 2014).

2.2 2013BY Marking and Release

Working in conjunction with staff from Marion Drain Hatchery (MDH), the combined 2013 broodstock capture efforts by Grant PUD and Public Utility District No. 1 of Chelan County, Washington (Chelan PUD) resulted in the production of 10 half-sib genetic families of juvenile White Sturgeon. These families were held in 3 m (10 ft.) and 6.0 m (20 ft.) circular rearing pens at MDH.

The total 2013BY release in 2014 was determined through the PRFF dispute resolution process and negotiation during the first six months of 2014. As a negotiation resolution was not possible in a timely manner, the Department of Ecology was requested to resolve the issue and determine the total 2013BY release. In September, the decision returned by Ecology was in support of the full annual release allotment of 6,500 2013BY. The process and rationale behind this decision were outlined in a letter provided to Grant PUD (H. Bartlett, Department of Ecology, September 3, 2014). Prior to the September decision by Ecology, the PRFF had agreed to process and release approximately 4,300 juveniles in April 2014. Upon receipt of the Ecology decision on September 3, a second batch of approximately 2,200 juveniles was processed and released by mid-September 2014.

The scute marking and PIT-tagging procedures were conducted at MDH and, as in previous studies, approximately 1% of total juvenile release group were implanted with acoustic telemetry tags (Vemco® V9 coded pingers) to allow examination of post-release movements by a portion of the release group.

During the April processing session, LGL responsibilities included coordinating the tagging effort with MDH staff, organizing tagging and data recording equipment, assisting with the PIT-tagging and marking process, and surgically implanting acoustic tags. These fish were held for two weeks prior to release to recover from the tagging process.

During the September session, personnel provided by Golder Associates Ltd. (Golder), LGL, and Blue Leaf Environmental (BLE) conducted the tagging with assistance from MDH staff. As directed by Ecology in their decision, the remaining fish had to be released prior to September 18. To meet this timeline, fish were released in groups of approximately 600 fish by BLE personnel at the end of each day using the Grant PUD transport trailer. In Wanapum Reservoir, reduced reservoir levels required that all fish were released at Rocky Coulee launch at River Mile (RM) 421.5, the only available access point to the reservoir. Priest Rapids Reservoir fish were released at the Wanapum Dam tailrace launch, the same release location used in all previous release years.

2.3 Broodstock Capture

Broodstock capture was conducted from May 31 to June 13, 2014 and sample efforts were mainly focused in the 5 km section of river below Rock Island Dam in Wanapum Reservoir. Due to the success of angling efforts during the 2013 broodstock capture program (i.e., similar numbers of fish as captured by set line), the decision was made at the end of the 2013 program that angling would be the only capture method used in future broodstock capture efforts. Coincidentally, with the emergency reduction of Wanapum Reservoir in February 2014 angling was the only feasible method of broodstock capture in 2014, as water levels were too low and velocities too high to effectively deploy set lines at many of the set line sampling locations used in previous studies years.

The PRPA broodstock capture program was part of a collective broodstock program conducted in the mid-Columbia basin in support of White Sturgeon conservation aquaculture efforts at MDH. In addition to the PRPA program, a capture program co-funded by Chelan PUD and Grant PUD was conducted by BLE below McNary Dam in John Day Reservoir from May 18 to 28 and on June 1 and 2 (Appendix B). This capture effort consisted of guide-assisted angling conducted by BLE biologists, Chelan and Grant PUD personnel, MDH staff, and volunteers. Additional broodstock angling capture efforts were also conducted by MDH staff at The Dalles from May 21 to 23 and from May 26 to 28 (Donella Miller, MDH, May 29, 2014, personal communication).

2.3.1 Angling

Angling for the PRPA broodstock capture program was conducted daily by up to four boats with two to four anglers per boat. Two boats provided by Hurd’s Guide Services conducted angling each day, with additional angling effort provided by the Grant PUD and Golder research vessels. On average, eight rods were fished each sample day and each sample day was approximately 8-hours long. Due to the reduced Wanapum Reservoir levels in 2014, the research vessels had to be left on the water and moored overnight at a safe location (Plate 1). Fish captured that were wild adults but not suitable candidates for the MDH hatchery (i.e., non-spawners) and juvenile and sub-adult fish from the release of juveniles in the Rock Island Reservoir by the Columbia River Inter-Tribal Fisheries Commission (CRITFC) in 2003, were either processed (see Section 2.3.2 for definition of processing) by the fishing guide or were left in a safe location, attached to shore by a tail noose, until retrieved and processed by Golder. Large wild White Sturgeon considered as potential broodstock candidates were held in the water until the Golder research vessel arrived at the capture location to retrieve and process the fish. If a large fish was angled late in the day and it was too late to allow processing and surgical examination, the fish was held overnight in a deep pool, secured to shore in a vented fish transport bag.

Plate 1 **Overnight mooring location of research vessels used during the 2014 Grant PUD broodstock capture program below Rock Island Dam during the emergency drawdown period of Wanapum Reservoir.**

2.3.2 Fish Handling, Processing and Transport

The 2014 broodstock capture program represented a pilot study to assess the feasibility of using a fishing guide boat for both angling and processing of captured fish. Initially, Hurd's Guide Service outfitted one of their guide boats with a portable winch/davit and canopy system to allow on-board processing of adult sturgeon. Although the davit and canopy system were effective at bringing fish on board for processing, the guide boat itself was too small to carry a full complement of anglers and still serve as an effective processing boat. Furthermore, the anglers on this boat were idle for extended periods while captured fish were processed. Therefore, a decision was made to use the Golder research vessel as a dedicated processing boat and use the guide processing boat as an additional angling boat to increase angling effort.

Fish were handled and processed in a similar manner as during previous broodstock capture programs (Golder 2013). All capture fish were scanned for a PIT-tag and a PIT-tag applied if none were detected. Once the PIT-tag number was confirmed, weight, fork length, total length, head, snout, and girth measurements were recorded. Sex and maturity of broodstock candidates were assessed by surgical examination and visual inspection of the gonads with an otoscope. The assessment of sex and maturity followed the methods used in the upper Columbia River White Sturgeon Recovery Program (Table 2; UCWSRI 2006). Large wild White Sturgeon that were not ripe, but were consider as possible broodstock candidates were implanted with a ten-year Vemco® V16 acoustic tag to allow the fish to be tracked in the future and possibly located prior to spawning. All data were entered in the field, directly into Golder's White Sturgeon capture database. DNA samples were obtained and preserved for all first-time captured wild fish. A canopy installed over the rear half of the Golder research boat protected the fish from direct sunlight and reduced overall thermal stress and exposure to UV radiation during processing.

As the focus was to capture adult broodstock, only rudimentary processing was conducted by the fishing guide if a small hatchery White Sturgeon, of either MDH or CRITFC hatchery origin, was captured and the Golder processing boat was unavailable. In this case, only the PIT-tag number, fork length, and girth were recorded and the fish was released after processing near the site of capture. To obtain a general indication of hatchery White Sturgeon diet, the 2014 Grant PUD scientific collection permit allowed up to ten CRITFC fish to be sacrificed and the stomach and gut removed. These stomach and gut samples were briefly inspected in the field to determine the general content and then was preserved in 70% isopropyl and archived for future analysis. The flesh from sacrificed fish was kept in a cooler on ice and provided to a food bank or the Wanapum tribe.

Table 2 Sexual maturity codes for White Sturgeon (adapted from Bruch, et al. 2001).

Sex	Code	Developmental State Description
Male	Mv	**Virgin male juvenile**; Testes are ribbon-like in appearance with lateral creases or folds , dark grey to cream colored attached to a strip of adipose fat tissue.
	M1	**Developing male**; Testes are tubular to lobed, light to dark grey, and embedded in substantial amounts of fat. Testes moderately to deeply lobed have distinct lateral folds.
	M2	**Fully developed male**; Testes large, cream to whitish in color, deeply lobed and filling most of the abdominal cavity. If captured during active spawning, may release sperm if stroked posteriorly along the abdomen.
	M3	**Spent/recovering male**; Testes size are much reduced, with very distinct lobes and whitish to cream color.
	M0	**Male based on previous capture**; general unknown maturity
Female	Fv	**Virgin female juvenile**; small feathery looking, beige ovarian tissue attached to a thin strip of adipose fat tissue.
	F1	**Early developing female**; pinkish/beige ovarian tissue with brain-like folds and smooth to rough surface, imbedded in heavy strip of fat tissue. The visible whitish eggs are <0.5 mm in diameter. Ovarian tissue of F1 females that have previously spawned is often ragged in appearance.
	F2	**Early “yellow egg” female**; Yellowish/beige ovarian tissue with deep “brain-like folds embedded in extensive fat tissue giving it a bright yellow appearance. Eggs, 1 to 2 mm in diameter with no apparent grayish pigmentation.
	F3	**Late “yellow egg” female**; large yellowish ovaries with deep lateral folds and reduced associated fat. Yellow/greenish to grey eggs 2.5 mm in diameter. May indicate next year spawning.
	F4	**“Black egg” female**; Large dark ovaries filling much of the abdominal cavity. Exhibiting a distinct “bulls-eye”. Very little fat, Eggs are still tight in the ovary, dark grey to black, shiny and large, >3 mm in diameter.
	F5	**Spawning female**; Loose flocculent-like ovarian tissue with eggs free in body cavity shed in layers from deep ovarian folds. Eggs large, from grey to black, similar to F4.
	F6	**Post spawn female**; ovaries immediately after spawning are folded with a mushy pinkish and flaccid appearance, with little or no associated fat. Post spawn females display a characteristic abdominal mid-line depression. Large dark degeneration eggs buried amongst small oocytes.
	F0	**Female based on previous capture**; general unknown maturity
Unknown	97	adult based on size, (i.e., 1.5 m FL or greater) no surgical examination
	98	juvenile/sub-adult based on size, (i.e., no surgical examination)
	99	gonad undifferentiated or not visible during surgical examination

Broodstock transfer from the research boat to the transport trailer was conducted at the Columbia Siding launch (RM450.6). Due to low reservoir levels, direct access to the water by the Grant PUD White Sturgeon transport trailer was not possible at Columbia Siding; the closest approach possible with the trailer was 45m (150 ft.) from the water’s edge. In response, an innovative approach was developed to enable fish to be effectively and safety loaded and transported at Columbia Siding. Several lengths of fire hose were connected together to pump water from the reservoir to the trailer and a wheeled stretcher cart was fabricated to allow fish up to 2.4 m (8 ft.) in length to be safely and easily transported from the boat to the trailer over the uneven ground. Once at the transport trailer, a winch and davit system was used to safely lift the fish from the cart into the transport trailer (Plate 2).

Plate 2 **The White Sturgeon transport system used during the 2014 broodstock capture program on Wanapum Reservoir.**

2.4 VR2W Telemetry Array Download and Maintenance

In 2014, two of the six VR2W station telemetry receivers (model VR2W, Vemco-Amirix Systems Inc., Halifax, NS) used to monitor movements of acoustic-tagged White Sturgeon in Wanapum Reservoir were lost (Table 3). This loss was due to a combination of cumulative metal fatigue of anchor components (deployed since 2010) and increased water velocities and reservoir level fluctuations due to the emergency draw down. A third station at RM446.9 in Wanapum Reservoir was removed by field crews in June 2014 as a precaution as loss of the station was considered a reasonable possibility. A loss of three out of five stations occurred in Priest Rapids Reservoir, again likely related to fatigue failure of the cable to anchor connections. Due to access restrictions in 2014, service and maintenance opportunities of the VR2W stations in Wanapum Reservoir were conducted opportunistically from May 30 to June 14, and then again on October 8. Of the five stations lost in the PRPA, three of the five receivers floated downstream and were eventually recovered.

Table 3 Acoustic receiver station locations, deployment dates, and status in the PRPA as of October, 2014.

Station Name	River Mile	UTM Zone	UTM Easting	UTM Northing	Reservoir	Deployment Date	Station Status
VRRM392.0	392.0	11	284680	5167847	McNary	18-May-12	Active
VRRM398.1	398.1	11	276897	5170976	Priest Rapids	22-Jun-10	Lost (not recovered)
VRRM404.0	404.0	11	272861	5180011	Priest Rapids	22-Jun-10	Lost (recovered)
VRRM410.5	410.5	11	276868	5188281	Priest Rapids	23-Jun-10	Active
VRRM413.5	413.5	11	274586	5192162	Priest Rapids	23-Jun-10	Lost (recovered)
VRRM415.5	415.5	11	274044	5195579	Priest Rapids	19-Sep-10	Active
VRRM416.1	416.1	11	273719	5196719	Wanapum	7-Oct-10	Lost (not recovered)
VRRM426.5	426.5	10	727309	5211953	Wanapum	23-Jun-10	Active
VRRM437.1	437.1	10	726171	5227514	Wanapum	17-May-12	Active
VRRM442.0	442.0	10	725506	5234769	Wanapum	21-Jun-10	Active
VRRM446.9	446.9	10	719589	5237495	Wanapum	29-Jun-11	Removed
VRRM452.4	452.4	10	720484	5246202	Wanapum	20-Sep-10	Lost (recovered)

2.5 Juvenile Movements

Telemetry data from acoustic tagged 2013BY juveniles released in 2014 were screened for errors. Spurious detections, defined as acoustic tag IDs that were detected only once during a 24 hour or longer period, were removed from the dataset prior to analysis.

The screened data were analyzed as presence/absence data. If a fish was detected at a receiver more than once in a day (i.e., the detection was defined as non-spurious), it was considered to be present near that receiver on that day. This approach allowed the examination of temporal patterns of presence/absence rather than simply reporting the numbers of detections recorded at each VR2W station. Daily presence/absence data were then used to estimate 1) a weekly estimates of fish numbers at each station; and, 2) a weekly residency ratio, calculated as the number of days an individual fish was present at each receiver station out of the available number of days in that week. During the week of fish release, the weekly residency ratio was adjusted to account for the date of release; i.e., the ratio of residency was estimated as:

days present/(days in week - date of release+1)

Individual residency ratios were then used to calculate mean weekly residency ratios across fish from the same release site. Net movement was calculated as the sum of all changes in RM values between every two consecutive detections. All data analyses were performed in the statistical environment R, v. 3.1.0 (R Development Core Team 2014). Plots were created in R using the package ggplot2 (Wickham 2009).

2.6 Juvenile White Sturgeon Population Indexing

2.6.1 Study design

Setline sampling for juvenile hatchery origin sturgeon was conducted in Priest Rapids Reservoir from 12 to 14 August and 18 to 22 August, 2014, and in Wanapum Reservoir from 25 to 29 August and 2 to 5 September, 2014.

Setline gear consisted of a 182.9 m (600 ft.) ground line (0.64 cm [¼ in] diameter twisted three-strand tarred nylon line) marked at 4.6 m (15 ft.) intervals for placement of 40 gangions. Setlines were anchored at each end with 13.6 kg (30 lb.) pyramid lead weights and line ends were marked with buoys (Polyform LD2). Gangions consisted of a halibut clip and swivel, a 45.7 cm (18”) gangion leader, and a single hook (Plate 3). Hooks were offset point Gamakatsu Octopus circle hooks of sizes 2/0, 4/0, 6/0, and 8/0 (Plate 3). Hooks were snelled to the gangion leader and 10 hooks of each size were deployed per setline set. Higher than expected hook loss (presumably from interactions with large sturgeon) rapidly depleted our stock of spares and consequently Mustad 12/0 (39960D series) circle hooks were occasionally substituted for 8/0 hooks during sampling in Wanapum reservoir. Gangion line consisted of 36.3 kg (80 lb - 2/0 hooks) and 59.0 kg (130 lb. -4/0, 6/0, 8/0 hooks) test Dacron line, or #42 gangion twine (12/0 hooks). Dacron lines were sheathed in clear vinyl aquarium air-line tubing to help protect against abrasion, as well as provide stiffness to limit tangling with the groundline (Plate 3). Hooks were baited with commercially available pickled squid (*Loligo* spp.) which was cut to match the size of each hook. For consistency, only the squid mantle was used for baiting; heads were removed and discarded. Old bait was removed from hooks at gear retrieval each day and new bait was applied prior to re-deployment.

Sampling each day was conducted from two CCT aluminum landing craft research boats (a combination of an 8.5 m Almar; 7.9 m Almar, or 9.1 m Munson) each staffed with a three-person crew. All three boats used during the survey were equipped with hydraulic line haulers to facilitate line retrieval. Due to the relatively light-duty construction of the gangions and the potential for losing fish, crews were careful to moderate the line haul-in speed particularly during the initial lift of the line from the bottom and when lifting the second anchor (i.e., those periods during the retrieval process when water drag on hooked fish is greatest). Each boat usually picked and re-set ten lines per day. Setlines were deployed overnight and were generally set in an upstream-downstream orientation in order to minimize the depth range sampled at each site. Data recorded during gear deployment and/or retrieval included: line end locations (latitude/longitude, decimal degrees, WGS84 datum); set depth (m; the average of minimum and maximum depths observed during the set); set start and end date/time; number of gangions set; and the number of bent, broken or lost hooks at time of line retrieval.

Plate 3 **An illustration of the circle hooks (left) and gangion construction (right) used during the 2014 setline survey. Hooks are (from left to right) 2/0, 4/0, 6/0, and 8/0 Gamakatsu Octopus circle hooks with offset points, and a 12/0 Mustad circle hook also with offset point.**

A single pass, unstratified, unequal probability Generalized Random Tessellation Stratified (GRTS; Stevens and Olsen 2004) area-based survey design was employed in each reservoir with sample sites drawn prior to the survey using the spsurvey package in R (Kincaid and Olsen 2013; R Core Team 2014). The sampling frames used for drawing sites were equal area projection polygons defined in ESRI shapefiles. These polygons were extracted from shapefiles of PRPA bathymetry data supplied by Grant PUD using ArcMap10. The Wanapum Reservoir sampling frame polygon was delineated by the 10.7 m (35 ft.) depth contour to account for the drawdown in effect at the time of the survey due to spillway repairs at Wanapum Dam (Figure 2). The Priest Rapids Reservoir sampling frame polygon was delineated by the 6.1 m (20 ft.) depth contour; depths shallower than 6.1 m were excluded to avoid sampling in areas where beds of aquatic macrophytes were prevalent (Figure 2).

The PRPA acoustic telemetry studies conducted by Golder on 2010BY and 2012BY sturgeon prior to the 2014 juvenile population survey suggested that hatchery White Sturgeon densities may be greatest in the middle and upper sections of each reservoir. Therefore, to maximize catch it was desirable to maximize sampling intensity (i.e., effort per unit area) in these sections. An unequal probability GRTS design allows for specifying different levels of sampling intensity between sections ("multi-density categories") without the need to employ true stratification. Accordingly, multi-density categories were defined by subdividing the sampling frame polygon of each reservoir into approximate thirds by length ("lower", "mid", and "upper" sections; Figure 2). While ostensibly arbitrary, these sections superficially reflected the transition from riverine to reservoir conditions in each pool. In Wanapum Reservoir, the GRTS sample draw specified to the spsurvey package was 150 sites (with a 100% overdraw) with sites apportioned equally among sections (i.e., 50 sites per section). Thus, because the areal extent of sections progressively decreased moving upstream, sampling intensities increased accordingly. In Priest Rapids reservoir, the specified GRTS draw was 80 sites (also with 100% overdraw) with sites apportioned among the three sections such that each section received a similar level of sampling intensity as the corresponding section in Wanapum Reservoir. In addition to the formal GRTS sample, 20 overnight setline sets were deployed in Wanapum (n = 4) and Priest Rapids (n = 16) as time allowed with the aim of supplementing the total catch.

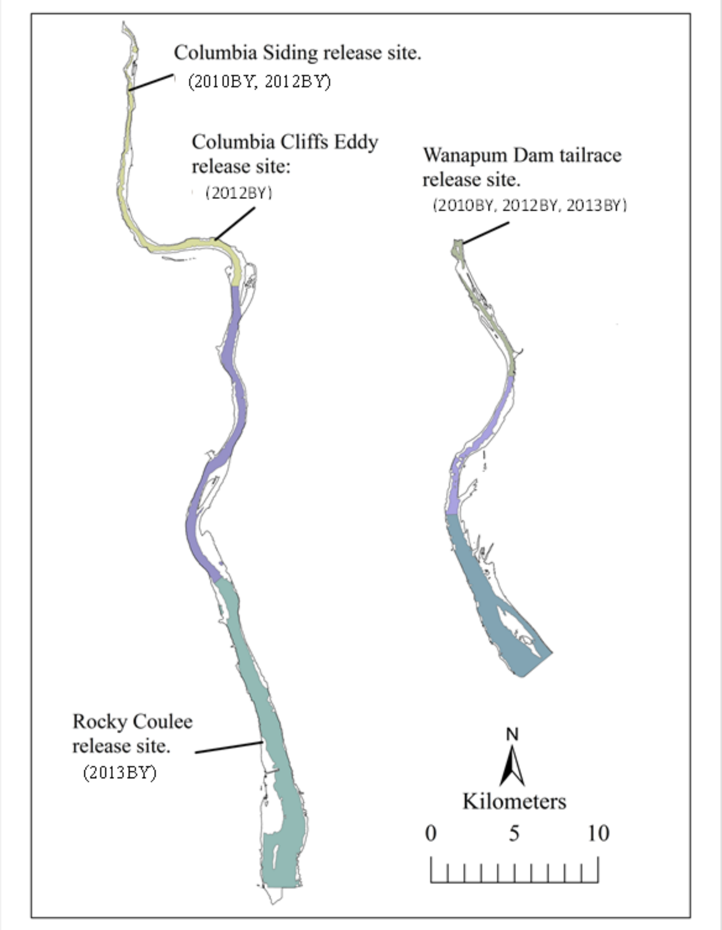

Figure 2 **Overview map of the PRPA study area showing sampling frame polygons (shaded areas) used for the GRTS-based setline survey. Colors differentiate the sampling frame of each reservoir into multidensity categories ("sampling sections") which received varying levels of sampling effort according to the unequal probability GRTS survey design. Hatchery sturgeon release sites are shown.**

At capture, White Sturgeon were placed in an onboard live well and held for processing following completion of setline retrieval. Sturgeon were measured for fork length (FL; to the nearest cm), weighed (nearest 10 g), scanned for the presence of a PIT-tag (AVID Power Tracker VIII reader) and checked for scute scar patterns and physical abnormalities. Sturgeon were immediately released back into the reservoir following processing. Bycatch was identified, enumerated, and released.

The relationship between sturgeon $\log_{10}$ transformed FL and weight data was estimated via linear regression for each reservoir separately. Sturgeon condition was estimated by calculating relative weight based on the standard weight (W_s) equation for White Sturgeon: $W_s = 2.735 \text{ E-6} * \text{FL}^{-3.232}$ (Beamesderfer 1993). Absolute growth (cm) in FL, and average annual growth rate (cm y^{-1}) in FL between tagging and capture was calculated for individual fish. For sturgeon caught more than once during the survey, data from the first capture was used in growth calculations.

Because the setline represented the experimental unit in the study design, catch-per-unit-effort (CPUE) was standardized as the number of sturgeon captured per overnight setline set.

Variability in set duration was not accounted for on the basis that catch rates were generally low and that performing adjustments would likely have had negligible effects on estimates of arithmetic mean CPUE (µCPUE). Calculations of µCPUE and associated 95% confidence intervals used untransformed CPUE data and followed the local neighborhood methods of Stevens and Olsen (2004) using the spsurvey package in R (Kincaid and Olsen 2013). The proportion of efforts where sturgeon catch was greater than zero (Ep; Counihan et al. 1999; Bannerot and Austin 1983; Uphoff 1993) was also calculated as an alternative to µCPUE for comparing sturgeon densities among areas. Ep values from individual sampling sections were mean averaged to provide an estimate of Ep (µEp) for each reservoir as a whole. To further aid the visualization of sturgeon catch distribution, capture sites were plotted on maps of the study area using symbols that were proportional in size to the observed catch.

River discharge and water temperature during the time of the survey were obtained from the Columbia River Data Access in Real Time webpage (DART 2014).

2.7 Data Analysis

Custom task-specific field databases were designed and used to record field data. Within these databases, queries were used to extract and process White Sturgeon capture, spawning, and telemetry data, as well as screen for data entry errors. Broodstock and egg capture CPUE calculations, summary tables, and simple figures were produced in Excel® using pivot tables and data filters, or in SigmaPlot®. More complicated figures were created in R using the package ggplot2 (Wickham 2009). Customized datasheets and manifests were used to record information during the juvenile release, broodstock transport, VR2W download and servicing, and mobile telemetry tracking.

3.0 Results

3.1 Discharge and Temperature during Study Components

The Columbia River hydrograph in 2014 exhibited a distinct bimodal pattern over the spring-summer freshet period, with a peak on June 1 (5,988 m^3/s), followed by a substantial decrease in flows by June 15 (3,390 m^3/s), with flows increasing again on July 1 (5,695 m^3/s; Figure 3). The broodstock capture effort was conducted over a period of substantial change in total river discharge, with very high mean daily flow (5,302 m^3/s) conditions at the start of the capture effort on May 31, followed by a sharp decrease and much lower flows(4,038 m^3/s) at the end of the program on June 13, 2014. Average mean daily temperature during broodstock capture was 13.4°C.

Discharge and water temperature varied substantially between the May and September juvenile White Sturgeon 2013BY releases (Figure 3). During the May 5 and 6 releases, average mean daily discharge of 5109 m^3/s was higher than the 1981 m^3/s during the September 15 to 18 releases. Conversely, average mean daily water temperatures during the May release (9.8°C) was lower that during the September release (18.7°C).

Average mean daily discharge during the juvenile White Sturgeon indexing study was 2,906 m^3/s, and declined from 3,568 m^3/s on August 12 to 2,033 m^3/s on September 5. Average mean daily temperature during juvenile indexing was 19.9°C, with the maximum mean daily temperature recorded on August 21 (20.3°C).

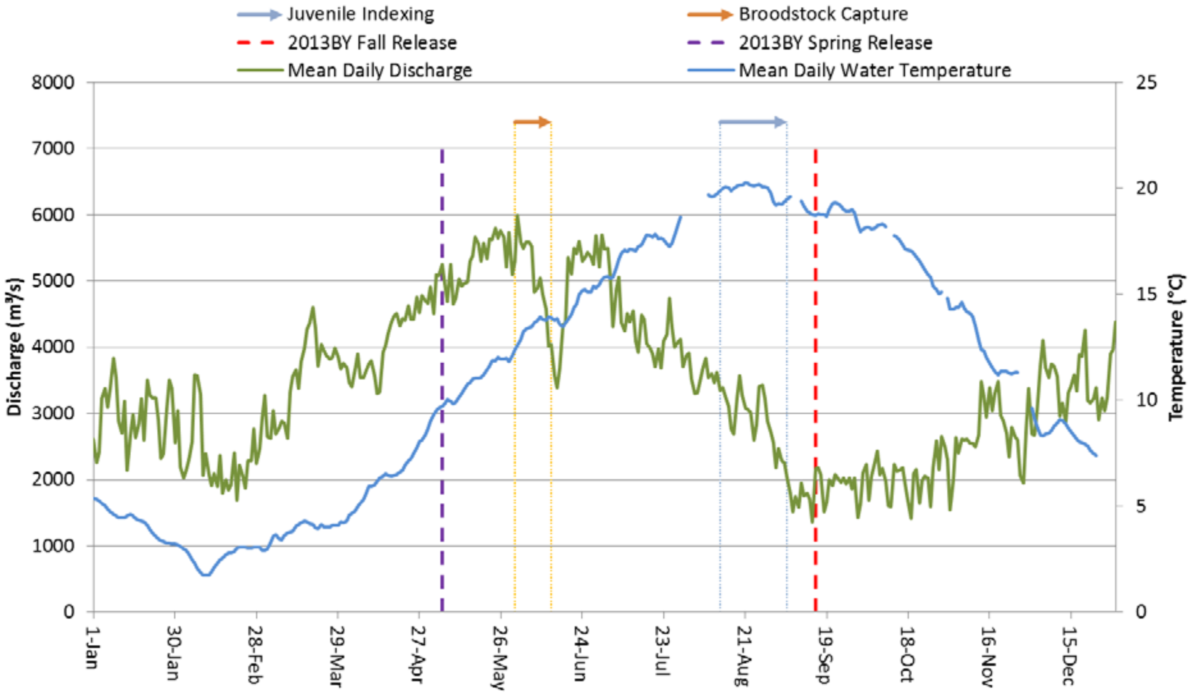

Figure 3 Mean daily discharge and mean hourly water temperature, as measured below Wanapum Dam. Horizontal arrows between the dotted vertical lines indicate broodstock (orange) and juvenile indexing (blue) sessions. Vertical dash lines denote 2013BY juvenile White Sturgeon release dates.

3.2 2012BY Juvenile Marking and Release

In 2014, a total of 6594 juvenile White Sturgeon (2013BY) were released in the PRPA as part of two releases, one in early May (May 5 and 6; 4328 fish) and one in mid-September (September 15 to 18; 2266 fish; Table 4). All fish released were produced, tagged, and processed at MDH. Within the PRPA, 5093 fish were released in Wanapum Reservoir, with the remaining 1501 fish released in Priest Rapids Reservoir. In total, 66 of the 2013BY release were implanted with acoustic telemetry tags, with 52 acoustic-tagged fish released in Wanapum Reservoir and 14 acoustic-tagged fish released in Priest Rapids Reservoir. The 2013BY juveniles exhibited a high incidence of fin deformities, with deformities recorded for approximately 51% of the May release and 90% of the September release.

Table 4 **Release number and mean fork length and weight of the 2013BY juvenile White Sturgeon released in the PRPA, 2014.**

	May 2014 Release			September 2014 Release			PRPA 2014 Total		
Release Location Reservoir (River Mile)	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**	**No. of Fish (acoustic-tagged)**	**Mean FL (+/- SD) mm**	**Mean Weight (+/- SD) g**
Wanapum (421.5)	3331(32)	266 (40)	118 (53)	1762(20)	291 (44)	151 (75)	5093 (52)	275 (43)	129 (63)
Priest Rapids (415.6)	997(9)	272 (42)	131 (56)	504(5)	281 (43)	135 (73)	1501(14)	275 (42)	132 (63)
Total	**4328(41)**	268(41)	121(54)	**2266(25)**	289 (44)	147(75)	**6594(66)**	275 (43)	130 (63)

3.3 Broodstock Capture

Approximately 1058 hook-hours of angling effort during the 2014 broodstock capture program below Rock Island Dam captured 33 White Sturgeon (22 wild and 11 hatchery; CPUE = 0.03 fish/hook-hours). Seven of the 22 wild fish had been previously captured; three of the seven had been tagged during studies conducted from 1999 to 2002. The four other recaptures were previously tagged during the Grant PUD White Sturgeon M&E studies conducted from 2010 to 2013. Annual growth rates of the recaptured fish (i.e., the difference in fork length between first and last capture divided by years at large), were consistent with previous findings that White Sturgeon in the PRPA were growing and smaller fish generally grow at a faster rate than larger fish (Table 5; Golder 2011, 2013). Out of the 11 hatchery fish captured, 4 were second captures and of these, 2 were 2010BY MDH fish and 2 were CRITFC hatchery fish. The 2010BY fish had almost doubled in FL since release, while the CRITFC fish growth was variable, with only one of the two exhibiting substantial annual growth. The life history data from all fish captured during the broodstock program are provided in Appendix A, Table A1.

Due to the success of the 2014 broodstock collection program below McNary Dam in John Day Reservoir, nine females were on station at MDH prior to the start of the PRPA broodstock program. In total, 64 White Sturgeon were captured below McNary Dam; a summary of the capture results is provided (Appendix B). Broodstock capture efforts by MDH staff at The Dalles caught large numbers of sturgeon, but the fish captured were either immature or too large to be considered suitable as broodstock (i.e., > 2.74 m or 9 ft.).

Surgical inspection of all large wild White Sturgeon captured in the PRPA identified two ripe females and one flowing male as potential broodstock candidates. At the time of capture of the two ripe females during the PRPA program, Golder and Grant PUD biologists discussed whether there was a need for additional ripe females as broodstock at MDH. Based on this discussion, a decision was made to release the two ripe females and allow them to spawn naturally below Rock Island Dam. The flowing male captured in the PRPA was transported to MDH and contributed to 5 of the 40 half-sib 2014BY genetic families produced (Appendix C). Six other adult White Sturgeon, were identified as possible future broodstock candidates and were each implanted with a 10-year V16 acoustic telemetry tag (see Section 3.6).

Table 5 Days at large and annual average increase in FL of re-captured White Sturgeon.

Origin	FL at First Capture (cm)	FL at Last Capture (cm)	Days at large	Delta FL (cm/year)	Origin
Wild	226.0	257.0	4626	2.4	Wild
Wild	91.5	192.5	4997	7.4	Wild
Wild	91.0	179.5	5363	6.0	Wild
Wild	138.0	146.0	1330	2.2	Wild
Wild	125.5	157.0	1344	8.6	Wild
Wild	125.5	125.0	367	0.0	Wild
Wild	158.0	160.5	369	2.5	Wild
CRITFC	68.0	79.0	1330	3.0	CRITFC
CRITFC	83.5	91.0	365	7.5	CRITFC
2010BY	23.1	48.0	1131	8.0	2010BY
2010BY	24.0	44.0	1144	6.4	2010BY

3.4 Broodstock Catch Size Distribution and Frequency

Of the fish captured, the average length of wild White Sturgeon (n = 22) captured was 180.0 cm FL and ranged from 125.0 cm to 257.0 cm FL (Figure 4). The average length of hatchery White Sturgeon captured during the 2014 broodstock program below Rock Island Dam (n = 11) was 92.0 cm FL (range from 30.0 cm to 141.0 cm FL). The largest single day capture of fish (n = 6) was on May 31, after which catches declined (Figure 5).

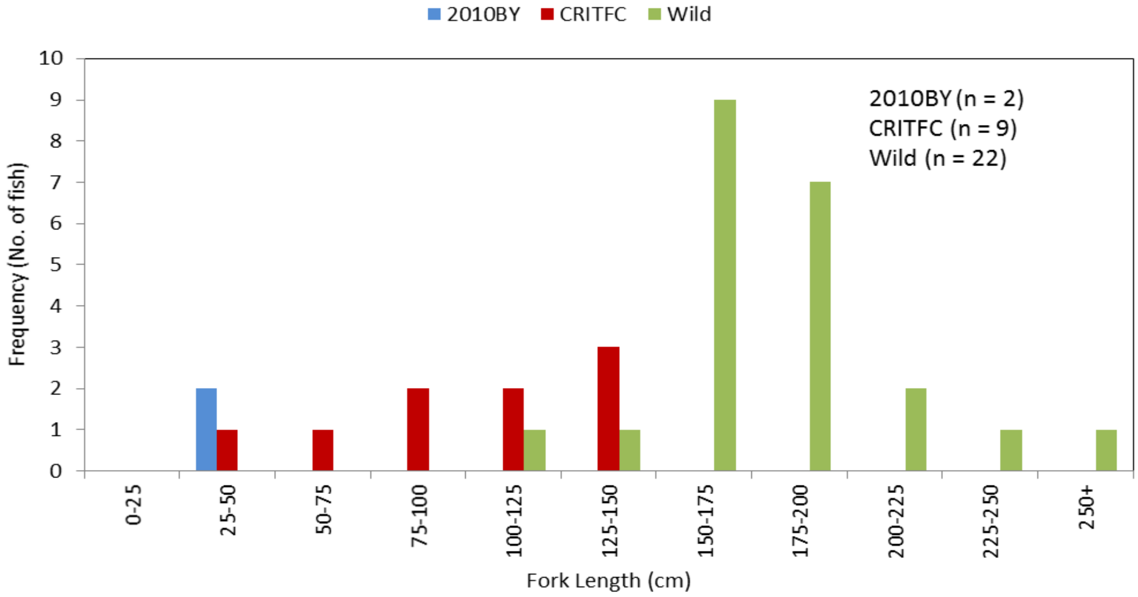

Figure 4 Length–frequency of wild and hatchery (2010BY and CRITFC) White Sturgeon captured in Wanapum Reservoir during the broodstock capture program, May 31 to June 13, 2014.

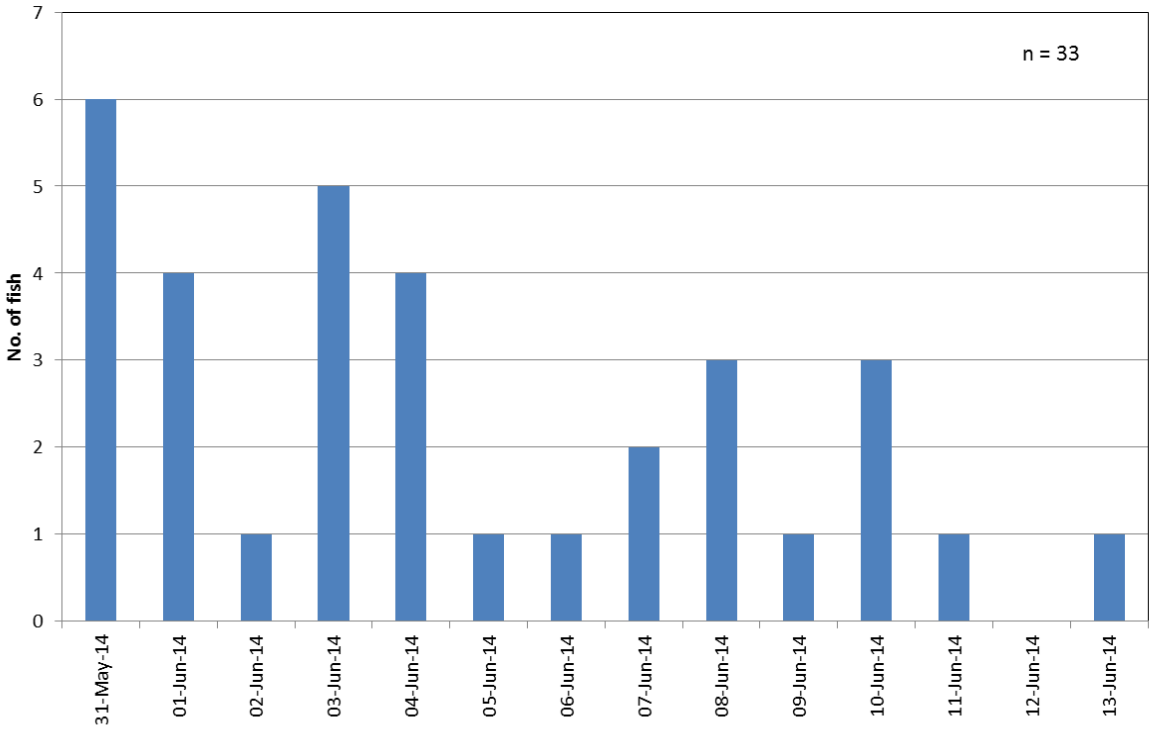

Figure 5 **Daily capture frequency of White Sturgeon in Wanapum Reservoir during the PRPA broodstock capture program, May 31 to June 13, 2014.**

3.5 Broodstock Transportation

In 2014, only 1 of the 33 wild fish captured in Wanapum Reservoir warranted transport to MDH to supplement the broodstock on station (Table 6). The fish transferred was a mature flowing male (i.e., M2). A sample of milt was obtained during processing of this fish and prior to transport; this milt was kept on ice and provided to the hatchery, in case milt production from the fish decreased due to transport stress. At the hatchery, transport crews assisted MDH hatchery staff in weighing and moving the fish from the transport trailer into a holding pen. Hatchery personnel returned the fish to Wanapum Reservoir once spawning of all broodstock at MDH was completed in June.

Table 6 **Information from candidate broodstock captured in Wanapum Reservoir below Rock Island Dam and transported to Marion Drain Hatchery, 2014.**

Capture Date	PIT-tag Number	Fork Length (cm)	Weight (kg)	Sex/Maturity[1]
1-Jun-14	985121028969926	221.5	82.6	M2

[1] See Table 1 for definitions of Sex / Maturity codes.

3.6 Acoustic Telemetry Tagging

In 2014, six adult wild White Sturgeon captured during the broodstock collection program were tagged with acoustic telemetry transmitters before being released (Appendix A, Table A1). Due to the limited number of acoustic tags available (i.e., 10 tags), only select fish were implanted with an acoustic tag based on the judgment of the field lead and selectively applied tagging criteria. For example, a large ripe female (PIT-tag 4110493172) captured on May 31 was not implanted with an acoustic tag due to the risk that the internal tag would be shed once the fish spawned. However, with the decrease in catch as the broodstock capture program progressed, opportunities to implant tags were also reduced. As a result, the fish that were originally deemed as borderline candidates earlier in the program, and not implanted with an acoustic tag, were later considered as a lost opportunity to deploy a tag. Consequently, four of the ten tags were not deployed and conserved for use in future tagging efforts.

3.7 White Sturgeon Diet Assessment

The stomach contents of three CRITFC hatchery origin White Sturgeon were examined to obtain information on the diet of sturgeon in the PRPA. Two fish captured on May 31 were sacrificed at capture and their gut contents processed on June 1. The stomach and hind gut contents of the larger fish (FL = 133.0 cm) contained an intact signal crayfish (*Pacifastacus leniusculus),* crayfish claws and carapace fragments, and a whole unidentified salmonid approximately 230 mm FL. The gut of the smaller fish (not PIT-tagged; estimated FL = 95.0 cm) was empty. The stomach and hind gut of the third fish captured on June 7 (FL = 122.0) was also empty. A fourth fish caught on June 10 and held overnight was not sacrificed under the assumption that time and stress since capture likely resulted in the fish digesting or expelling its stomach and gut contents.

3.8 Avian Predation

Evidence of avian predation on the 2010BY and 2012BY juvenile White Sturgeon was detected based on 143 PIT-tags detected and identified at a known bird colony located in the forebay of Rock Island Dam (Lance Keller, Chelan PUD, February 3, 2015, personal communication); PIT-tags from 2013BY sturgeon were not detected. Potentially, these PIT-tags were not deposited at the bird colony in 2014, but were missed during previous surveys. To date, 246 PIT-tags have been detected since 2011, comprised of PIT-tags from 92 2010BY and 115 2012BY released at Columbia Siding (RM450.6), and 39 2012 BY released at Columbia Cliffs Eddy (RM442.0).

3.9 2013BY Juvenile White Sturgeon Movement

Acoustic telemetry positional data from the 2013BY juveniles recorded from May 5 to October 8 were analyzed to determine the post-release dispersal of juvenile White Sturgeon from the release locations in each reservoir. In Wanapum Reservoir, of the 52 tagged fish released at RM421.5, 47 were subsequently detected during the study (Figure 6; Figure 7). Of these, most fish (n = 39 of 47 tags detected) were first detected upstream of the release site (Figure 8).

Changes in the weekly counts of fish indicated that fish moved initially both up- and downstream from the RM 421.5 release location (Figure 6). By mid-summer, fish were found mainly upstream of the release location. Three (5.8%) of the 52 fish released in Wanapum were entrained into Priest Rapids Reservoir. The three entrained fish were part of the May 6 release of 32 acoustic-tagged fish; two fish (tag codes 25883 and 25871) were entrained within four days after release and the third (tag code 25868) entrained 80 days post-release (Figure 6).

Fish were present at RM426.5, a known high-use area of White Sturgeon, throughout the monitoring period, although highest counts were recorded in early May, early June, and mid-September, with lower numbers of fish during mid-summer. More upstream sites (RM 427.1 and RM 442.0) had fish present during most of the study period, albeit in low numbers, with increased counts after mid-September (Figure 6).

Residency ratios were generally stable at RM 426.5, ranging between 0.21 and 0.833, with fish present throughout the study period (Figure 7). At the RM442.0 overwintering site, residency ratios ranged from zero (early May and late June) to 1.0 (late May), with high values in mid to late August. Fish entrained into Priest Rapids reservoir had high residency ratios at RM410.5 in mid-late May, after which they were detected only at RM404.0 during June and early July. These fish moved upstream to RM415.5 in mid-July, where high residency ratios were recorded from mid-August to early September and early October.

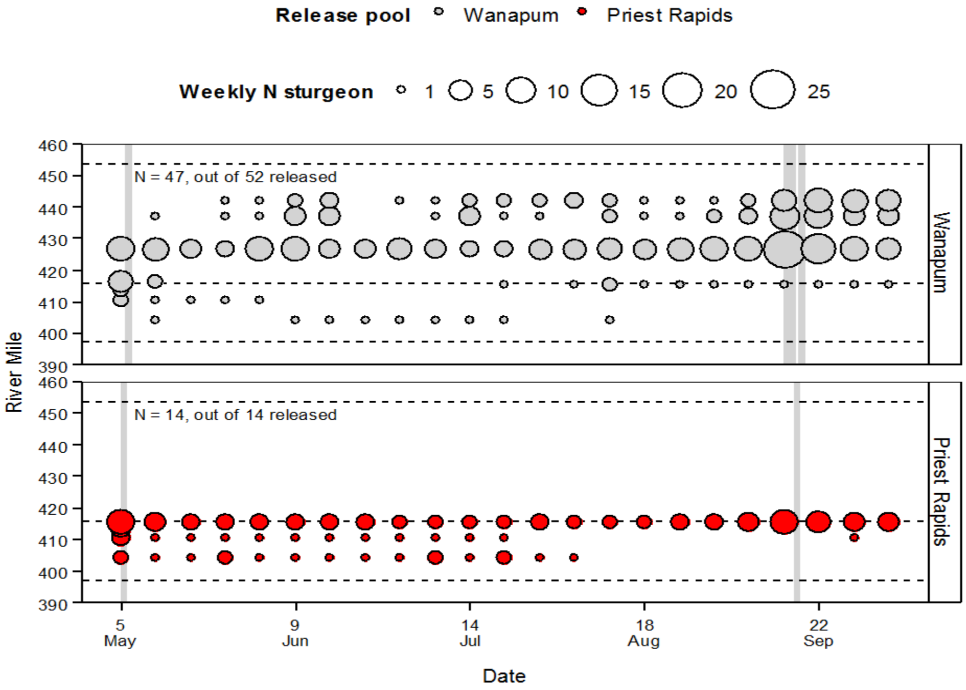

Figure 6 **Weekly counts of acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014. Dot sizes represent the number of unique tags detected every week. Dot colors correspond to release locations at RM421.5 (grey; Wanapum) and RM15.6 (red; Priest Rapids). The number of detected tags out of total number of tags deployed in each reservoir is provided on each panel. The vertical grey bars represent release dates for the 2013BY juveniles; the horizontal dashed lines represent the location of Rock Island Dam (top), Wanapum Dam (middle), and Priest Rapids Dam (bottom).**

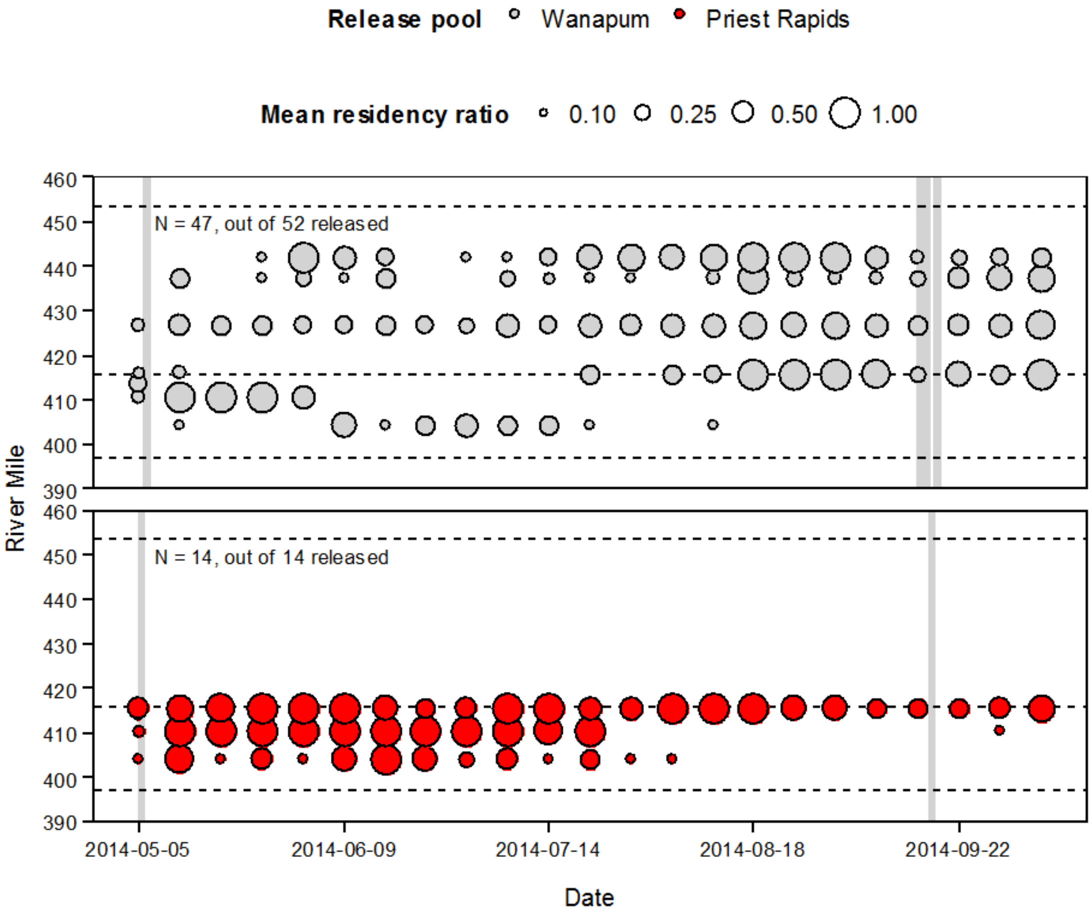

Figure 7 **Weekly residency ratios of acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014. Dot sizes represent the residency ratio value estimated for every week. Dot colors correspond to release locations at RM421.5 (grey; Wanapum) and RM15.6 (red; Priest Rapids). The number of detected tags out of total number of tags deployed at each reservoir is provided on each panel. The vertical grey bars represent release dates for the 2013BY juveniles; the horizontal dashed lines represent the location of Rock Island Dam (top), Wanapum Dam (middle), and Priest Rapids Dam (bottom).**

In Priest Rapids Reservoir, fish were released in the Wanapum tailrace (RM415.6); these sturgeon may either remain in the tailrace area or move downstream into the reservoir. The highest weekly counts of juveniles were recorded in the Wanapum tailrace near the release site immediately after the May and September releases. All 14 tags released in the reservoir were detected during the study period; all were recorded for the first time just below the release site (Figure 8). Fish dispersing downstream were recorded throughout May to early August, when tags were detected at RM410.5 and RM404.0, and late September, when a tag was detected at

RM 410.5 (Figure 6). Acoustic-tagged fish were not detected further downstream in the reservoir or downstream of Priest Rapids Dam.

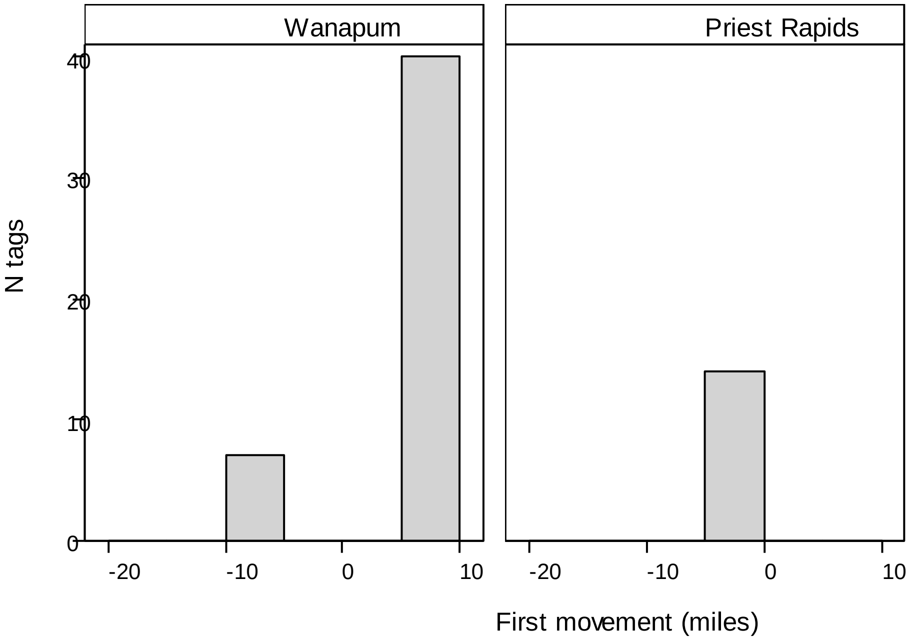

Figure 8 **Histogram of first movement by release pool, calculated as the difference between river mile at release and first detection for acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014.**

Net movement of 2013BY fish ranged from -12.1 to 25.9 miles, depending on reservoir (Figure 9). In Wanapum, net movement ranged from -12.1 to 25.9 miles; the 25th quantile was 0 miles, and the median net movement was 10.6 miles. The 75th quantile was 15.5 miles, as was the 90th quantile. In Priest Rapids, three fish moved -11.5 miles, whereas the median, 75th and 90th quantiles, and maximum net movements were 0 miles.

3.10 Movements by Juveniles from Other Brood Years in 2014

In addition to the 2013BY, locations of acoustic tagged fish from all previous brood year releases were recorded during the 2014 study period (Figure 10; Figure 11). In 2014, of the 70 2010BY fish released in Wanapum Reservoir, only two were detected; one at RM452.4 in Wanapum Reservoir and the other in Priest Rapids Reservoir at RM404.0. Tag detection data were insufficient to estimate the entrainment date of these fish. Of the 21 2010BY fish released in Priest Rapids Reservoir, none were detected in 2014. Residency ratios of both tags were low to intermediate (Figure 11).

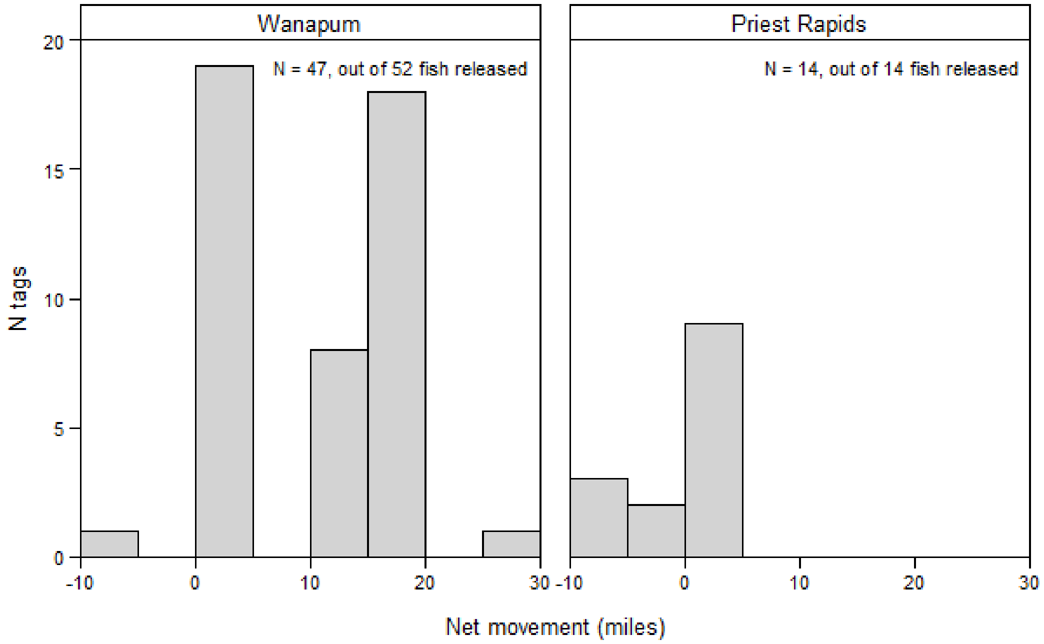

Figure 9 **Histograms of net movement (sum of all RM changes) of 2013BY fish, calculated separately for the two reservoirs for acoustic tagged 2013BY juvenile White Sturgeon detected in the PRPA in 2014. Negative values represent downstream movements.**

Of the 24 juvenile White Sturgeon released into the Wanapum Reservoir in 2013, only 4 (16.7%) were detected in 2014. Of these, 1 fish per week was detected at the RM442.0 overwintering site between January and April, with less detection at RM437.1; and 1-2 fish per week were detected at RM 426.5 throughout the year (Figure 10). One fish (ID 44517) was detected upstream at RM452.4 repeatedly between January 2 and March 6. None of the Wanapum-released 2013BY fish were entrained in 2014. Of the 6 fish released into Priest Rapids Reservoir in 2013, only one (16.7%) was recorded in 2014, at RM413.5 on March 15-16 and at RM410.5 between July 21 and July 24. Residency ratios were high at RM452.4 between late January and late February (due to the constant presence of ID44517), at the RM442.0 overwintering site during March-May, at RM437.1 in January, and at RM426.5 throughout July-October (Figure 11).

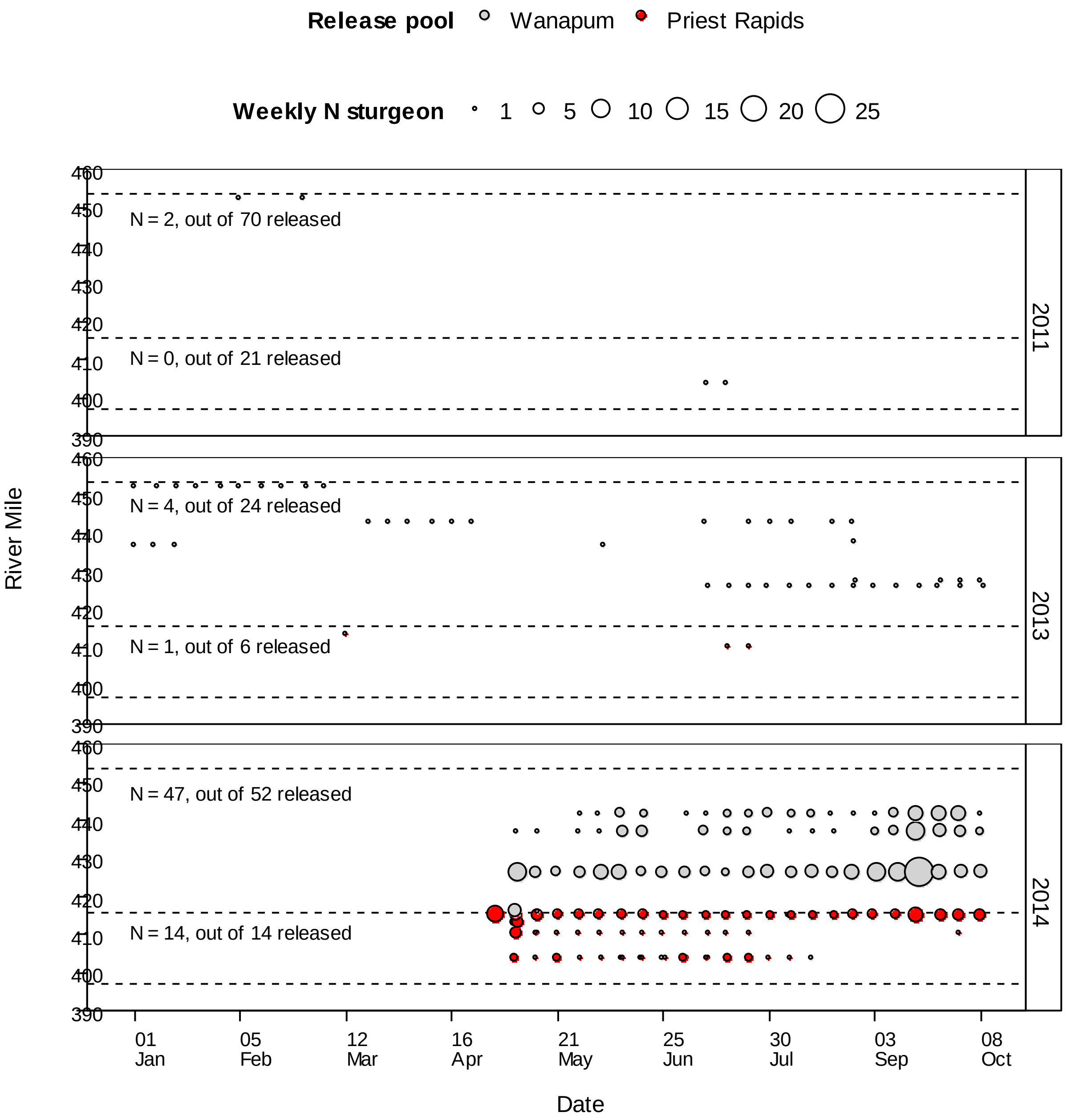

Figure 10 **Weekly counts of acoustic tagged 2010BY (top panel), 2012BY (middle panel) and 2013BY (bottom panel) juvenile White Sturgeon detected in the PRPA in 2014. Dot sizes represent the number of unique tags detected every week. Dot colors correspond to release reservoirs (grey and red for Wanapum and Priest Rapids, respectively. The number of tags detected in 2014 out of total number of tags deployed in each release year and each reservoir is provided on each panel. Dots were slightly jittered horizontally to better show entrained individuals. The horizontal dashed lines represent the location of Rock Island Dam (top), Wanapum Dam (middle), and Priest Rapids Dam (bottom).**

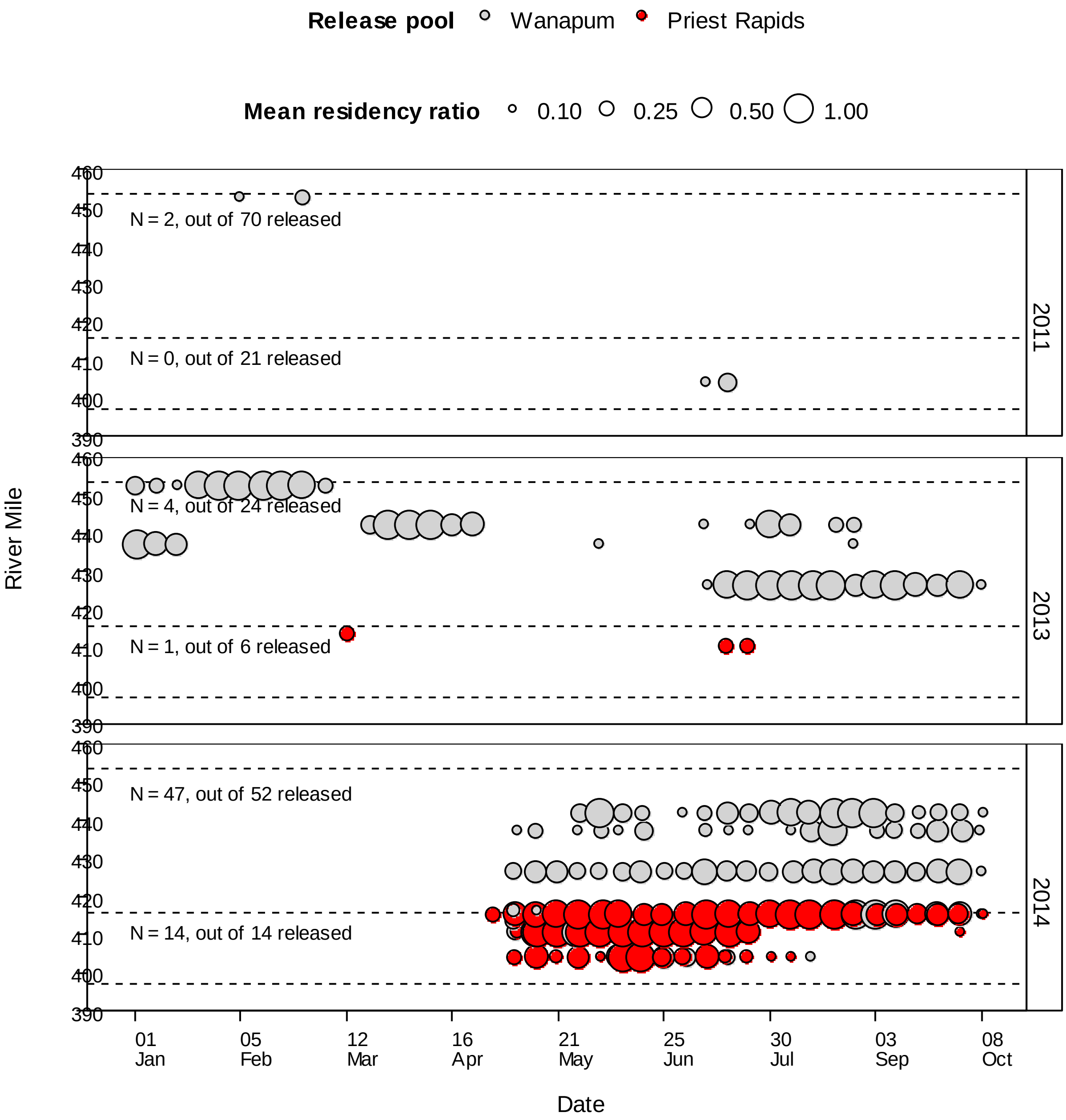

Figure 11 Weekly residency ratios of acoustic tagged 2010BY (top panel), 2012BY (middle panel) and 2013BY (bottom panel) juvenile White Sturgeon detected in the PRPA in 2014. Dot sizes represent the residency ratio value estimated for every week. The number of tags detected in 2014 out of total number of tags deployed in each release year and each reservoir is provided on each panel. The horizontal dashed lines represent the location of Rock Island Dam (top), Wanapum Dam (middle), and Priest Rapids Dam (bottom).

3.11 Juvenile Population Assessment

As was expected from an unstratified unequal probability design, the spsurvey GRTS sample draw resulted in an allocation of sites among reservoir sections that differed slightly from specifications (Table 7). Assessments made in the office prior to the survey and while in the field resulted in the rejection of several sites, which required oversamples be used as replacements, that in turn resulted in further deviations from the desired sample allocations (Table 7). However, deviations were relatively minor and similar levels of sampling intensity were applied to the corresponding sections of each reservoir (Table 7). Sampling intensity increased progressively moving upstream through the sampling sections in each reservoir such that mean effort per unit area in the upper sections of each reservoir was approximately two to three times that in the lower reservoir sections (Table 7).

Physical conditions (discharge and temperature) recorded in the study area during the survey are presented in Figure 12. For Priest Rapids Reservoir GRTS samples, mean water temperature (average of surface water temperatures recorded at set deployment and at set retrieval) was 19.5 ^{o}C (range = 18.7 to 21.3; n = 79), mean set duration was 22.7 h (range = 19.1 to 42.7; n = 80) and mean water depth sampled was 11.9 m (range = 4.5 to 30.4; n = 80) (Table 7). Severe storms on August 13 forced field crews off the water early and prevented them from retrieving all the gear that had been set the previous day. As a result, three sets were left to fish for two consecutive nights. No sturgeon were captured on these sets. For Wanapum Reservoir GRTS samples, mean water temperature was 19.1 ^{o}C (range = 18.3 to 20.6; n = 150), mean set duration was 22.7 h (range = 14.5 to 30.6; n = 150), and mean water depth sampled was 13.1 m (range = 3.0 to 30.4; n = 150)(Table 7).

Catch

A total of 367 White Sturgeon were captured and processed during GRTS and supplemental setlining in Wanapum (GRTS n = 233; Supplemental n = 16) and Priest Rapids (GRTS n = 89; Supplemental n = 29) reservoirs, and these captures represented 362 individual fish (five fish were captured twice: four in Wanapum and one in Priest Rapids) (Tables 8 and 9). An additional 16 sturgeon were captured in Wanapum (n = 12) and Priest Rapids (n = 4) reservoirs but broke off and escaped before they could be brought on board for processing. Bycatch during the survey included 381 Northern Pikeminnow (*Ptychocheilus oregonensis*), seven Largescale Sucker (*Catostomus macrocheilus*), one Carp (*Cyprinus carpio*), and one Channel Catfish (*Ictalurus punctatus*).

Table 7 **Details of GRTS sample site distribution among Wanapum and Priest Rapids reservoir sections, areal extent of reservoir sections, estimates of sampling intensity, and setline sample depths and durations recorded during the 2014 White Sturgeon juvenile indexing effort in the PRPA.**

	Reservoir and section							
	Wanapum				Priest Rapids			
	Lower	Middle	Upper	All	Lower	Middle	Upper	All
Number of sample sites								
Specified draw	50	50	50	150	40	20	20	80
spsurvey draw	51	51	48	150	40	21	19	80
Actual sample	51	55	44	150	39	24	17	80
Sampling area (Ha)	2,185	941	551	3,677	1,369	346	213	1,928
Samples/100Ha	2.3	5.8	8.0	4.1	2.9	6.9	8.0	4.2
Sample depths (m)								
mean	12.9	13.9	12.4	13.1	13.5	11.2	9.0	11.9
min	3.0	4.1	4.9	3.0	4.5	5.8	5.2	4.5
max	29.1	30.4	29.3	30.4	25.5	16.2	16.3	30.4
Sample duration (h)								
mean	22.2	22.8	23.1	22.7	22.0	23.8	22.8	22.7
min	14.5	18.5	16.3	14.5	20.0	20.4	19.1	19.1
max	24.5	30.6	28.2	30.6	24.8	42.7	41.9	42.7

Table 8 **Capture details for five hatchery White Sturgeon encountered twice during the 2014 PRPA juvenile indexing effort. DAL= days at large between encounters; movement indicates the distance between capture sites with negative values indicating downstream movement; ΔFL and ΔW indicate the difference in fork length and weight measurements from first to second encounter.**

		First encounter				Second encounter			
PIT	BY	Date	River Mile	FL (cm)	W (kg)	DAL	Movement (RM)	ΔFL (cm)	ΔW (kg)
985120019382977	2002	8/26/2014	435.0	72.0	2.15	7	5.0	0.2	-0.02
985120019557207	2002	8/26/2014	428.4	62.3	1.72	9	5.5	0.2	-0.15
985120030497273	2002	8/19/2014	405.4	95.6	6.20	1	1.7	0.2	-0.10
985121022035479	2010	9/2/2014	438.1	60.2	1.52	2	5.1	-0.5	-0.04
985121021807862	2012	9/3/2014	440.7	43.9	0.52	1	-0.1	0.4	0.02

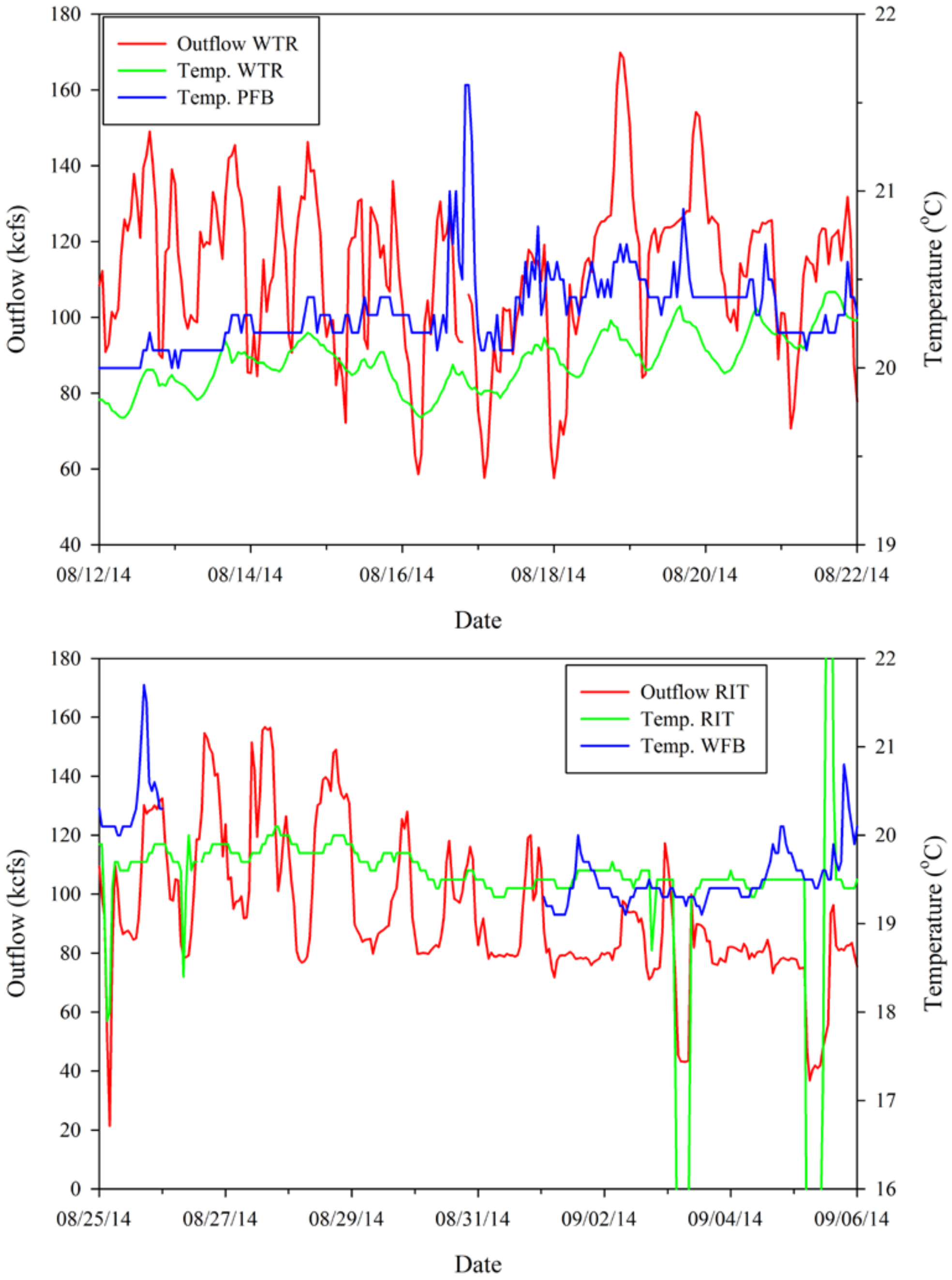

Figure 12 **Physical conditions in Priest Rapids (upper panel) and Wanapum (lower panel) reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Note different axes scales between plots. RIT = Rock Island tailrace; WFB =Wanapum forebay; WTR = Wanapum tailrace; PFB = Priest Rapids forebay. Spikes and troughs in temperature for RIT are likely erroneous and due to the influence of dam operations on water levels in Wanapum Reservoir. Data from www.cbr.washington.edu/dart.**

Table 9 **Hatchery and wild sturgeon captures during GRTS and supplemental (Supp.) setline sampling in Wanapum and Priest Rapids reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA.**

BY	Release reservoir	Release group	# released	Capture reservoir and sampling type						Total
				Wanapum			Priest Rapids			
				GRTS	Supp.	Total	GRTS	Supp.	Total	
2002	Rock Island	All	≈20,600	78	11	89	24	9	33	122
2010	Rocky Reach	All	6,376	18	--	18	2	--	2	20
	Wanapum	UCW brood	2,020	15	1	16	--	--	--	16
		MCW brood	2,996	21	2	23	1	--	1	24
		LCC brood	2,000	21	1	22	3	3	6	28
		All	7,016	57	4	61	4	3	7	68
	Priest Rapids	UCW brood	601	--	--	--	24	3	27	27
		MCW brood	900	--	--	--	13	6	19	19
		LCC brood	600	--	--	--	2	--	2	2
		All	2,101	--	--	--	39	9	48	48
2012	Wanapum	Columbia Siding	1,135	14	--	14	--	--	--	14
		Columbia Cliffs	1,129	34	--	34	--	--	--	14
		All	2,264	48		48	--	--	--	48
	Priest Rapids	All	1,717	--	--	--	17	7	24	24
2013	Wanapum	All	3,331	22	--	22	--	--	--	22
	Priest Rapids	All	997	--	--	--	--	1	1	1
Unknown[1]	Unknown	Unknown	NA	6	--	6	3	--	3	9
Wild	NA	NA	NA	4	1	5	--	--	--	5
All sturgeon	NA	NA	NA	233	16	249	89	29	118	367

The sturgeon catch consisted primarily of hatchery origin fish with only five individuals identified as wild based on the absence of scute marks or PIT-tags at time of capture. All five wild sturgeon were captured in Wanapum Reservoir. Individuals from all three hatchery sturgeon brood years released into the PRPA prior to the survey were represented in the catch: 2010BY, n = 116, one individual captured twice; 2012BY, n = 72, one individual captured twice; 2013BY, n = 23 (Table 9). The remainder of the hatchery origin sturgeon catch comprised BY2002 CRITFC releases (n = 122; three individuals captured twice; released into Rock Island Reservoir in 2003), Chelan PUD 2010BY releases (n = 20; released into Rocky Reach Reservoir in 2011), and nine individuals of uncertain provenance due to missing/inoperative PIT tags (n = 7; these fish were re-tagged) or PIT numbers that were not found in the GPUD or PTAGIS databases (n = 2; Table 9). These fish were identified as (Grant or Chelan) PUD hatchery program origin based on the presence of the characteristic batch scute mark applied as a secondary mark on juveniles prior to release.

Distribution and catch rates

Based on GRTS setline sampling, juvenile sturgeon were distributed widely throughout both reservoirs (Figure 13). As expected, CPUE was generally low and variable and exhibited statistical properties characteristic of samples taken from spatially aggregated populations (Figure 14). Estimates of sampling section µCPUE and Ep indicated that sturgeon densities progressively increased moving upstream through each reservoir (Figure 15). Overall, sturgeon densities were greater in Wanapum Reservoir (µCPUE [95%CI] =1.325 [1.085-1.564]; µEp=0.62) than in Priest Rapids Reservoir (µCPUE [95%CI]=0.885 [0.619-1.152]; µEp =0.46) (Figure 15, Tables 10 and 11). Confidence intervals for µCPUE for the Priest Rapids middle and upper sampling sections were very wide (Figure 15; Table 11), likely due to the influence of a small number of samples with high CPUE values (Figure 14). Due to the influence of these samples, µCPUE estimates for Priest Rapids middle and upper sections likely represent overestimates of sturgeon density in these areas. As such, Ep may provide a more representative measure of sturgeon density in these areas of the reservoir.

The BY2002 CRITFC releases were captured throughout both reservoirs (Figure 16). In Wanapum Reservoir, µCPUE and Ep for BY2002 were similar across sampling sections suggesting a relatively uniform distribution of this group in this reservoir (Table 10). In Priest Rapids, BY2002 µCPUE and Ep were similar between the lower and middle sections and were elevated in the upper section (Table 11). Overall, BY2002 densities were greater in Wanapum Reservoir (µCPUE [95%CI]=0.529 [0.388-0.670]; µEp=0.32) than in Priest Rapids Reservoir (µCPUE [95%CI]=0.256 [0.146-0.366]; µEp =0.21) (Tables 10 and 11).

Similar to BY2002, 2010BY PRPA releases were distributed throughout both reservoirs (Figure 16). Interestingly, four 2010BY Wanapum releases (one from the MCR group and three from the LCC group) were captured in Priest Rapids during GRTS sampling (a total of seven were captured in Priest Rapids overall when supplemental samples are included; one from the MCR group and six from the LCC group; Table 9). Wanapum 2010BY releases represented 9% of all 2010BY PRPA releases captured in Priest Rapids during GRTS sampling, and 13% of all 2010BY PRPA releases captured in Priest Rapids when GRTS and supplemental samples were combined (Table 9). Densities of 2010BY PRPA releases progressively increased moving upstream through sections in both reservoirs (Tables 10 and 11). Overall, densities of 2010BY PRPA releases were greater in Priest Rapids Reservoir (µCPUE [95%CI]=0.465 [0.304-0.625]; µEp =0.31) than in Wanapum Reservoir (µCPUE [95%CI]=0.292 [0.204-0.381]; µEp=0.25) (Tables 10 and 11).

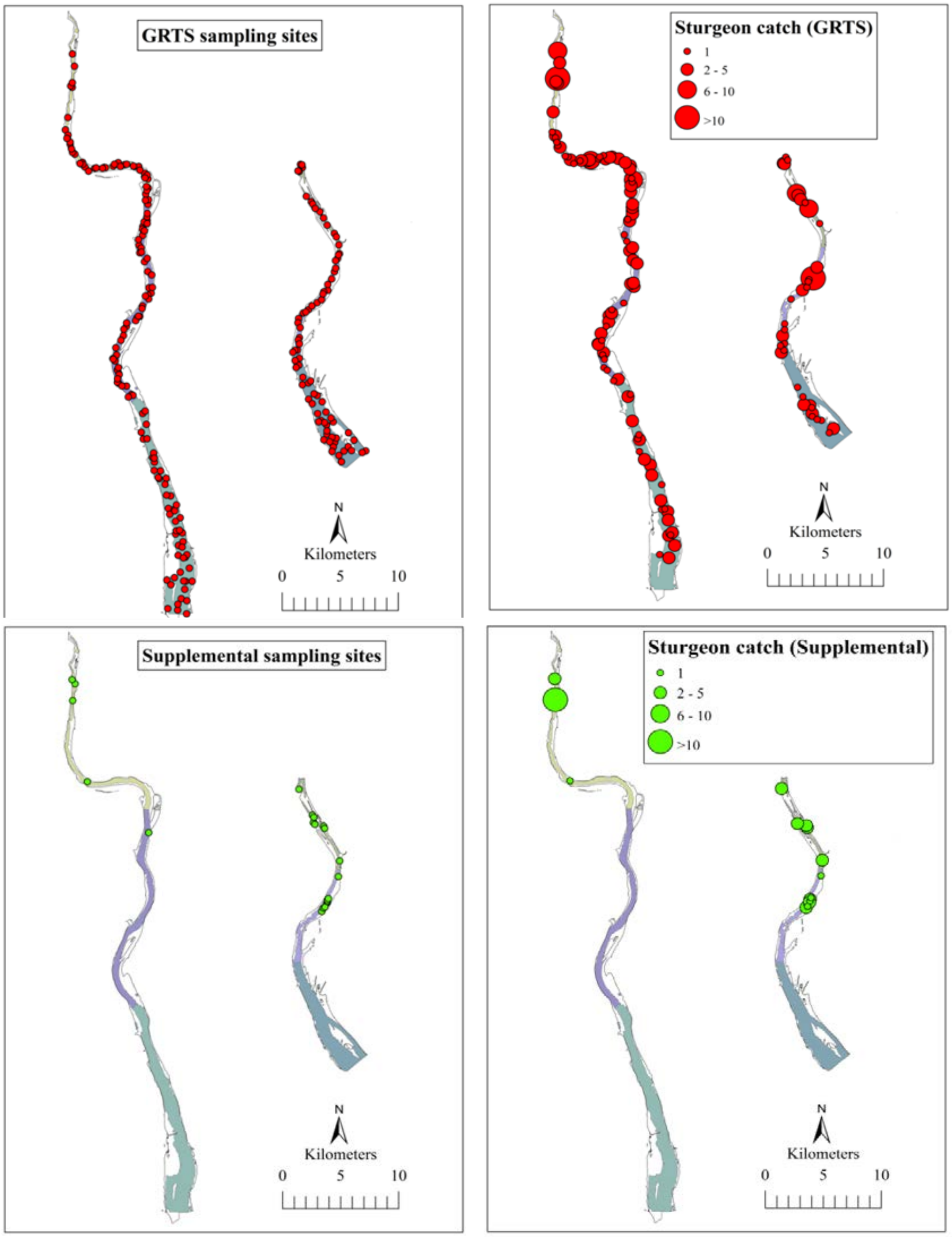

Figure 13 **Maps showing locations of GRTS and supplemental sample sites during the 2014 White Sturgeon juvenile indexing effort in the PRPA (left panels) and the location and magnitude of sturgeon catch for sites where catch >0 (right panels).**

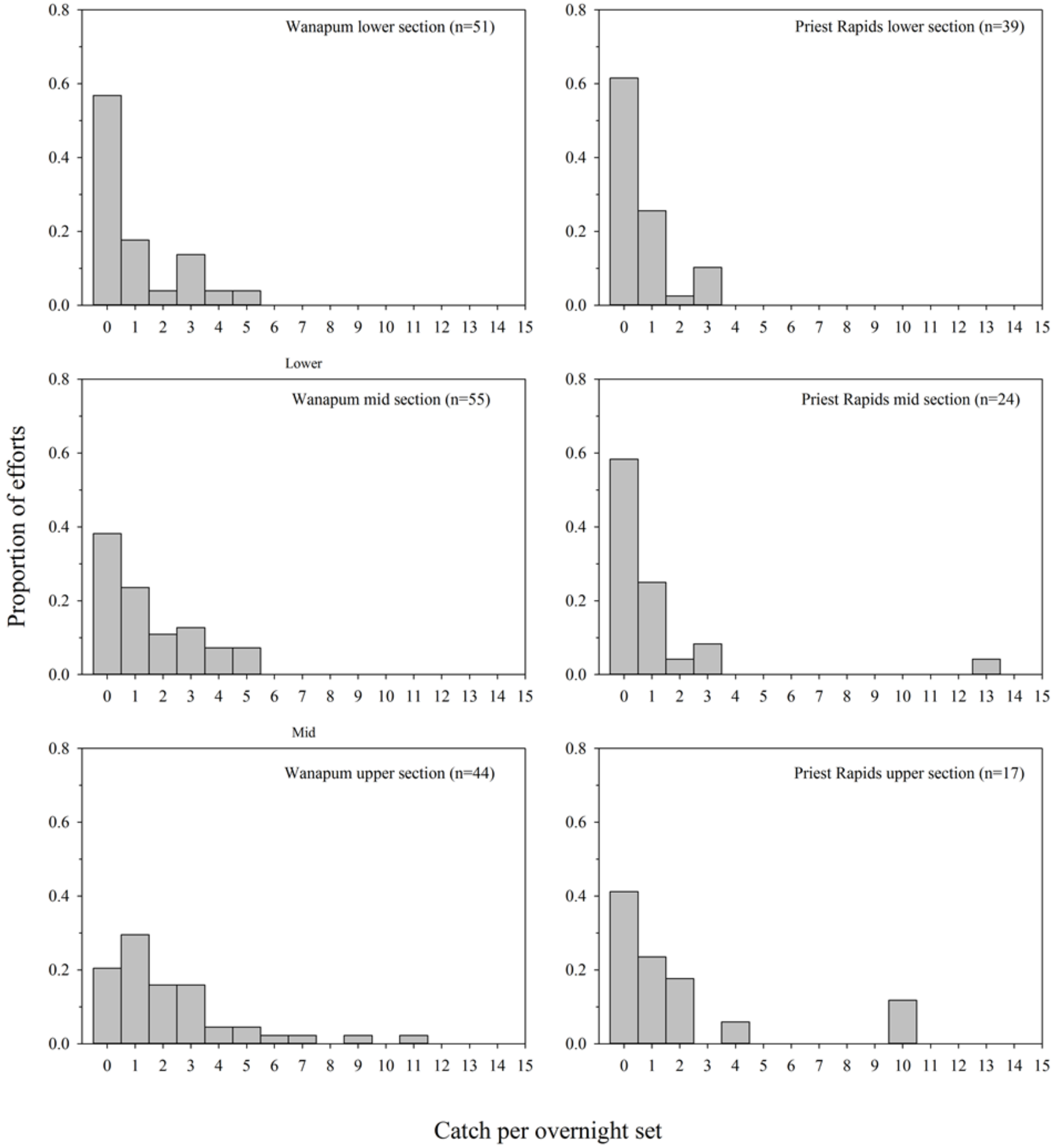

Figure 14 Frequency histograms of sturgeon catch-per-overnight-set during GRTS based setline sampling in Wanapum and Priest Rapids reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA.

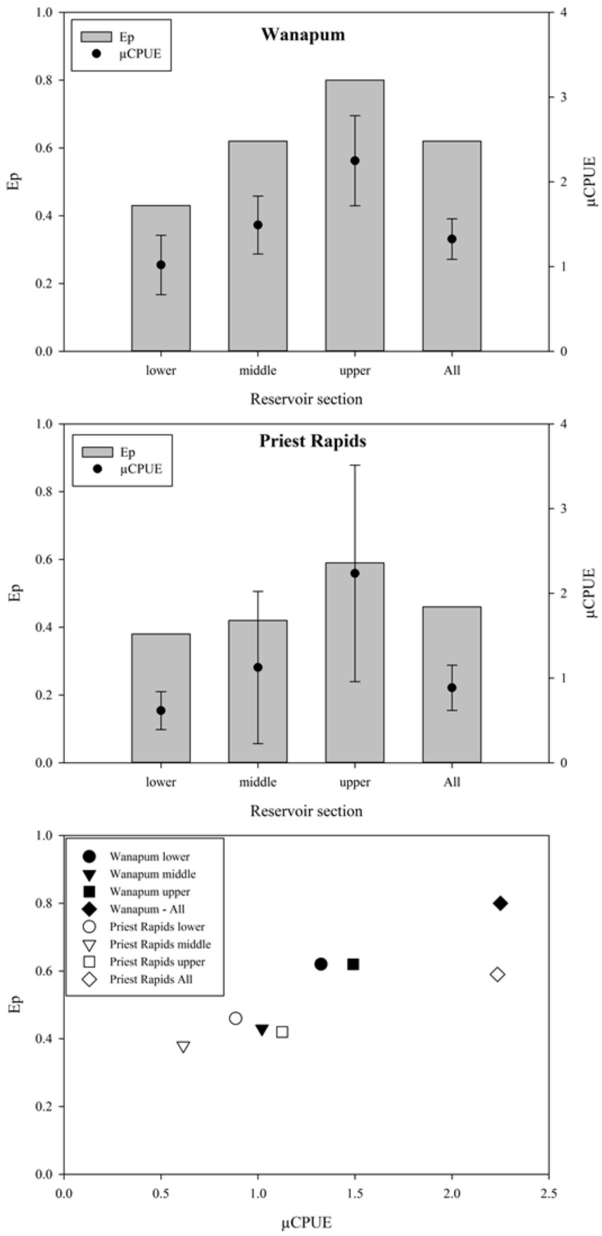

Figure 15 Relationships between sturgeon (all GRTS captures) µCPUE and Ep by sampling section in Wanapum and Priest Rapids reservoirs based on GRTS setline sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA. In the upper and middle panels error bars represent 95% confidence intervals. Note that due to differences in areal extent of sampling sections, µCPUE and Ep represent measures of sturgeon density within individual sections and may not necessarily reflect relative abundance between sections.

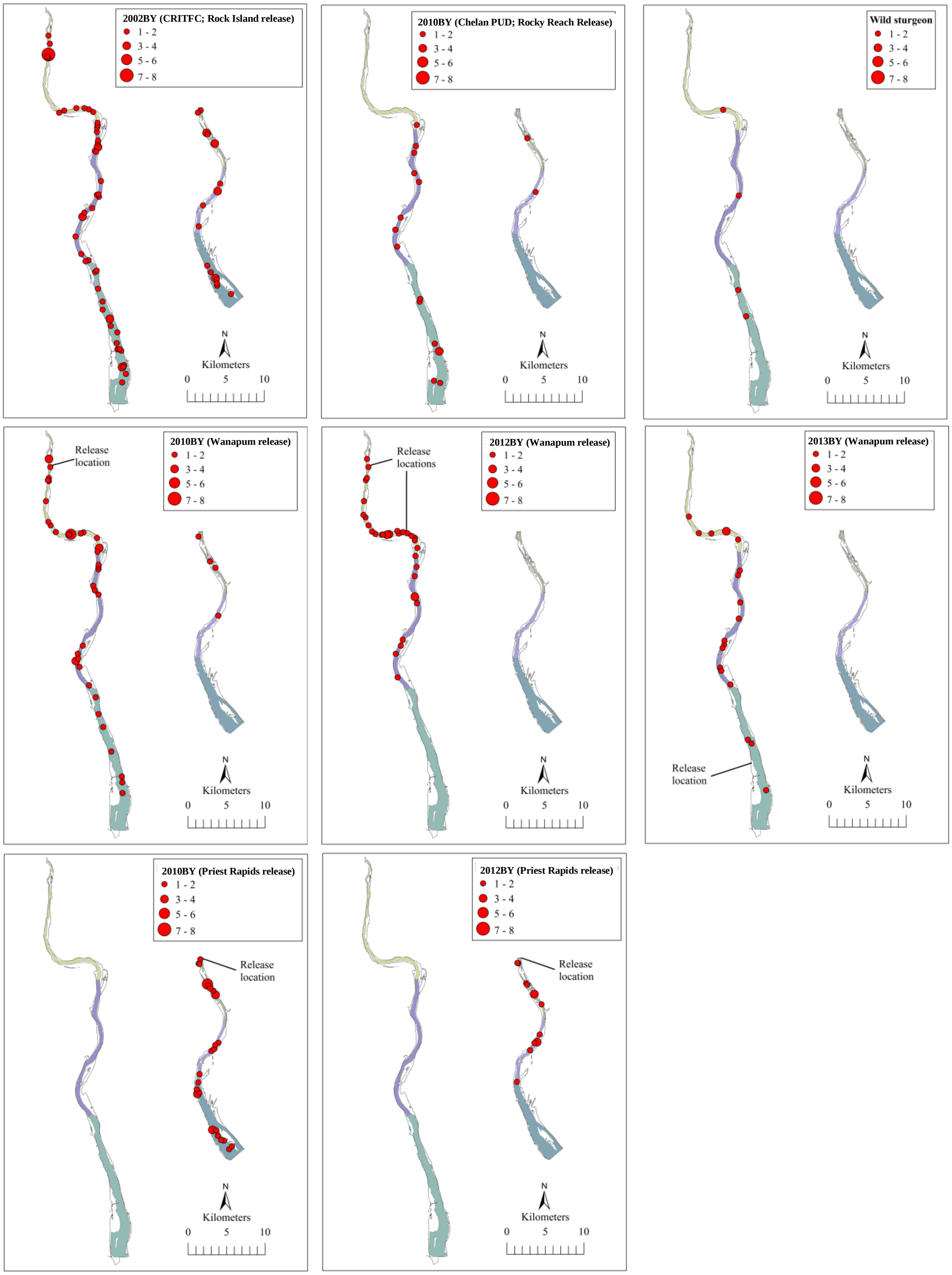

Figure 16 Maps of sturgeon catch distribution by release group based on GRTS sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA. No map is presented for the 2013BY Priest Rapids release group as none were encountered during the GRTS sampling effort.

There were differences in the distribution of the three different release groups that composed the 2010BY PRPA release (i.e., LCC, UCW, and MCW brood sources) (Figures 17 and 18). For the Wanapum and Priest Rapids LCC releases, catch distributions suggested both groups had undergone substantial downstream dispersal following release including documented entrainment of some fraction of the Wanapum release into Priest Rapids (Table 9; Figures 17 and 18; also see Section 3.9). Fish from the Priest Rapids LLC group were only found in the lower section of Priest Rapids where their density was very low, possibly indicating the occurrence of substantial entrainment through Priest Rapids Dam. The MCW releases were fairly widely distributed in each reservoir and there was some evidence for entrainment of the Wanapum MCW group into Priest Rapids (Figures 17 and 18; Table 9). However µCPUE and Ep indicated that MCW densities were greatest in the upper sampling sections of both reservoirs suggesting that post-release dispersal for these groups was generally less pronounced than the LCC groups (Figures 17 and 18).Unlike the LCC and MCW groups, the distributions of the UCW releases were not similar in both reservoirs: the Wanapum UCW group was almost entirely confined to the upper section of Wanapum Reservoir indicating little post-release dispersal, while the Priest Rapids UCW group was captured throughout Priest Rapids Reservoir at similar densities in each section, indicative of a generally stronger post-release dispersal (Figures 17 and 18).

In addition to PRPA 2010BY releases, a further 20 individuals from the 2010BY released into Rocky Reach Reservoir by Chelan PUD in 2011 were captured in Wanapum (n = 18) and Priest Rapids (n = 2) reservoirs during the GRTS setline survey. These fish were distributed widely throughout the middle and lower sections of Wanapum Reservoir and in the upper and middle sections of Priest Rapids Reservoir (Figure 16). In Wanapum, Chelan PUD 2010BY releases accounted for 24% of all 2010BY fish caught during GRTS sampling. In Priest Rapids, Chelan PUD 2010BY releases accounted for 4% of all 2010BY fish caught during GRTS sampling.

Captures of 2012BY PRPA releases were confined to the upper and middle sections of Wanapum and Priest Rapids reservoirs, and all fish were captured within their respective reservoir of release (Figure 16). Overall, 2012BY densities were slightly greater in Wanapum Reservoir (µCPUE [95%CI]=0.182 [0.128-0.236]; µEp=0.22) than in Priest Rapids Reservoir (µCPUE [95%CI]=0.118 [0.053-0.183]; µEp =0.19) (Tables 10 and 11). The longitudinal ranges of the two Wanapum experimental release groups (i.e. Columbia Siding and Columbia Cliffs release locations) were very similar (Figure 19). However, µCPUE and Ep indicated that the relative abundance of the Columbia Cliffs group was substantially greater in both the middle and upper sampling sections, which suggested the Columbia Cliffs group experienced higher post-release survival than the Columbia Siding group (Table 10).

Captures of 2013BY releases during GRTS sampling were limited to the Wanapum Rocky Coulee group, although one individual of the Priest Rapids 2013BY release group was captured during supplemental sampling in Priest Rapids Reservoir (Table 9). The 2013BY Rocky Coulee release group was distributed throughout Wanapum Reservoir indicating strong upstream dispersal had occurred during the 4 months following release (Figure 16). Values of µCPUE and Ep indicated that densities of this group were greatest in the middle section of Wanapum Reservoir (Table 10).

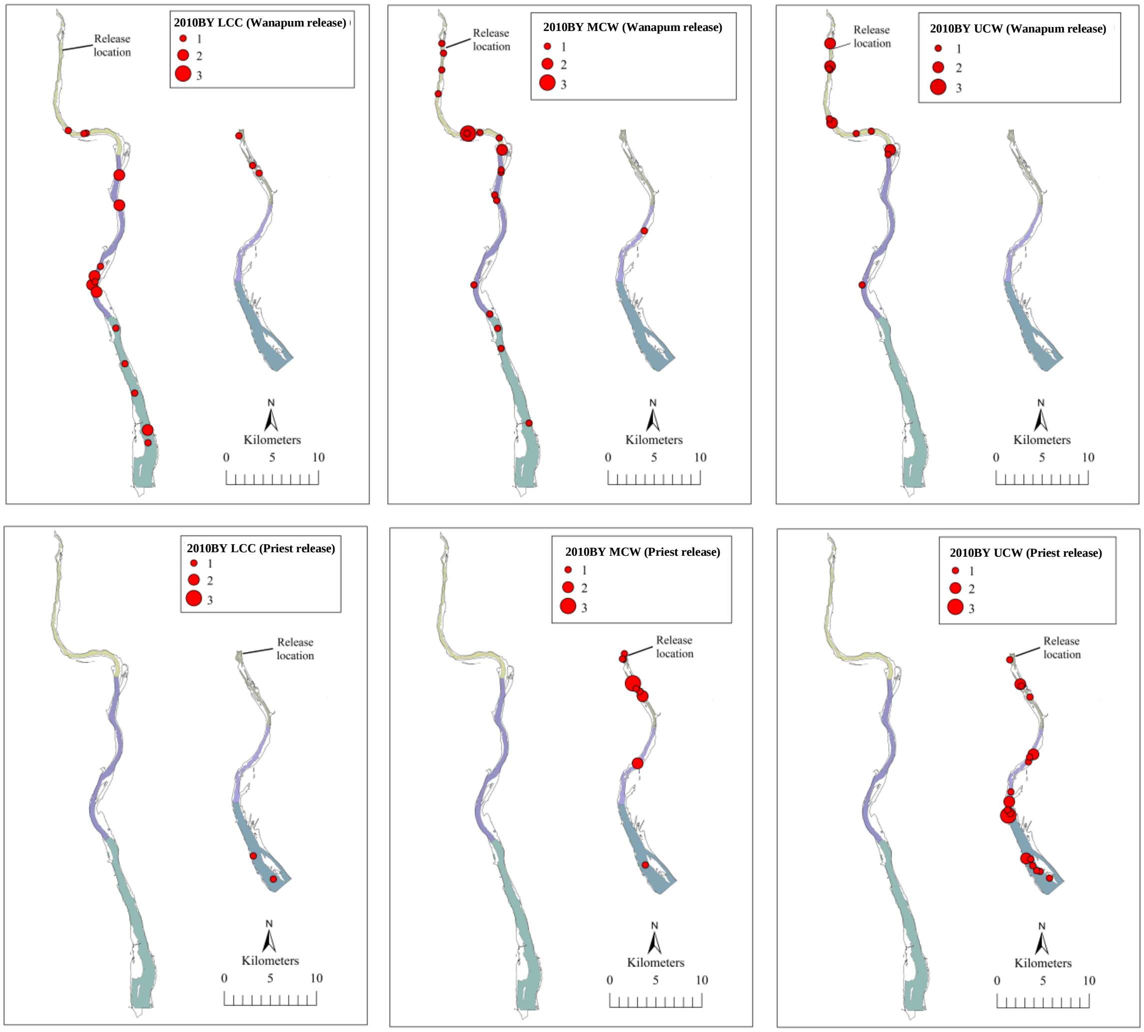

Figure 17 Maps of 2010BY catch distribution by release location and brood origin (LCC, progeny of lower Columbia River captive brood; MCW, progeny of middle Columbia River wild brood; UCW, progeny of upper Columbia River wild brood) based on GRTS sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA.

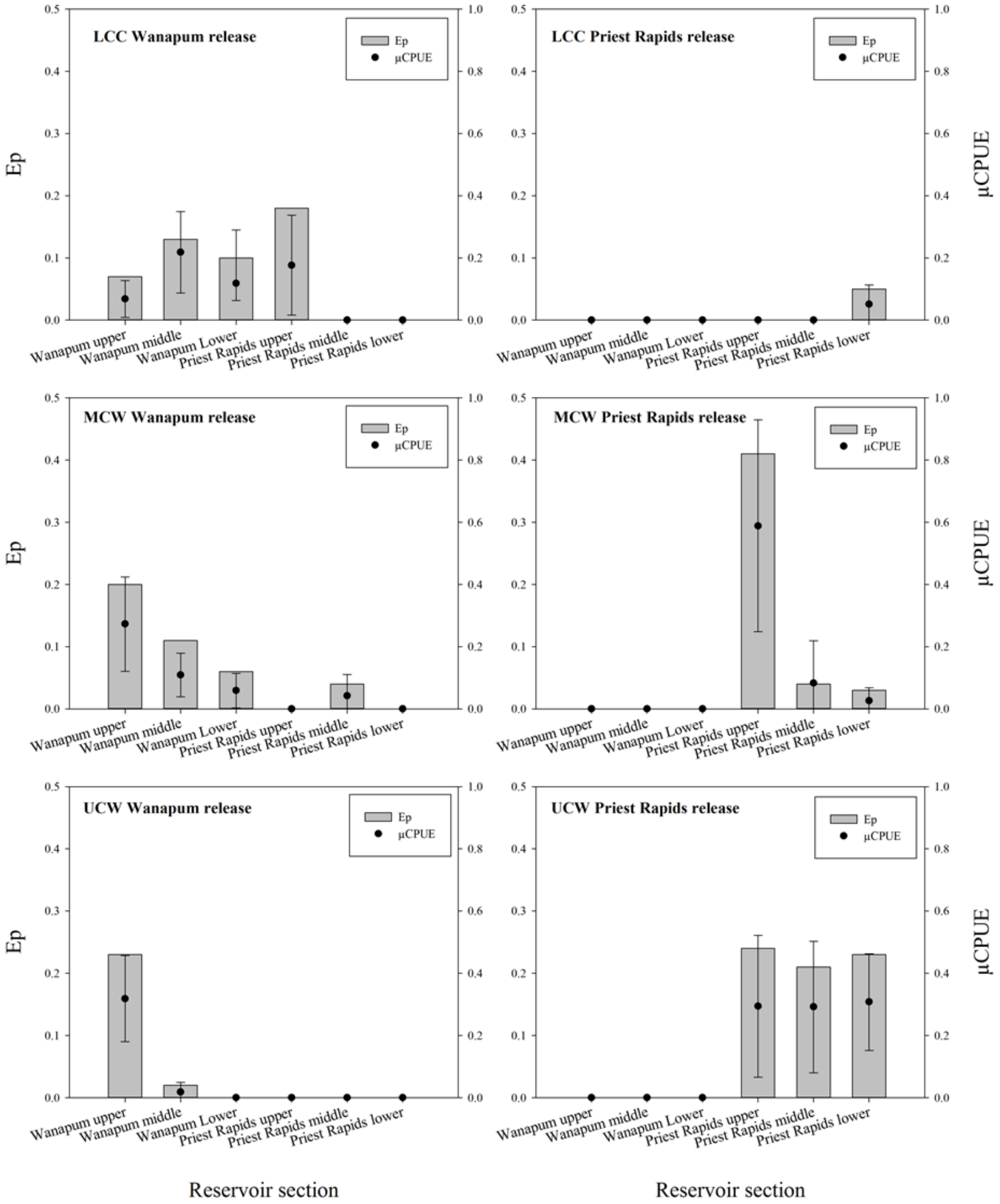

Figure 18 Comparisons of µCPUE and Ep by reservoir section for BY2010 LCC, MCW, and UCW release groups based on GRTS setline sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA. µCPUE error bars indicate 95% confidence intervals. Note that due to differences in areal extent of sampling sections, µCPUE and Ep represent measures of sturgeon density within individual sections and may not necessarily reflect relative abundance between sections.

Table 10 White Sturgeon mean catch per setline (µCPUE) and proportion of setlines where sturgeon catch was greater than zero (Ep) in Wanapum Reservoir during the 2014 White Sturgeon juvenile indexing effort in the PRPA. For clarity, double dashes (--) replace zero values.

			Wanapum Reservoir Section (number of overnight setline sets)											
			Lower (n=51)			Middle (n=55)			Upper (n=44)			All (n=150)		
Brood Year	Release Reservoir	Release Group	µ CPUE	95%CI	Ep	µ CPUE	95%CI	Ep	µ CPUE	95%CI	Ep	µ CPUE	95%CI	µEp
2002	Rock Island	All	0.549	0.337-0.761	0.33	0.473	0.286-0.659	0.31	0.545	0.262-0.829	0.32	0.529	0.388-0.670	0.32
2010	Rocky Reach	All	0.176	0.043-0.310	0.12	0.145	0.049-0.242	0.13	0.023	-0.015-0.061	0.02	0.145	0.062-0.229	0.09
	Wanapum	UCW brood	--	--		0.018	-0.013-0.049	0.02	0.318	0.180-0.457	0.23	0.052	0.030-0.075	0.08
		MCW brood	0.059	0.003-0.114	0.06	0.109	0.039-0.179	0.11	0.273	0.121-0.424	0.20	0.104	0.060-0.147	0.12
		LCC brood	0.118	0.026-0.209	0.10	0.218	0.087-0.349	0.13	0.068	0.009-0.127	0.07	0.136	0.072-0.200	0.10
		All	0.176	0.063-0.290	0.14	0.345	0.177-0.514	0.22	0.659	0.404-0.914	0.39	0.292	0.204-0.381	0.25
	Priest Rapids	UCW brood	--	--	--	--	--		--	--		--	--	
		MCW brood	--	--	--	--	--		--	--		--	--	
		LCC brood	--	--	--	--	--		--	--		--	--	
		All	--	--	--	--	--		--	--		--	--	
2012	Wanapum	Columbia Siding	--	--	--	0.073	0.012-0.133	0.07	0.227	0.117-0.338	0.23	0.053	0.030-0.075	0.10
		Columbia Cliffs	--	--	--	0.200	0.084-0.316	0.15	0.523	0.329-0.717	0.39	0.130	0.088-0.171	0.18
		All	--	--	--	0.273	0.120-0.425	0.16	0.750	0.499-1.001	0.50	0.182	0.128-0.236	0.22
	Priest Rapids	All	--	--	--	--	--		--	--		--	--	
2013	Wanapum	All	0.059	0.005-0.112	0.06	0.200	0.101-0.299	0.18	0.182	0.032-0.332	0.11	0.113	0.067-0.160	0.12
	Priest Rapids	All	--	--	--	--	--		--	--		--	--	
Unknown[1]	Unknown	Unknown	0.020	-0.014-0.053	0.02	0.036	-0.008-0.081	0.04	0.068	0.006-0.131	0.07	0.031	0.006-0.056	0.04
Wild	NA	NA	0.039	-0.007-0.086	0.04	0.018	-0.014-0.050	0.02	0.023	-0.014-0.060	0.02	0.031	0.002-0.061	0.03
All sturgeon	NA	NA	1.020	0.669-1.370	0.43	1.491	1.148-1.834	0.62	2.250	1.718-2.782	0.80	1.325	1.085-1.564	0.62

Table 11 Summary of White Sturgeon mean catch per setline (µCPUE) and proportion of setlines where sturgeon catch was greater than zero (Ep) in Priest rapids Reservoir during the 2014 White Sturgeon juvenile indexing effort in the PRPA. For clarity, double dashes (--) replace zero values.

			Priest Rapids Reservoir Section (number of overnight setline sets)											
			Lower (n=39)			Middle (n=24)			Upper (n=17)			All (n=80)		
Brood Year	Release Reservoir	Release Group	µ CPUE	95%CI	Ep	µ CPUE	95%CI	Ep	µ CPUE	95%CI	Ep	µ CPUE	95%CI	µEp
2002	Rock Island	All	0.205	0.087-0.323	0.18	0.292	-0.005-0.588	0.17	0.529	0.101-0.958	0.29	0.256	0.146-0.366	0.21
2010	Rocky Reach	All	--	--	--	0.042	-0.028-0.111	0.04	0.059	-0.043-0.161	0.06	0.014	-0.003-0.031	0.03
	Wanapum	UCW brood	--	--	--	--	--	--	--	--	--	--	--	--
		MCW brood	--	--	--	0.042	-0.028-0.111	0.04	--	--	--	0.007	-0.005-0.020	0.01
		LCC brood	--	--	--	--	--	--	0.176	0.016-0.337	0.18	0.019	0.002-0.037	0.06
		All	--	--	--	0.042	-0.028-0.111	0.04	0.176	0.016-0.337	0.18	0.027	0.005-0.049	0.07
	Priest Rapids	UCW brood	0.308	0.152-0.463	0.23	0.292	0.080-0.503	0.21	0.294	0.066-0.522	0.24	0.303	0.184-0.422	0.22
		MCW brood	0.026	-0.016-0.068	0.03	0.083	-0.053-0.219	0.04	0.588	0.248-0.929	0.41	0.098	0.044-0.152	0.16
		LCC brood	0.051	-0.010-0.113	0.05	--	--	--	--	--	--	0.036	-0.007-0.080	0.02
		All	0.385	0.190-0.579	0.26	0.375	0.146-0.604	0.25	0.882	0.356-1.409	0.47	0.438	0.283-0.593	0.33
	PRPA	All	0.385	0.190-0.579	0.26	0.417	0.146-0.687	0.25	1.059	0.463-1.655	0.42	0.465	0.304-0.625	0.31
2012	Wanapum	Columbia Siding	--	--	--	--	--	--	--	--	--	--	--	--
		Columbia Cliffs	--	--	--	--	--	--	--	--	--	--	--	--
		All	--	--	--	--	--	--	--	--	--	--	--	--
	Priest Rapids	All	--	--	--	0.333	0.052-0.614	0.21	0.529	0.165-0.864	0.35	0.118	0.053-0.183	0.19
2013	Wanapum	All	--	--	--	--	--	--	--	--	--	--	--	--
	Priest Rapids	All	--	--	--	--	--	--	--	--	--	--	--	--
Unknown[1]	Unknown	Unknown	0.026	-0.016-0.067	0.03	0.042	-0.028-0.111	0.04	0.059	-0.038-0.156	0.06	0.032	-0.003-0.067	0.04
Wild	NA	NA	--	--	--	--	--	--	--	--	--	--	--	--
All sturgeon	NA	NA	0.615	0.392-0.839	0.38	1.125	0.226-2.024	0.42	2.235	0.958-3.513	0.59	0.885	0.619-1.152	0.46

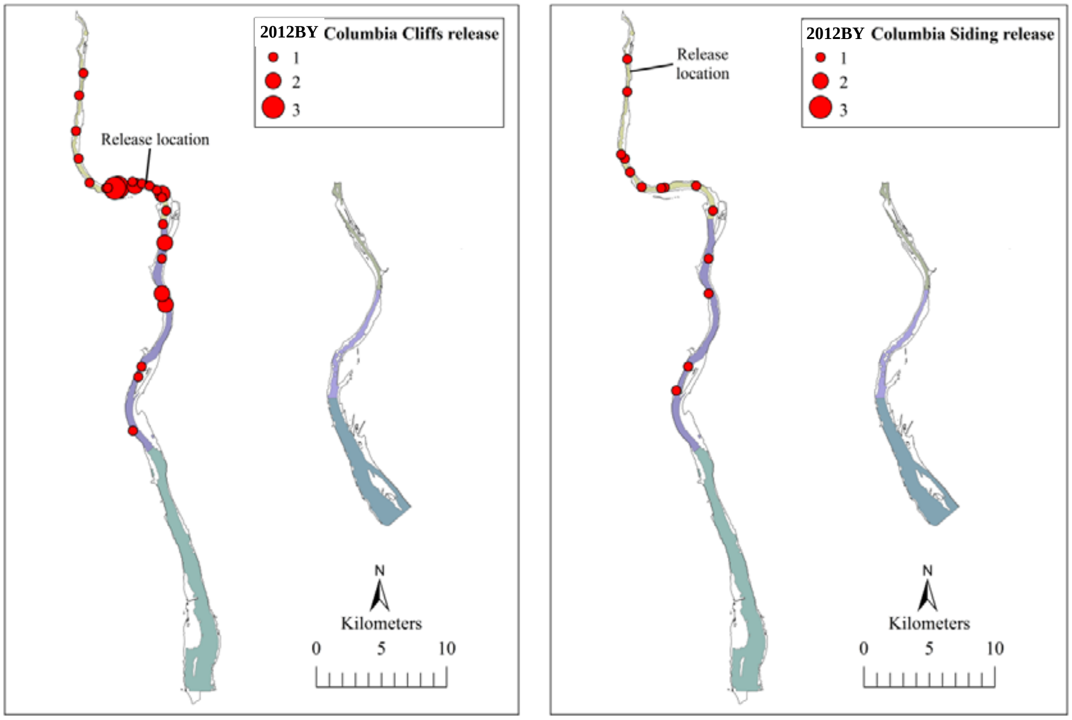

Figure 19 **Maps of 2012BY catch distribution by release location based on GRTS sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA.**

Depth

During GRTS setline sampling, sturgeon were captured at depths from 4.9 to 30.4 m (mean = 14.2; n = 126). In Priest Rapids Reservoir middle and upper sampling sections, water depths for sets that captured sturgeon were similar to those that did not capture sturgeon (Figure 20). By contrast, water depths for sets that captured sturgeon in the lower section of Priest Rapids were generally greater than for sets that did not capture sturgeon (Figure 20). For all sampling sections in Wanapum Reservoir, the water depths of sets that caught sturgeon were generally greater than sets that did not (Figure 20).

Size, Growth, and Condition

Sturgeon captured during GRTS and supplemental sampling ranged in size from 27.1 to 199.8 cm FL (mean = 69.6; n = 361), from 0.13 to 46.80 kg in weight (mean = 3.91; n = 357), and from 63 to 151% in relative weight (mean = 97; n = 356). Fork length, weight, and relative weight for the various sturgeon release groups (i.e., brood years) were generally similar in Wanapum and Priest Rapids reservoirs (Table 12; Figure 21). Relationships between $\log_{10}$ FL and $\log_{10}$ weight were highly significant and regression parameter estimates were similar between reservoirs (Figure 21).

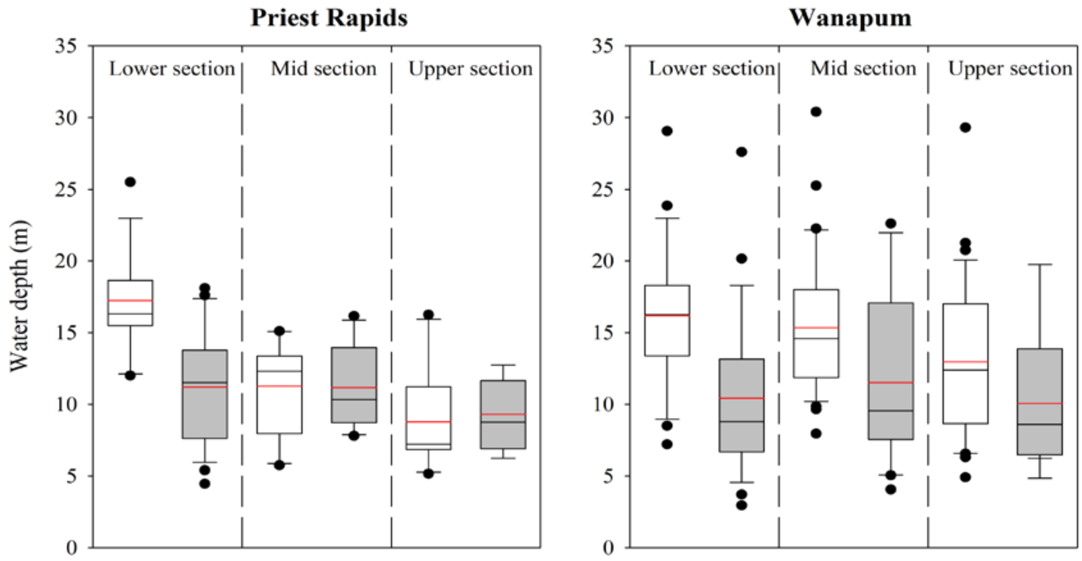

Figure 20 Box plots of set depths for samples that captured sturgeon (white boxes) or did not capture sturgeon (grey boxes) during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Box boundaries indicate the 25th and 75th percentiles. Solid lines within the box indicate the mean (red) and median (black). Whiskers indicate the 10th and 90th percentiles and black circles indicate outlying data points.

Table 12 Fork length (cm) summary for hatchery and wild origin sturgeon captured during GRTS and supplemental setline sampling in Wanapum and Priest Rapids Reservoirs during the White Sturgeon juvenile indexing effort in the PRPA, August 12 to September 6, 2014. FL's are averaged for individuals that were captured twice during the survey.

Program	BY	Wanapum					Priest Rapids					All				
		n	mean	SD	min	max	n	mean	SD	min	max	n	mean	SD	min	max
CRITFC	2002	86	102.9	23.7	58.3	145.8	32	97.9	16.4	64.7	133.6	118	101.6	22.0	58.3	145.8
Chelan PUD	2010	18	65.5	9.1	51.0	85.5	2	61.1	5.2	57.4	64.7	20	65.0	8.8	51.0	85.5
Grant PUD	2010	60	58.8	11.3	41.8	86.3	55	65.8	11.3	43.2	89.7	115	62.1	11.8	41.8	89.7
	2012	47	42.3	3.8	34.3	52.0	24	42.6	3.3	35.5	48.3	71	42.4	3.6	34.3	52.0
	2013	22	37.1	3.5	27.1	42.4	1	39.0	--	--	--	23	37.2	3.4	27.1	42.4
Unknown[1]	Unknown	6	50.7	12.8	38.5	68.4	3	44.8	5.4	40.5	50.9	9	48.7	10.9	38.5	68.4
All PUD	2010-2013	153	51.1	13.1	27.1	86.3	85	58.1	14.3	35.5	89.7	238	53.6	13.9	27.1	89.7
Wild	Unknown	5	82.4	66.0	46.9	199.8	--	--	--	--	--	5	82.4	66.0	46.9	199.8
All sturgeon	Various	244	70.0	31.4	27.1	199.8	117	68.9	23.2	35.5	133.6	361	69.6	29.0	27.1	199.8

1/ PIT tag not present/inoperable at capture (n=7) or PIT present but not found in Grant PUD database or PTAGIS (n=2). Fish were identified as (Grant or Chelan) PUD origin based on the presence of a 123LAD batch scute mark.

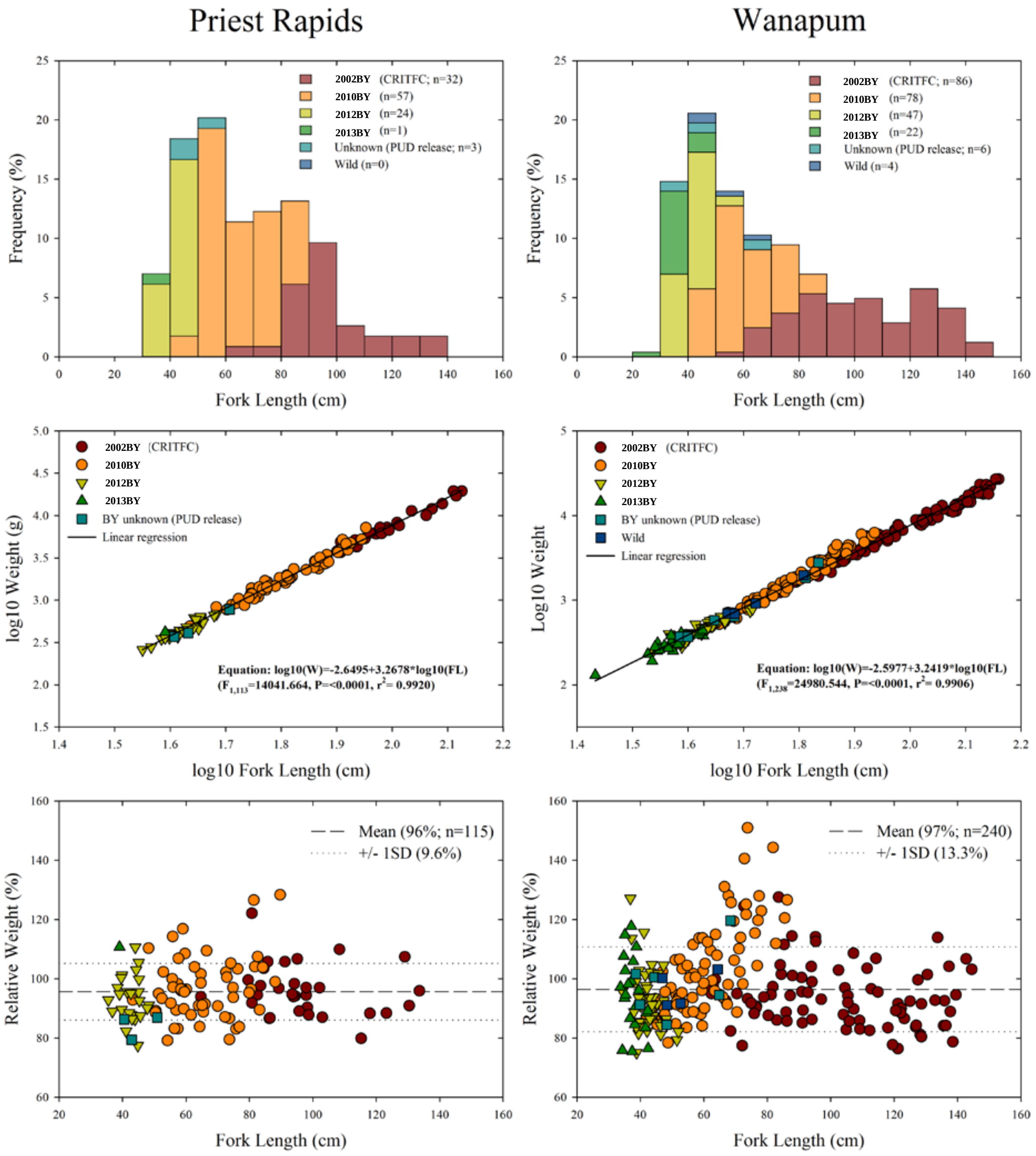

Figure 21 FL-frequency distributions, FL-weight relationships, and FL-relative weight relationships for sturgeon captured during GRTS and supplemental setline sampling in Priest Rapids and Wanapum reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Plots exclude one adult sturgeon (199.8 cm FL) caught in Wanapum Reservoir.

For hatchery sturgeon where origin could be determined, all had grown in FL since release although growth and growth rates were highly variable (Table 13; Figure 22). This variability was partly attributable to capture location: plots of post-tagging growth by capture location (RM) showed that fish caught in the lower sections of both reservoirs had generally grown more than fish of corresponding age that were captured in upper reservoir sections (Figure 23). This effect was most apparent for the 2010BY releases that were distributed throughout both reservoirs (Figure 23). For this group, fish captured in the lower reaches of each reservoir had generally grown at approximately twice the rate of fish captured in the upper reaches of each reservoir (Figure 23). Plots of relative weight against capture location showed fish condition also generally improved moving downstream through both reservoirs (Figure 23).

Table 13　Summary of growth (cm) and growth rate (cm· y^{-1}) in FL since tagging for hatchery sturgeon captured during GRTS and supplemental setline sampling in Priest Rapids reservoirs during the White Sturgeon juvenile indexing effort in the PRPA, August 12 to September 6, 2014. For fish captured twice during the survey, data from the first capture were used for analyses.

)Reservoir	Program	BY	n	Time at Large (Years)				Growth (cm)				Growth Rate (cm· y^{-1})			
				mean	SD	min	max	mean	SD	min	max	mean	SD	min	max
Wanapum	CRITFC	2002	50	11.34	0.01	11.33	11.35	83.0	24.0	39.7	130.3	7.3	2.1	3.5	11.5
	Chelan PUD	2010	18	3.46	0.03	3.35	3.49	37.1	10.1	21.4	61.1	10.7	2.9	6.2	17.6
	Grant PUD	2010	60	3.34	0.01	3.32	3.36	28.4	10.1	9.7	51.0	8.5	3.0	2.9	15.2
		2012	47	1.30	0.01	1.28	1.31	12.2	4.1	2.5	21.7	9.4	3.2	1.9	16.9
		2013	22	0.32	0.01	0.30	0.33	7.1	2.5	1.7	10.9	22.1	7.9	5.2	32.9
Priest Rapids	CRITFC	2002	21	11.31	0.01	11.29	11.32	77.2	16.9	41.3	113.2	6.8	1.5	3.7	10.0
	Chelan PUD	2010	2	3.44	<0.01	3.44	3.45	36.9	5.7	32.8	40.9	10.7	1.7	9.5	11.9
	Grant PUD	2010[1]	55	3.31	0.01	3.29	3.32	37.4	13.3	12.6	62.1	11.3	4.0	3.8	18.8
		2012	24	1.26	0.01	1.24	1.27	13.5	4.1	3.2	21.4	10.7	3.2	2.5	16.8
		2013	1	0.30	--	--	--	5.7	--	--	--	19.3	--	--	--
All	CRITFC	2002	71	11.33	0.02	11.29	11.35	81.3	22.2	39.7	130.3	7.2	2.0	3.5	11.5
	Chelan PUD	2010	20	3.45	0.03	3.35	3.49	37.0	9.7	21.4	61.1	10.7	2.8	6.2	17.6
	Grant PUD	2010	115	3.33	0.02	3.29	3.36	32.7	12.6	9.7	62.1	9.8	3.8	2.9	18.8
		2012	71	1.29	0.02	1.24	1.31	12.6	4.1	2.5	21.7	9.8	3.2	1.9	16.9
		2013	23	0.32	0.01	0.30	0.33	7.0	2.5	1.7	10.9	22.0	7.7	5.2	32.9

[1/] These values include data from BY2010 fish that were released in to Wanapum Reservoir and captured in Priest Rapids Reservoir.

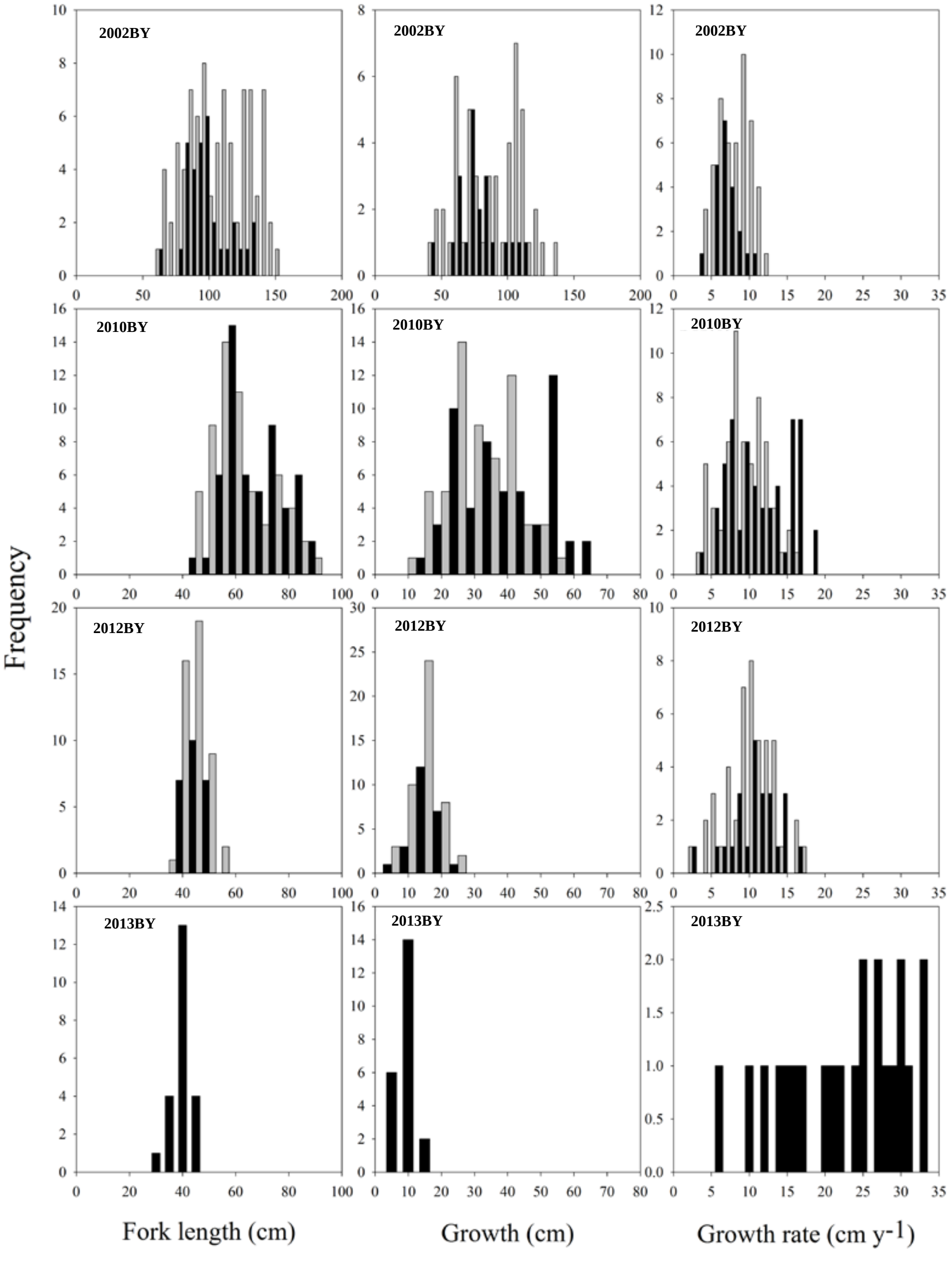

Figure 22 Comparisons of FL, growth in FL since tagging, and FL growth rate since tagging by brood year for hatchery sturgeon captured in Wanapum (black bars) and Priest Rapids (gray bars) reservoirs during GRTS and supplemental setline sampling during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Note scales are not consistent across plots.

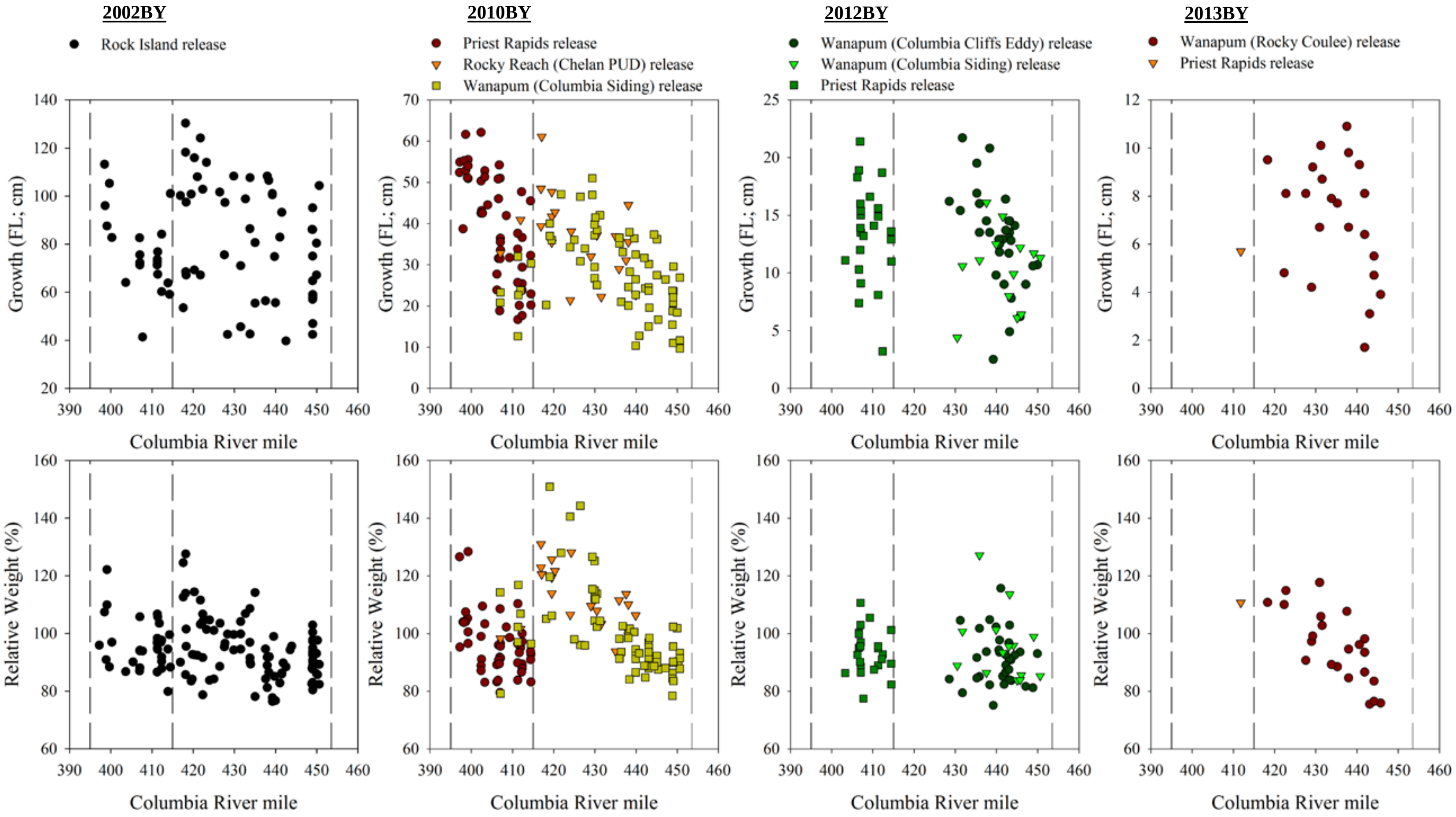

Figure 23 Growth in FL (cm) since tagging (upper panels), and relative weight at capture (%; lower panels) by capture location for hatchery White Sturgeon captured during GRTS and supplemental setline sampling in the PRPA in 2014. Vertical dashed lines in each panel indicate the location of (from left to right) Priest Rapids, Wanapum, and Rock Island Dams.

Gear performance

Similar numbers of sturgeon were captured by each hook size during the survey and the size range of fish captured by each hook size was broad (Figure 24). However, as would be expected, there was a tendency for smaller hooks to catch a greater proportion of small fish and for larger hooks to catch a greater proportion of large fish (Figure 25). Approximately equal proportions of sturgeon were captured by all hook sizes for fish in the size range of 60 to 100 cm FL (Figure 25).

In total, 3.7% (367 of 10,035) of all overnight hook sets resulted in a sturgeon capture (i.e., a sturgeon that was successfully landed and processed). However, an additional 4.6% (n=457) of hooks set were either lost due to gangion leader breakage (2.8%; n=285) or were found to be bent or broken (1.7%; n=172) at time of retrieval (Table 14). Interestingly, the rate of hook loss through gangion breakage increased with increasing hook size while the rate of occurrence of bent/broken hooks declined with increasing hook size; or put another way, the proportion of hooks lost to gangion breakage relative to hooks that were bent/broken was greatest for larger hooks and least for smaller hooks (Table 14).

Table 14 Summary of the percentage of hooks lost from setlines through gangion line breakage or that were bent/broken at time of line retrieval during the 2014 White Sturgeon juvenile indexing effort in the PRPA.

	Reservoir and Hook Fate														
	Wanapum					Priest Rapids					All				
	#Set	Lost		Bent/broken		#Set	Lost		Bent/broken		#Set	Lost		Bent/broken	
Hook size		n	%	n	%		n	%	n	%		n	%	n	%
2/0	1,545	19	1.2	60	3.9	960	27	2.8	23	2.4	2,505	46	1.8	83	3.3
4/0	1,551	18	1.2	53	3.4	960	21	2.2	11	1.1	2,511	39	1.6	64	2.5
6/0	1,565	49	3.1	9	0.6	960	16	1.7	7	0.7	2,525	65	2.6	16	0.6
8/0	1,374	98	7.1	3	0.2	960	36	3.8	6	0.6	2,334	134	5.7	9	0.4
12/0	160	1	0.6	0	0.0	--	--	--	--	--	160	1	0.6	0	0.0
All	6,195	185	3.0	125	2.0	3,840	100	2.6	47	1.2	10,035	285	2.8	172	1.7

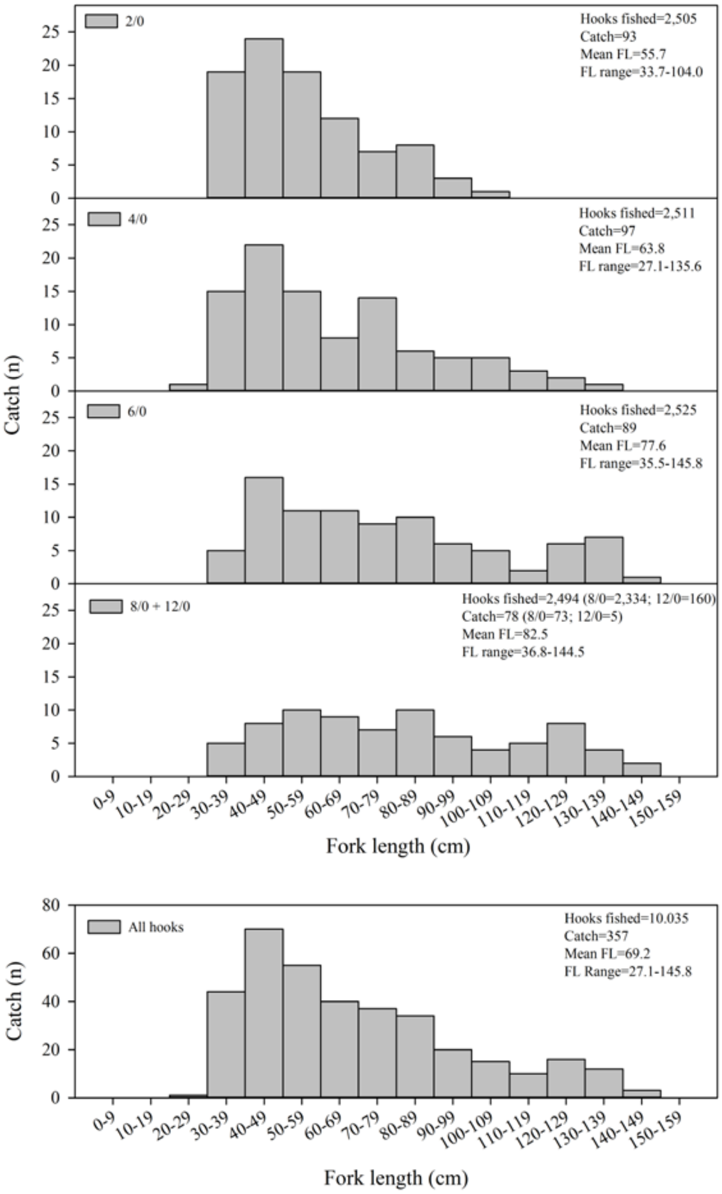

Figure 24 FL frequency distributions each hook size used during GRTS and supplemental setline sampling of Wanapum and Priest Rapids reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Data from Gamakatsu 8/0 and Mustad 12/0 hooks combined. One wild adult (FL 199.8 cm) captured on a 6/0 hook is not shown.

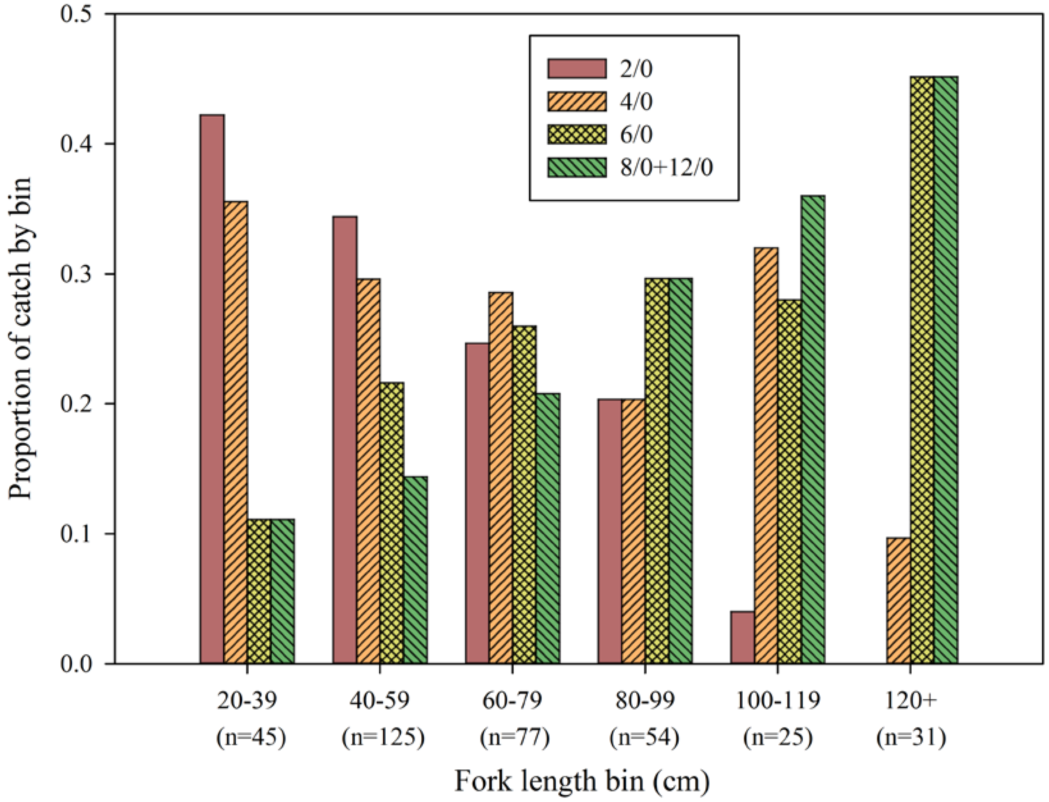

Figure 25 The proportion of sturgeon in 20 cm FL bins that were captured by four hook sizes used during GRTS and supplemental setline sampling in Wanapum and Priest Rapids reservoirs during the 2014 White Sturgeon juvenile indexing effort in the PRPA. Greater than expected values for 4/0 hooks and lower than expected values for 2/0 hooks (based on overall trends) in the 60-79 cm and 100-119 cm FL bins indicate that hook size identification by field staff may not have been wholly accurate.

4.0 Discussion

The following sections provide a brief discussion of the Year 7 study efforts that included tagging and release of 2013BY juvenile White Sturgeon, broodstock capture, and telemetry monitoring of 2013BY movements after release. A more detailed discussion of the 2014 juvenile White Sturgeon indexing study has been provided to in order to review factors that affect juvenile White Sturgeon growth, distribution, and abundance in the PRPA and that may have implications for the Grant PUD hatchery juvenile White Sturgeon supplementation program as well as future juvenile sturgeon indexing studies in the PRPA.

Juvenile White Sturgeon Release (2013BY)

With the successful release of 5093 juvenile White Sturgeon at Rocky Coulee launch (RM421.5) in 2014, conducting all future Wanapum Reservoir releases at Rocky Coulee should be considered due to the logistic advantages (i.e., reduced transport time and ease of access) and, based on preliminary data, lower avian predation pressure on juvenile sturgeon compared to upstream release locations. The negotiations surrounding the 2013BY release numbers resulted in two separate release events in 2014. This provides an opportunity to examine the effect of seasonal release timing (i.e., May versus September), and to a lesser extent, the effect of size at release, on aspects of juvenile White Sturgeon dispersal, survival, and downstream entrainment. However, assessing the effects of this release strategy will require additional data from future juvenile surveys before data on optimum release timing and size at release for juvenile White Sturgeon in the PRPA can be determined at a level of confidence that warrants changes to the existing stocking and release approach outlined in the WSMP. The Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) is presently in the process of conducting a review of 13 years of juvenile White Sturgeon release data in the upper Columbia River in order to determine the effects of family, size at release, and release timing. Results from this analysis will hopefully help guide juvenile release planning in the PRPA, although factors that affect juvenile White Sturgeon survival can vary between regions, and the applicability of the study findings would have to be considered in context with conditions and factor specific to PRPA.

Broodstock Capture 2014

The 2014 broodstock collection efforts below Rock Island Dam captured 33 White Sturgeon. Highest catch rates were recorded in the initial four days of the sample program; thereafter, catch rates declined sharply and remained low for the rest of the study program. This decline in catch rate coincided with a rapid decrease in total river discharge. Under these low flow conditions, large pre-spawning fish may have moved further upstream into the tailrace of Rock Island Dam, where angling could not be conducted for safety reasons.

Two ripe females and one flowing male were captured in the initial sample period and were considered as candidates for broodstock. Due to the success of broodstock collection effort below McNary Dam conducted just prior to the PRPA broodstock program (i.e., 64 fish captured), a sufficient number of females (n = 9) and males (n = 12) had been transported to MDH to meet the requirements of the 5 X 5 cross stipulated in the PRPA WSMP breeding plan (Appendix B). As such, the females captured in Wanapum Reservoir were released in the hope they would spawn naturally. The ripe male was transported to the MDH and milt from this fish was used in the breeding program. In total, the MDH achieved a 5 X 5 cross and a 3 X 5 cross using the combination of McNary fish and the one male from the PRPA (Appendix C).

Although capture of viable broodstock in Wanapum Reservoir is possible, angling and set lines have been the only the feasible capture options. Angling requires considerable effort, skill, and some luck to bring the fish to the boat. Capture with set lines can be effective, but the number of safe, effective, and productive set line deployment locations are limited, especially immediately downstream of Rock Island Dam, where broodstock tends to concentrate. Large fish that are angled typically are fought for more than one hour. Even if a fish is successfully hooked by an experienced angler, basalt bottom obstructions and deep fast water frequently results in an estimated lost rate of 50% collection. If a suitable broodstock candidate is successfully landed, transport time to the closest take out location (Columbia Siding Road) and then to MDH is approximately two hours and regular water quality checks are required during transport. Given the high capture success below McNary Dam and the limitations to broodstock capture in Wanapum Reservoir, future Grant PUD broodstock capture efforts may be better spent on providing support for the capture program below McNary Dam.

Movements of Acoustic Tagged Juveniles

The acoustic tagged 2013BY juveniles released in Wanapum Reservoir at Rocky Coulee launch (RM421.5) underwent substantial upstream movements in 2014, with some fish detected as far upstream as Columbia Cliffs Eddy (RM442.0).In Priest Rapid Reservoir, the 14 acoustic tagged 2013BY released in the reservoir were detected at RM415.5 near the release site and were subsequently detected at RM410.5 and RM404.0 as the fish dispersed downstream. Net movement and residency data indicated the 2013BY that initially dispersed downstream, subsequently returned upstream and were detected again at RM415.5. This post-release movement pattern of initial downstream movement followed by a return upstream movement was also evident in the 2010BY release in Priest Rapids Reservoir.

Consistent with other juvenile broodyear releases, the 2013BY were more frequently detected by receivers located at RM442.0 and RM426.5 in Wanapum Reservoir and at RM415.5 in Priest Rapid Reservoir (Golder 2012, 2013, 2014). Other high use areas may exist; however, these would require mobile seasonal telemetry tracking of the reservoir to locate.

As expected, acoustic tagged 2010BY were rarely detected (n = 2 fish) in 2014 as the three year battery life of these tags either have expired or are near expiration. Detection frequency of the 2012BY in the release year (2013) was lower than expected, given the number of tags deployed (n = 24), and detection levels declined again in 2014. This low detection rate was initially attributed to a low survival rate of the 2012BY. However, the 2014 juvenile indexing results (see Section 3.11), indicated that the 2012BY comprised approximately 20% of the total juvenile catch in Wanapum Reservoir, which suggested this initial assumption of low survival was incorrect.

In terms of future telemetry monitoring in the PRPA, restoration of the VR2W stations lost in 2014 is a priority. The station placement and deployment methods used should be re-evaluated to determine if a change in the mooring method would result in improve station longevity. To avoid loss of the station and data, replacement of all components every three years is recommended. New mooring methods for monitoring stations in the forebays of Priest Rapids Dam and Wanapum Dam may be required due to extreme wave action in these areas that accelerates wear and damage to station mooring hardware.

2013BY Juvenile Entrainment

Three of 32 (9.4%) acoustic-tagged 2013BY released in Wanapum Reservoir in May were subsequently detected in Priest Rapids Reservoir, which indicated that some entrainment of this release group occurred. However, both the telemetry and the juvenile indexing data indicated most of the 2013BY either remained in the vicinity of release or moved upstream after release and have since remained in the middle and upper portions of Wanapum Reservoir.

As of October 8 2014, the overall entrainment rate of acoustic tagged 2013BY released at Rocky Coulee in Wanapum Reservoir was 5.8%, however, this is likely an underestimate as the second release of acoustic-tagged 2013BY in September were only at large and monitored for approximately 20 days. High flow conditions during the May release (5109 m^3/s) compared to the September release (1981 m^3/s) may have affected both the rate and direction (i.e., upstream or downstream) of dispersal from the release site. Collection of additional telemetry data in 2015 should allow refinement of the 2013BY entrainment rate for the September release group.

Entrainment of 2103BY from Priest Rapids Reservoir into McNary Reservoir through Priest Rapids Dam was not detected in 2014. However, the absence of detections may reflect the low tag detection success by the single receiver below Priest Rapids Dam (RM392.0).

Compared to previous releases, entrainment rate of the 2013BY in 2014 was higher than entrainment rates recorded for the 2012BY (0%) in 2013, but lower than the 11.4% entrainment rate of the 2010BY released in 2011 (Table 15). To date, the overall entrainment percentage (all releases combined) out of Wanapum Reservoir and into Priest Rapids Reservoir was 8.2%.

Entrainment of acoustic tagged fish released at Wanapum Dam through Priest Rapids Dam was 0% in 2013 and 2014, lower than the 9.5% entrainment rate for fish released in 2011. However, tag detection success may have been higher in 2011 compared to subsequent years following the relocation of the station below Priest Rapid Dam in late 2011 (Table 15). The overall percentage of fish (all releases combined) entrained out of Priest Rapids Reservoir was 4.9%, excluding one fish released in 2011 that was entrained through both Wanapum and Priest Rapids dams.

Entrainment of acoustic tagged fish released at Wanapum Dam through Priest Rapids Dam was 0% in 2013 and 2014, lower than the 9.5% entrainment rate for fish released in 2011. The overall percentage of fish (all releases combined) entrained out of Priest Rapids Reservoir was 4.9% (excluding the one fish entrained through both Wanapum and Priest Rapids dams).

The annual variability in entrainment rates of juvenile White Sturgeon was likely related to a variety of potentially influencing factors. The highest entrainment rates occurred in 2011 in both reservoirs within the PRPA. This release involved three family groups from different geographic and genetic origins (see Section 1.0). Most of the fish entrained were members of the captive broodstock group that had a greater propensity to move downstream that the other two wild origin groups, suggestive of a family effect. However, entrainment rates maybe have also been affected by high discharge in 2011, as peak mean daily discharge approached 10,000 m^3/s.

None of the fish from the 2013 release group that were released into either the Wanapum or Priest Rapids reservoirs was subsequently entrained. These fish were released at Columbia Siding (RM450.6) and Columbia Cliffs (RM442.0) in Wanapum Reservoir and Wanapum Dam tailrace in Priest Rapids Reservoir. River and reservoir conditions during this release year were more typical, with a peak mean daily discharge of approximately 6000 m^3/s. In 2014, 0% of released fish were entrained through Priest Rapids dam but 5.8% were entrained through

Wanapum Dam. This pattern differed from the previous two years where trends in entrainment from both reservoirs followed a similar pattern. The main difference in 2014 was the extremely low Wanapum Reservoir levels that resulted in increased flow velocities throughout the reservoir, which may have affected entrainment rates from this reservoir. Assuming more typical reservoir levels and velocity conditions occur in future years, releases at the Rocky Coulee site may exhibit lower entrainment rates than those seen in 2014.

Table 15 Entrainment rate for acoustic tagged juvenile White Sturgeon released into the PRPA between 2011 and 2014, detailed by release pool, year, and dam of entrainment.

Release Details				**Entraining Dam (RM)**	**Number Entrained**	**Percent Entrainment (%)**
Pool	Year	N	Release RM			
Priest Rapids	2011	21	415.6	Priest Rapids (397.1)	2	9.5
Priest Rapids	2013	6	415.6	Priest Rapids (397.1)	0	0.0
Priest Rapids	2014	14	415.6	Priest Rapids (397.1)	0	0.0
Subtotal		**41**			**2**	**4.9**
Wanapum	2011	70	450.6	Wanapum (415.6)	9	12.9
Wanapum	2013	24	450.6/442.0	Wanapum (415.6)	0	0.0
Wanapum	2014	52	421.5	Wanapum (415.6)	3	5.8
Subtotal		**146**			**12**	**8.2**

Juvenile Indexing

The 2014 PRPA hatchery juvenile indexing effort survey yielded useful information on general patterns of sturgeon distribution, catch rates, growth, and the performance of the experimental setline gear. Individuals from all three PRPA hatchery sturgeon brood years released prior to the survey, including all related sub groups (i.e., release locations and brood sources) were represented in the catch. Growth and condition were generally good but variable, and this variability was partially related to capture location; sturgeon caught in the upstream areas of each reservoir had grown less and were in poorer condition than fish of the same age captured in downstream areas. While growth and condition were not poor in upstream, riverine habitats, the comparatively slower growth and lower condition of sturgeon in these areas could indicate density dependent effects; indeed, estimates of µCPUE and Ep indicated that juvenile sturgeon densities were greatest in the upstream sampling sections of each reservoir.

Sturgeon captured during the setline survey ranged in size from 27.1 to 145.8 cm FL (one adult of 199.8 cm FL was captured on a 6/0 hook but this represented an outlier in the data) demonstrating that the hook sizes used in the experimental setline gear successfully targeted the size range of sturgeon of interest in juvenile indexing efforts. The size range captured by each hook size was broad, however the smaller hooks clearly caught a greater proportion of small fish and larger hooks caught a greater proportion of large fish. In total, 3.7% (367 of 10,035) of overnight hook sets resulted in a documented sturgeon capture (i.e., a sturgeon that was successfully landed and processed); however an additional 4.6% (457 of 10,035) were either lost due to gangion leader breakage or were found to be bent or broken at time of retrieval. While bottom snagging may have been a contributing factor, it seems more likely that most cases of hook loss and bending/breakage were due to interactions with larger sturgeon.

The rate of hook loss increased with increasing hook size and the rate of hook bending/breakage decreased with increasing hook size. This is likely because small hooks with a relatively light wire gauge construction would tend to bend or break before the gangion line. Conversely, due to the greater strength of larger hooks, the gangion line would tend to break before bending or breaking the hook. If hook loss and hook bending/breakage were largely due to sturgeon interactions, then the rates observed during the 2014 survey represent the loss of a substantial amount of potentially useful catch data. As such, gear refinements are needed in order that retention rates are improved in future studies. Recommendations for gear modification include the following:

1). Continue using the same setline configuration, hook spacing, bait, and hook sizes but switch to heavier gauge hooks to limit bending and breaking and improve sturgeon retention rates. For example, Gamakatsu offers a range of Octopus Circle offset point hooks of the same size range used in the study but constructed of heavier gauge wire (4x Strong model).
2). Discontinue the use of Dacron for gangion leader. While Dacron is a cost effective material, it requires sheathing to protect it from failure due to bottom chafing as well as provide some stiffness to prevent it entangling with the groundline. Clearly, gangion line breakage is undesirable as it leaves the hook lodged in a sturgeon’s mouth. Therefore transitioning to a material (e.g., stainless steel cable leader) that has a greater breaking strength than the attached hook will ensure that hooks bend or break before the leader during encounters with large fish.
3). Carry a large dip net on board with which to lift sturgeon out of the water into the boat. Several sturgeon were lost at the boat during the 2014 survey when crews attempted to lift them out of the water by the gangion line. A large dip net would have prevented the loss of these fish and should be considered for future efforts.

Reducing the rate of sturgeon stocking in more dense, and possibly less productive upstream areas of the PRPA reservoirs may be warranted. This could potentially be achieved by conducting future releases at lower reservoir locations as was done in 2014 at the Rocky Coulee site. During their short period (approximately four months) at large, the 2013BY Rocky Coulee releases distributed themselves throughout Wanapum Reservoir and were captured as far upstream as RM446.0, several RM above Crescent Bar. If the behavior of this release group is generally representative, then conducting future introductions at this location may help reduce the rate of density increase in upstream areas of Wanapum Reservoir. Other advantages of the Rocky Coulee site are 1) the transport time between there and MDH is about 45 minutes less than release sites used in 2011 and 2103; and, 2) the deep water available at this site helps protect released fish from avian predation and promotes acclimation of fish from the hatchery to the wild environment.

Similar to Wanapum, catch data indicated that sturgeon densities in Priest Rapids were highest in upstream areas. Therefore experimental releases further down in the reservoir may also be warranted. Access points in the lower reaches of Priest Rapids are few; however, fish could potentially be released off the Desert Aire boat launch. While not particularly deep itself, the slough area off the Desert Aire launch is in relatively close proximity to deep water areas off Goose Island where numbers of juvenile sturgeon were captured during the 2014 setline survey.

Regardless of release location within the reservoirs, future releases should occur in deep water areas to limit the effects of avian predation. Catch data obtained from 2012BY Wanapum releases provided evidence that survival of the deep water Columbia Cliffs eddy release group was greater than the shallow water Columbia Siding release group. Differential survival between these releases was likely the result of different rates of exposure to avian predation. As reported in Golder (2013), predation on the Wanapum 2012BY release groups was documented from PIT-tag recovery data collected at a known bird colony located on an island in the forebay of Rock Island Dam. In total, 45 PIT-tag codes detected on the island in 2013 were from Wanapum 2012BY releases. Of these, 32 (71%) were from the Columbia Siding release and the remaining 13 (29%) were from fish released at Columbia Cliffs Eddy.

The catch distributions of the 2010BY release groups were generally consistent with telemetry data obtained from these groups in 2011 (Golder 2013). Interestingly, unlike the LCC and MCW releases, the UCW release groups differed substantially in apparent behavior between reservoirs; the Wanapum UCW fish remained largely within the upper sampling section of Wanapum reservoir close to their release site, while the Priest Rapids UCW fish distributed themselves evenly throughout Priest Rapids Reservoir. Why this should be the case is unclear although it does indicate that sturgeon of common parentage may behave differently depending on the environment into which they are introduced.

Catch and telemetry data showed that LCC groups strongly dispersed downstream from release locations and that a detectable fraction of the releases entrained downstream through Wanapum and Priest Rapids dams. The apparently poorer retention of this group within the study area suggests that Lower Columbia River origin sturgeon may be unsuitable for PRPA stocking efforts. However, the number of parents contributing to each of the 2010BY release groups was relatively small and therefore the observed post-release behaviors may not necessarily be representative of the area of origin. Realistically, definitive answers regarding stock suitability can only be achieved through a multi-year study using the progeny of large numbers of adults from each area of interest.

Literature Cited

Bannerot, S.P. and C.B Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Journal: Transactions of The American Fisheries Society - TRANS AMER FISH SOC , vol. 112, no. 5, pp. 608-617, 1983Beameserfer, R. 1993. A standard weight (W), equation for white sturgeon. California Fish and Game 79:63-69.

Bruch, R. M., T. A. Dick, and A. Choudhury. 2001. A field guide for the identification of stages of gonad development in lake sturgeon (*Acipenser fulvescens*). Sturgeon for Tomorrow, Fond du Lac, Wisconsin. 38 pp.

Counihan, T. D., M. J. Parsley, D. G. Gallion, C. N. Frost, and Morgan. February 1999. Report C. Effects of Mitigative Measures on Productivity of White Sturgeon Populations in the Columbia River Downstream From McNary Dam, and Determine the Status and Habitat Requirements of White Sturgeon Populations in the Columbia and Snake Rivers Upstream From McNary Dam, Annual Progress Report, April 1997-March 1998, Report C in Effects of Mitigative Measures on Productivity of White Sturgeon Populations in the Columbia River Downstream from McNary Dam, and Determine the Status and Habitat Requirements of White Sturgeon Populations in the Columbia and Snake Rivers Upstream from McNary Dam, Annual Progress Report, April 1997-March 1998. Ward, D. L. (ed.), Portland, OR: Oregon State University, 94-129.

DART 2014. Columbia River Data Access in Real Time webpage www.cbr.washington.edu/dart/river.html

Golder Associates Ltd. 2003. White sturgeon investigations in Priest Rapids and the Wanapum reservoirs on the Middle Columbia River, Washington, U.S.A. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 002-8817F: 82pp. + 5 app.

Golder Associates Ltd. 2011. White sturgeon monitoring and evaluation program annual report 2010. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0300: 42pp. + 7 app.

Golder Associates Ltd. 2012. White sturgeon monitoring and evaluation program annual report 2011. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0301: 34pp. + 5 app.

Golder Associates Ltd. 2013. White sturgeon monitoring and evaluation program annual report 2012. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0302: 67pp. + 6 app.

Golder Associates Ltd. 2014. White sturgeon management plan annual data report 2013. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0304: 25pp. + 5 app.Kincaid, T. M. and Olsen, A. R. (2013). spsurvey: Spatial Survey Design and Analysis. R package version 2.6. URL: http://www.epa.gov/nheerl/arm/.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Upper Columbia White Sturgeon Recovery Initiative (UCWSRI). 2006. Columbia River Adult White Sturgeon Capture, Transport and Handling Manual. May 2006 Version. 21pp + 5 app.

Wickham, H. 2009. ggplot2: elegant graphics for data analysis. Springer New York Bannerot, S. P. and C. B. Austin (1983). Using Frequency Distributions of Catch per Unit Effort to Measure Fish-Stock Abundance. Transactions of the American Fisheries Society 112: 608-617.

Stevens, D. L., Jr. and A. R. Olsen. 2004. "Spatially-balanced sampling of natural resources." Journal of American Statistical Association 99(465): 262-278

Uphoff, J. H., Jr. 1993. "Determining Striped Bass Spawning Stock Status from the Presence or Absence of Eggs in Ichthyoplankton Survey Data." North American Journal of Fisheries Management 13(4): 645-656.

Appendix A
Additional Data from White Sturgeon Broodstock Collection in Wanapum Reservoir

Table A1 Summary of capture, life-history and tagging information for all White Sturgeon caught by angling during broodstock capture in 2014. Origin was wild (W) or hatchery (H). See Table 2 for definitions of Sex / Maturity codes.

Reservoir	Site	Date	Origin	Fork Length (cm)	Weight (kg)	Sex / Maturity	PIT-tag#	Acoustic Tag Code[1]
Wanapum	AB452.4R	31-May-14	W	157.00	--	98	985120021743750	--
Wanapum	AB452.4R	31-May-14	W	158.00	--	98	985121028993067	--
Wanapum	AB452.4R	31-May-14	W	199.50	90.70	M1	985121029410298	--
Wanapum	AB452.4R	31-May-14	W	178.00	65.80	F1	985121029027791	--
Wanapum	AB452.4R	31-May-14	W	190.50	79.40	M1	985121028965506	--
Wanapum	AB452.8	31-May-14	H	133.00	--	98	985120024370828	--
Wanapum	AB452.4R	01-Jun-14	H	141.00	22.70	98	985120019494076	--
Wanapum	AB452.4R	01-Jun-14	W	164.00	37.60	98	985121029013935	--
Wanapum	AB452.4R	01-Jun-14	W	221.50	82.60	M2	985121028969926	25664
Wanapum	AB453.0	01-Jun-14	W	257.00	145.10	F5	4110493172	--
Wanapum	AB453.0	02-Jun-14	H	124.00	--	98	985121020822000	--
Wanapum	AB452.4R	03-Jun-14	W	179.50	53.50	M1	420401477D	30693
Wanapum	AB453.0	03-Jun-14	W	177.00	55.30	Fv	985121029026989	25665
Wanapum	AB453.0	03-Jun-14	W	241.00	149.70	F5	985121029028214	25661
Wanapum	AB453.0	03-Jun-14	H	48.00	--	98	985121020803197	--
Wanapum	AB453.0	03-Jun-14	H	91.00	--	98	985121029030588	--
Wanapum	AB452.4R	04-Jun-14	W	192.50	67.10	F3	41105E3804	25657
Wanapum	AB450.6L	04-Jun-14	W	167.00	37.60	M1	985121029005885	--
Wanapum	AB453.0	04-Jun-14	H	30.00	--	98	985120019950765	--
Wanapum	AB453.0	04-Jun-14	H	73.00	--	98	985120019340398	--
Wanapum	AB453.0	05-Jun-14	W	174.50	59.00	F2	985121028976734	25656
Wanapum	AB453.0	06-Jun-14	H	79.00	--	98	985120021602966	--
Wanapum	AB453.0	07-Jun-14	W	175.50	53.50	M1	985121029001260	--
Wanapum	AB450.3M	07-Jun-14	H	122.00	--	98	985120019502044	--
Wanapum	AB453.0	08-Jun-14	W	215.00	104.30	F2	985121028964762	25662
Wanapum	AB453.0	08-Jun-14	W	152.00	29.50	Fv	985121028980649	--
Wanapum	AB453.0	08-Jun-14	W	146.00	26.30	F0	985120017816961	--
Wanapum	AB452.4	09-Jun-14	W	156.50	29.50	M1	985121029030546	--
Wanapum	AB453.0	10-Jun-14	W	174.50	52.20	M1	985121029002469	--
Wanapum	AB453.0	10-Jun-14	W	160.50	37.60	M1	985121028977372	--
Wanapum	AB453.0	10-Jun-14	W	125.00	20.40	98	985120021829482	--
Wanapum	AB450.4L	11-Jun-14	H	125.50	16.93	98	985120019564150	--
Wanapum	AB453.0	13-Jun-14	H	44.00	--	98	985121022939146	--
Wanapum	AB452.4R	31-May-14	W	157.00	--	98	985120021743750	--

[1] Acoustic tag 30693 was applied in 2012; remaining six tags were applied in 2014.

Appendix B

2014 White Sturgeon Broodstock Collection Chelan and Grant County PUD and Blue Leaf Environmental

MEMORANDUM
TO: Lance Keller, Chelan County PUD and Mike Clement, Grant County PUD

FROM: Corey Wright *, Blue Leaf Environmental*

DATE: July 15, 2014

- SUBJECT: Broodstock Collection Below McNary Dam in 2014

The use of professional fishing guides to capture white sturgeon (*Acipenser transmontanus*) broodstock for the Mid-Columbia sturgeon recovery effort was utilized again, for the fourth year, in 2014. For the third year, fishing took place in the spawning sanctuary below McNary dam on the Columbia River. This year for the first time Grant County PUD provided a second guided boat for 8 of the 13 days fishing efforts took place. Previous broodstock collection efforts are summarized in the report titled, White Sturgeon (*Acipenser transmontanus*) Broodstock Collection with Professional Fishing Guides in 2011 and 2012, submitted to Chelan PUD in July 2012 and the memorandum titled Broodstock Collection Below McNary Dam in 2013. Please refer to these documents for background information on the study site and methods used. In 2014, fishing took place over 13 days from the 18th to the 28th of May and then on the 1st and 2nd of June. In May a total of 64 sturgeon were captured, of which 28 were juveniles and 36 were adults. In June approximately 7 fish were captured, however fish were immediately transferred to the Yakama Nation Fisheries Marion Drain staff so Blue Leaf does not have catch data on these fish. In total 9 ripe females were transported to Marion Drain Hatchery along with 11 ripe males and successful 5x5 and 3x5 spawning matrices were performed.

Catch per unit effort was not tracked, but we can say anecdotally that it was very similar to or better than 2013 levels. The mean number of fish captured per day remained the same in 2014 as 2013 with 6 fish. However, more juveniles were caught in 2013 and the mean daily catch for adults in 2014 was 3.3 fish, up from 2.6 in 2013 likely attributable to the second fishing boat. During biometric processing of captured sturgeon, two sturgeon were found to have consumed PIT tagged salmonid smolts. A complete summary of capture history and biometrics are found in Table 1.

ACKNOWLEDMENTS

Blue Leaf Environmental thanks the staff of Chelan PUD and Grant PUD for allowing us to assist them in this effort. We also thank Dan and Neil Sullivan of Rivers West Sport Fishing for all of their fishing services and expertise. Donella Miller and the staff at Marion Drain Hatchery for assisting with transported fish, assistance with equipment and identification techniques. There were too many fishing volunteers this year to name but without them the fish would not get landed. We thank ODFW and WDFW and there permitting staff. We finally thank Mike Clement and Grant County PUD for the use of their transport tank.

Table 1 . Catch data from white sturgeon broodstock collection efforts at McNary Dam from May 18th through May 28th, 2014.

No.	Date	SEX/MAT CODE	Fork	Total	GIRTH (cm)	Fate	Tagged	MARK @ Capture	DNA Vial #	PIT
1	5/18/2014	Male	226	247	95	released	PIT		0001	3DD.0077526DB0
2	5/18/2014	Female	265	289	107	released	PIT		0002	3DD.0077532EAF
3	5/18/2014	Juvenile	95	110	40	released	PIT		0003	3DD.007753235C
4	5/18/2014	Juvenile	118	141	55	released	PIT	R16	0004	3DD.007752B813
5	5/18/2014	UNK	183	207	73.5	released		L2	0005	3D9.1C2E0AAA13
6	5/19/2014	Male	231	254	91.5	released	PIT	L11	0006	3DD.007753237D
7	5/19/2014	Male	209.5	236	95.5	released	PIT	L1,L2, R21 R22	0007	3DD.0077530EC0
8	5/19/2014	Female	245	281	138	hatchery	PIT		0008	3DD.007752DBD9
9	5/19/2014	Male	233	268	94	released		L2	0009	3D9.1C2D2F7AAC
10	5/19/2014	Juvenile	72		28	released	PIT		0701	3DD.007752B794
11	5/19/2014	Juvenile	126		53	released		L2	0702	3D9.1C2DF52E24
12	5/19/2014	Juvenile	138		56	released	PIT		0703	3DD.0077530965
13	5/20/2014	Juvenile	91		37	released		L2		3D9.1C2DF5C6C7
14	5/20/2014	Juvenile	126	142	49	released		L2	0704	3D9.1BF268E2F8
15	5/20/2014	Female	175	197	69	released	PIT		0705	3DD.0077534332
16	5/20/2014	Male	202	224.5	86	hatchery	PIT		0706	3DD.0077538E76
17	5/21/2014	Male	225	247.5	83	hatchery	PIT		0707	3DD.007752F25D
18	5/21/2014	Juvenile	116.5	132	44	released	PIT		0708	3DD.007752B7D7
19	5/21/2014	Male	169	189	79	hatchery		R10	0010	3D9.1BF1D4DA0A
20	5/21/2014	Male	217	241	87	hatchery	PIT		0011	3DD.007753466E
21	5/21/2014	Male	262	291	121	released	PIT		0012	3DD.0077531486
22	5/22/2014	Juvenile	104		40	released	PIT		0709	3DD.0077533489
23	5/22/2014	Male	164	183	69	released	PIT		0710	3DD.0077528986
24	5/22/2014	Juvenile	79		34	released	PIT		0711	3DD.0077537A4B
25	5/22/2014	Juvenile	85		36	released			0712	
26	5/22/2014	Juvenile	110		44	released		L2	0713	3D9.1C2DCBC65E
27	5/22/2014	Juvenile	95		39	released		L2	0714	3D9.1C2DF5D068
28	5/22/2014	Juvenile	96		35	released	PIT		0715	3DD.0077537407
29	5/22/2014	Juvenile	168	189	68	released			E1	3DD.0077527D44
30	5/22/2014	Juvenile	95	111	40	released	PIT		0013	3DD.00775368DA
31	5/22/2014	Male	242	274	93	released	PIT		0014	3DD.0077530CBC
32	5/22/2014	Female	268	298	107	released	PIT		0015	3DD.0077538A83
33	5/22/2014	Juvenile	45.5	52	16	released	PIT		0016	3DD.0077528ECC
34	5/23/2014	Female	233	257	109	hatchery	PIT	R2,L2,L7	0017	3DD.007752898B
35	5/23/2014	Female	227	266	92	released	PIT		0018	3DD.0077528716
36	5/23/2014	Male	206	232	79	hatchery	PIT	R1,R2,R3	0019	3DD.0077537D6E
37	5/23/2014	Male	211	243	88.5	released	PIT		0020	3DD.007752F2D6
38	5/23/2014	Female	206	234	92	hatchery	PIT		0716	3DD.0077532810
39	5/23/2014	Male	214	235	85	hatchery	PIT		0717	3DD.0077533288
40	5/24/2014	Juvenile	98		43	released	PIT		0718	3DD.007752A996

41	5/24/2014	Juvenile	91.5		35	released		L2	0719	3D9.1C2DF5C6C7
42	5/24/2014	Male	231	250	86	hatchery	PIT		0021	3DD.00775290B1

Table 1 Cont'd. Catch data from white sturgeon broodstock collection efforts at McNary Dam from May 18th through May 28th, 2013.

No.	Date	SEX/MAT CODE	Fork	Total	GIRTH (cm)	Fate	Tagged	MARK @ Capture	DNA Vial #	PIT
43	5/24/2014	Male	183	205.5	79	hatchery		L2,R11	0022	3D9.1BF139B6E0
44	5/24/2014	Female	229	260	109	hatchery	PIT		0023	3DD.007752E6B4
45	5/24/2014	Juvenile	101		42	released	PIT	L9	0024	3DD.0077536F95
46	5/24/2014	Male	238	271	105	hatchery	PIT		0025	3DD.007752CD3A
47	5/25/2014	Female	243.5	272	115	hatchery	PIT	L29-32	0026	3DD.00775265ED
48	5/25/2014	Juvenile	101	113	41	released		L2		3D9.1BF264CBBF
49	5/25/2014	Juvenile	78		31	released		L2	0720	3D9.1C2DCBB8C4
50	5/25/2014	Juvenile	95		37	released		L2,R8	0721	3D9.1C2E0ABD33
51	5/25/2014	Male	230	257	89	hatchery	PIT		0722	3DD.007753573B
52	5/26/2014	Juvenile	76		44.5	released	PIT	L9	0801	
53	5/26/2014	Male	209	230	152	released	PIT		0802	3DD.00775330EB
54	5/26/2014	Female	247	279	128	hatchery	PIT		0803	3DD.0077525F91
55	5/26/2014	Female	214	241	93	hatchery			0723	3DD.007752F3E5
56	5/26/2014	Male	187	214	81.5	hatchery		L2,L4,L9,R2	0724	
57	5/26/2014	Juvenile	103.5	117	43	released		L2	0725	3D9.1C2D674734
58	5/26/2014	Juvenile	90.5	106	32	released	PIT		0726	3DD.007752CFB0
59	5/26/2014	Juvenile	119.5	137	48.5	released	PIT		0727	3DD.0077537673
60	5/26/2014	Male	231	256.5	93	released	PIT		0728	3DD.007752D363
61	5/27/2014	Female	238	266	106	released	PIT		0804	3DD.0077534C0E
62	5/27/2014	Male	239	268	105.5	released	PIT		0805	3DD.0077529606
63	5/28/2014	Juvenile	98		40.5	released			0806	3DD.0077528EC4
64	5/28/2014	Female	255	286	131.5	hatchery	PIT		0807	3DD.0077536AE8

Appendix C
2014BY Broodstock and Spawning Summary at Marion Drain Hatchery

Table C1 The 2014 broodstock inventory at Marion Drain Hatchery.

FEMALES					
#	**Date Captured**	**Capture Location**	**PIT TAG**	**Weight Lb**	**Comments**
1	5/19/14	John Day	3DD007752DBD9	307	
2	5/23/14	John Day	3DD007752898B	247	
3	5/23/14	John Day	3DD0077532810	215	
4	5/24/14	John Day	3DD007752E6B4	309	Regulator broke during transport DO's < 40%, pumped in river water at Benton City. D.O. 3.5 mg/L at arrival. Did not pull eggs at arrival due to transport issues. Lethargic when unloading but appeared okay in tank.
5	5/25/14	John Day	3DD00775265ED	-	
6	5/26/14	John Day	3DD007752F3E5	205	
7	5/27/14	John Day	3DD0077525F91	356	
8	5/28/14	John Day	3DD0077536AE8	391	
9	6/3/14	John Day	3D91C2DEC8A96	235	
MALES					
1	5/20/14	John Day	3DD0077538E76	145	No milt produced, Clear fluid after injection
2	5/21/14	John Day	3D91BF1D4DA0A	111	
3	5/22/14	John Day	3DD007752F25D	181	No milt produced, Clear fluid after injection
4	5/22/14	John Day	3DD007753466E	174	No milt produced, Clear fluid after injection
5	5/23/14	John Day	3DD0077537D6E	157	
6					
7	5/24/14	John Day	3DD0077533288	185	Bagged Overnight prior to transport.
8	5/24/14	John Day	3DD00775290B1	200	Belly up in tank upon arrival, still gilling
9	5/24/14	John Day	3D91BF139B6E0	138	
10	5/24/14	John Day	3DD007752CD3A	268	Regulator broke during transport DO's < 40%, pumped in river water at Benton City. D.O. 3.5 mg/L at arrival. Lethargic when unloading but appeared okay in tank.
11	5/25/14	John Day	3DD007753573B		
12	5/26/14	John Day	3D91BF10E073C	152	
13	6/1/14	Wanapum	3D91C2DE385C6	193	
14	6/3/14	John Day	3D91BF155B38E	-	Flowing at cap, did not transport fish to hatchery. 3 bags of 150mL milt collected

🟨	Spawn 1
🟩	Spawn 2

Table C2 Spawning summary of the capture date and origin of broodstock used for two spawning efforts (Spawn 1 and 2) at Marion Drain Hatchery in 2014, including fish that failed to spawn.

#	Date Captured	Capture Location	PIT TAG	Total mL Eggs Collected	Eggs/ mL	Total # Eggs
SPAWN 1 **Each of the female was crossed with each of the male to produce a 5x5 factorial matrix resulting in 25 half sib families.**						
FEMALES						
1	5/19/14	John Day	3DD007752DBD9	2,700	20.00	54,000
2	5/23/14	John Day	3DD007752898B	2,550	18.66	47,583
3	5/23/14	John Day	3DD0077532810	2,600	20.00	52,000
6	5/26/14	John Day	3DD007752F3E5	2,650	16.00	42,400
8	5/28/14	John Day	3DD0077536AE8	3,150	15.33	48,290
MALES			**Total**	**13,650**	**89.99**	**244,273**
2	5/21/14	John Day	3D91BF1D4DA0A			
5	5/23/14	John Day	3DD0077537D6E			
12	5/26/14	John Day	3D91BF10E073C			
13	6/1/14	Wanapum	3D91C2DE385C6			
14	6/3/14	John Day	3D91BF155B38E			
SPAWN 2 **Each of the female was crossed with each of the male to produce a 3x5 factorial matrix resulting in 15 half sib families.**						
FEMALES						
5	5/25/14	John Day	3DD00775265ED	3,000	17.66	52,980
7	5/27/14	John Day	3DD0077525F91	3,450	15.33	52,889
9	6/3/14	John Day	3D91C2DEC8A96	1,900	17.33	32,927
MALES				**8,350**	**50.32**	**138,796**
7	5/24/14	John Day	3DD0077533288			
8	5/24/14	John Day	3DD00775290B1			
9	5/24/14	John Day	3D91BF139B6E0			
10	5/24/14	John Day	3DD007752CD3A			
11	5/25/14	John Day	3DD007753573B			
DID NOT SPAWN						
FEMALES						
4	5/24/14	John Day	3DD007752E6B4	Regulator broke during transport DO's < 40%, pumped in river water at Benton City. D.O. 3.5 mg/L at arrival. Did not pull eggs at arrival due to transport issues. Lethargic when unloading but appeared okay in tank.		
MALES						
1	5/20/14	John Day	3DD0077538E76	No milt produced, Clear fluid after injection		
3	5/22/14	John Day	3DD007752F25D	No milt produced, Clear fluid after injection		
4	5/22/14	John Day	3DD007753466E	No milt produced, Clear fluid after injection		

Appendix D
2015 WSMP Study Plan and Schedule

INTRODUCTION

Golder proposes the following study plan and schedule for the 2015 (License Year 8) component of the White Sturgeon Management Plan (WSMP). The specific objectives and tasks were developed to meet the overall study objectives of the WSMP and address the specific Monitoring and Evaluation (M&E) tasks described in the Grant PUD RFP No. 11-31 (Table 1).

A summary of specific work scope and budget associated with each Project objective and task has been provided in the following sections.

Table 16: The 2015 WSMP Study Objectives and Tasks

WSMP Objective	WSMP Task No.	Task
1	2	Conservation Aquaculture and PRFF Support
1	3.1	Juvenile Marking
1	3.2	Juvenile Transport
2	1	Juvenile Movement Assessment
2	3	Adult Indexing (Capture-Recapture)
4	1	Evaluation of Existing Spawning Use
4	2	Hatchery White Sturgeon Growth, Survival, and Stocking Rate Adjustment
4	3	Database Management and Development Requirements
4	4	Annual WSMP Report

Objective 1 Task 2 – Conservation Aquaculture and PRFF Support (2015)

Golder has assembled an experienced team of senior biologists, each with between 10 and 30 years of sturgeon research expertise. Larry Hildebrand (Golder) has over 30 years of experience with sturgeon research and currently is a member of the transboundary UCRWSRI. He was the principal developer of the Grant PUD White Sturgeon Management Plan and also developed similar management programs for Chelan and Douglas Counties. Over his 20 year career in fisheries biology, Jason McLellan (CCT) has been directly involved in the development of the White Sturgeon hatchery programs at the Wells, Sherman Creek and Moses Lake. Former manager of the Freshwater Fisheries Society of British Columbia (FFSBC), Dr. Jim Powell of Fidelis Aquaculture Management has over 30 years of fish culture research, hatchery management, and has served as a coordinator for White Sturgeon recovery programs in the Upper Columbia and Nechako rivers.

The above senior biologists will assist Grant PUD Resource Managers in the development of cost effective strategies to fulfill the Project objectives and FERC license obligations. They will also participate in an advisory role to provide input and expertise into the White Sturgeon aquaculture component of the WSMP through participation at regional workgroups, the PRFF, and in support of aquaculture activities undertaken at MDH in Toppenish, Washington. The work associated with this study component will entail attendance of up to a maximum of 12 PRFF meetings (via teleconference), review of documents, and technical and professional communications. Golder assumes that physical attendance at PRFF meetings will only be required once per year for senior staff. If additional consultation and services are required, these can be provided upon receipt of an approved change order.

Assumptions: Objective 1 Task 2 Conservation Aquaculture (2015)

Key assumptions of our proposed approach are:

1. When required, senior or intermediate staff will participate in monthly PRFF meetings primarily via teleconferencing.
2. Physical attendance at PRFF meetings will be limited to once per year for senior staff (Golder -Larry Hildebrand or Paul Grutter, CCT - Jason McLellan or Matt Howell, Fidelis - Dr. Jim Powell).
3. If requested by Grant PUD, additional services beyond the contract work scope can be provided upon receipt of an approved change order and revised work scope.

Assets Allocated to this Task: Objective 1 Task 2 Conservation Aquaculture (2015)

Study Year	**Total Effort (hr)**	**Consultant Provided Equipment**	**Grant PUD Provided Equipment and Support**
2015	170	n/a	n/a

Schedule: If required, attend PRFF meetings the first Wednesday of each month for approximately one hour via teleconference.

Objective 1 Task 3.1 – Juvenile Marking (2015)

Processing and tagging of the 2014BY will be conducted by LGL staff based out of Sidney, British Columbia, with support from BLE staff based in Ellensburg, Washington. LGL will coordinate with MDH hatchery staff to assemble equipment and personnel to conduct the tagging effort over approximately a 10 day work window, tentatively scheduled in late April of each release year. MDH will provide basic fish processing equipment and support personnel. Study costs and effort for this component have been based on the annual tagging and marking of 6,500 juveniles. All hatchery White Sturgeon progeny raised at MDH will be implanted with glass 12.5 millimeter (mm), 134 kilohertz (kHz) ISO PIT tags, using an appropriate applicator, with the tag inserted on the left side at the base of the 4th dorsal scute and the tag oriented in line with body axis towards the head of the fish. Prior to release, ideally all fish will be held for up to two weeks to allow for healing. After transfer and release of all fish, the bottom of each holding pen will be inspected for lost PIT-tags to determine PIT-tag retention and loss rates. In total, 1% of the total juveniles released (i.e., up to 65 fish if 6,500 fish are released) will also receive a hydroacoustic tag, surgically implanted by LGL biologists. All PIT-tags and acoustic tags will be provided by Grant PUD. The hydroacoustic tag applied will be a Vemco V9-2L tag as outlined in Table 2.

Table 17: Tag Specifications of the Vemco V9-2L Acoustic Telemetry Tags to be Implanted in Juvenile White Sturgeon Raised at MDH

Specification	Unit Value
Output (dB/m)	142
wt in air (g)	4.7
Tag length (mm)	30
Tag diameter (mm)	9
Tag life at 240s burst interval (days)	959

The tags will be implanted internally by LGL biologists using standard surgical procedures developed for the Project. LGL staff will be responsible for coordinating the field tagging procedures, data recording using the Grant PUD Biomark fish processing table, and provision of these data to Golder for upload into PTAGIS once the fish are released.

Assumptions: Objective 1 Task 3.1 Juvenile Marking (2015)

Key assumptions of our proposed approach are:

1. Grant PUD will have a separate contract with MDH to provide hatchery staff and equipment to assist with fish processing.
2. PIT-tags and acoustic tags to be applied to juvenile White Sturgeon will be supplied by Grant PUD.
3. Grant PUD will provide all surgical supplies and processing equipment (i.e., a Biomark PIT tagging table with reader, pen, scale, tags, sutures, blades, PIT applicators, nets, tubs, MS-222, VR2W acoustic tag tester) either directly or through contract with MDH.
4. Costs are based on an annual release target of 6,500 juveniles, with all fish processed and tagged during a single session.

Assets Allocated to this Task: Objective 1 Task 3.1 Juvenile Marking (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	305.5	Data sheets Personal vehicles Specialized surgical tagging equipment	VR100 or VR2W tag verifier Up to 6,500 PIT tags Up to 65 Vemco V9 acoustic tags Surgical supplies, sutures, PIT syringes BioMark Table and programmed data entry computer Arrange MDH staff assistance to assist with fish processing

Schedule: Starting mid-April each study year.

Objective 1 Task 3.2 – Juvenile Transport (2015)

Juvenile White Sturgeon from each brood year will be held for approximately a two week recovery period after tagging and processing. Prior to release, the holding pen water temperature will be adjusted and the fish gradually acclimated (2 degrees Celsius per day [°C/day]) to approximate 10°C, the likely temperature of the Columbia River in early May. In the second week of May, BLE staff will be responsible for the coordination and transport of juvenile White Sturgeon from MDH to release locations in Wanapum and Priest Rapids reservoirs. Based on the Project WSMP, 77% of the annual juvenile White Sturgeon raised at MDH will be released in Wanapum reservoir at Rocky Coulee Launch, with the remaining 23% released in Priest Rapids reservoir in the tailwater of Wanapum Dam.

In an exchange of services and equipment, Chelan PUD will assist Grant PUD in the release of the juvenile White Sturgeon and will provide a Chelan PUD fish transport truck and a driver. The Chelan PUD transport truck is capable of transporting up to 3,500 fish per load and has two separate compartments so that fish can be partitioned by release site if required. During transport, the truck operator can monitor and regulate the oxygen concentration within individual compartments. Chelan PUD will also provide the necessary equipment to safely release the juvenile White Sturgeon through the blade valves on each tank. Typically, a specialized 10-inch diameter release chute at least 15 feet long is required to effectively release the fish and reduce the risk of injury to the fish upon release. In the absence of this release chute, release of the fish would require that fish be dip-netted from the transport tanks – a time consuming and labor intensive process. In conjunction with use of the Chelan transport truck, the BLE crew will use the Grant PUD fish transport trailer and a BLE truck to transfer up to 800 fish per trip. Conservatively, the transport of 6,500 juvenile White Sturgeon will require two to three trips over two days, depending on the size of the fish at the time of transport.

With high-level oversight provided by Golder, BLE will coordinate and assist MDH staff in the loading of fish into the transport truck. Golder will provide BLE with specific work instructions for filling and draining the trailer, monitoring and regulating water oxygen and temperature while in transit, highway transport safety, and fish release procedures. During fish transfers and transport, BLE crews will monitor and maintain water temperature and dissolved oxygen at optimum conditions. All aspects of each fish transport and release will be documented by BLE using fish transport and release data collection forms provided by Golder. BLE will provide digital copies of all completed forms to Golder after each release.

Assumptions: Objective 1 Task 3.2 Juvenile Transport (2015)

Key assumptions of our proposed approach are:

1. Grant PUD will arrange to have MDH staff assist with loading of juvenile White Sturgeon.
2. Grant PUD will contact Chelan PUD regarding provision of the hatchery transport truck.
3. Grant PUD will conduct annual mechanical inspections of the transport trailer, as well as service and test the oxygen supply system and gas-powered water pump prior to tentative transport and release date.
4. A YSI optical dissolved oxygen (DO) meter will be supplied by Grant PUD.
5. Grant PUD will obtain the appropriate fish transport permits to be provided to Golder and the BLE and Chelan PUD transport crews.
6. Completion of juvenile transport and release will be practical within two working days.

Assets Allocated to this Task: Objective 1 Task 3.2 Juvenile Transport (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	69.5	Heavy duty truck	VR100 or VR2W acoustic receivers Fish transport trailer YSI DO meter Transport permit MDH staff support

Schedule: Second week of May each study year.

Objective 2 Task 1 - Juvenile White Sturgeon Movement Assessment (2015)

A juvenile movement assessment program will be conducted in the Project area in 2015. Twelve acoustic telemetry stations were originally deployed in 2010 at select locations in the Project area to monitor movement of White Sturgeon implanted with acoustic tags. Each station consisted of a Vemco VR2W receiver mounted on an anchored stainless steel cable, suspended in the water column by a float. In the course of conducting the monitoring program and servicing the stations, the upper cable connections of each station are routinely inspected and repaired if required. However, cable connections at the station anchor cannot be easily inspected without completely removing the station and winching the 200-pound (lb) anchor to the surface – a time consuming and difficult process that typically requires specialized equipment and a crew of at least three people to conduct the work safely. In the absence of station removal and inspection of all cable connections, cumulative wear at the anchor connection since deployment was suspected at all stations. Consequently, in 2014, anchor connections failed at six of the twelve monitoring stations. Four of the six stations receivers were eventually recovered with the receiver still attached to the array float as well as a long length of stainless steel anchor cable. The emergency reduction of the Wanapum pool in late February 2014 may have also contributed to these failures. We suspect the anchor connections of the remaining six stations are likely weakened due to cumulative wear and are also at risk of failure over the 2014 to 2015 winter period.

Given the lessons learned in 2014, future monitoring programs will require that all stations are removed and fully serviced every three years. In March 2015, the six monitoring stations lost in 2014 will be redeployed at their original locations using the same deployment method developed in 2010. The six remaining stations and anchors will be retrieved by winch to inspect and replace any weakened components. In 2010, Grant PUD purchased scrap metal rail for anchor material. This material was cut into 3-foot and 1-foot lengths by Grant PUD welders. Purchase of additional anchor material by Grant PUD will be required for the deployment of the new stations in 2015. As some of the receivers were lost, at least three new VR2W's will be required to replace the lost stations. After station repair and redeployment in 2015, we assume that annual inspection of the upper cable connections will likely be sufficient to maintain overall station integrity until 2018, at which point, station removal and a full inspection of all connections should be conducted. Alternative VR2W deployment methods will also be considered at select locations.

In the 2015 study year, the VR2W stations will be inspected and downloaded at approximately four-month intervals each study year. When practical, this activity will be scheduled in conjunction with other field studies (e.g., spawn monitoring) to reduce study costs. During servicing, active tracking with a VR100 and an omnidirectional hydrophone provided by Grant PUD will be conducted at each VR2W station to confirm the presence or absence of same day detections at the station. Station deployment and servicing will be conducted by Golder personnel with assistance from BLE technicians. All downloaded telemetry data will be inspected and archived within the Grant PUD telemetry database managed by Golder. Once within database, these data can be easily queried to provide movement summaries of both adult and juvenile White Sturgeon.

Assumptions: Objective 2 Task 1 Juvenile White Sturgeon Movement Assessment (2015)

Key assumptions of our proposed approach are:

1. Grant PUD will provide all needed VR2W receivers, batteries, and mooring gear to replace six lost stations and to service and maintain the integrity of the remaining six stations.
2. Grant PUD will purchase an additional 72 feet of rail material for anchor material, cut into 16 3-foot lengths and 24 1-foot lengths, and burn a hole in one end of each piece to allow attachment of a length of chain.
3. Golder and BLE crews will use the Grant PUD VR100 receiver and hydrophones to conduct the active tracking.
4. Any additional substantial servicing or replacement of stations will be covered under a change order.

Assets Allocated to this Task: Objective 2 Task 1 Juvenile Movement Assessment (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	451.5	Heavy-duty truck Research boat with retrieval winch Field computer DOT truck	VR100 receiver Omni-directional, and directional hydrophones Spare VR2W receivers VR2W bluetooth key Vemco VR2W lithium batteries VR2W anchor material repair hardware

Schedule: Station deployment and servicing March 2015. Four-month service interval in each study year (e.g., March, July, and October).

Objective 2 Task 3 – Adult Indexing (2015)

A capture-recapture study will be conducted in fall 2015 to obtain population data on adult and sub-adult White Sturgeon in Wanapum and Priest Rapids reservoirs. In past studies, baited set lines were used effectively to capture adult fish, with the highest White Sturgeon capture rates recorded in early fall from September to October during previous adult indexing programs (Golder 2003, 2011, 2013).

In order to attain a sample effort comparable to the 2012 study, a total of 182 individual set line sample sets will be deployed over two 14-day sample sessions in fall 2015. Set line deployment locations will be determined in advance using a GRTS design, with samples drawn in a manner identical to the approach used during the 2012 adult indexing study (Golder 2013).

Each set line will be approximately 184 m in length and deployed with 10 small hooks #7 (12/0), 10 medium size hooks #5 (14/0), and 10 large hooks #3 (16/0) enable capture of all size classes of fish. The 10 hooks of each size will be placed in random order on each line. The barbs on all hooks will be removed to facilitate fish release and reduce the severity of hook-related injuries. Set line hooks will be baited with commercially available pickled squid. This is the same bait type used during the 2000 to 2002, 2010, and 2012 studies. Set lines will be set overnight and deployed parallel to the bank and the prevailing flow direction so that gear is deployed in the same manner at all sample locations, regardless of flow conditions and water velocity. A piece of 1-foot railway rail will be attached as an anchor to the upstream and downstream ends of each set line. In high flow locations, a claw anchor or shore line will also be attached to the upstream end of the set line to prevent downstream drift. Each set line will have a float retrieval line attached to upstream and downstream ends of the set line. Two boats with crews of three people per boat will be required to deploy and retrieve up to 12 set lines total per day. These lines will be pulled, cleaned, re-baited and reset at a new sample location each day. Crews will be composed of Golder staff as crew leads, with support from BLE personnel.

White Sturgeon capture and handling procedures will be identical to those used in past adult indexing assessments and will adhere to the methods outlined in the Project WSMP (Golder 2003, 2011, 2013). All White Sturgeon will be scanned for PIT tags and checked for marks that indicated if the fish was previously captured. PIT tags and scute marks will be applied to all newly captured fish. The crew will record life-history attributes including fork length, total length, head and snout lengths, girth, and weight. The sex and reproductive status will be determined for all wild adult fish captured following surgical inspection methods outlined in the Project WSMP. Up to 10 Vemco V16-6H acoustic tags will be deployed in mature adult White Sturgeon during the surgical inspections. The V16 acoustic tags will be programmed to transmit at 180-second burst intervals and will have a life expectancy of 10 years. A sample of soft tissue will be collected for DNA analysis from White Sturgeon captured in the Project area. The tissue sample will be removed from the distal end of the left pelvic fin, preserved, and archived for future analysis.

Assumptions: Objective 2 Task 3 Adult Indexing (2015)

Key assumptions of our proposed approach are:

1. Our sampling activities will be covered under Grant PUD’s Federal ESA permits and incidental captures of ESA listed salmonids will not exceed permit limits.
2. Golder and BLE will conduct sampling under the Grant PUD state Scientific Collection Permit.
3. Grant PUD will provide all gangion and set line fabrication material, pickled squid bait, ISO Full Duplex PIT tags, rope, anchors, buoys, and hardware.

Assets Allocated to this Task: Objective 2 Task 3 Adult Indexing (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	1701	2 Sturgeon research boats 2 Field computer 2 DOT Trucks Surgical supplies 2 PIT tag readers	Set line sampling equipment, gangions, and bait ISO Full duplex PIT tags Ropes, anchors, buoys, hardware

Objective 4 Task 1 - Evaluation of Existing Spawning Use (2015)

Egg collection mats will be deployed by boat below Rock Island Dam to capture wild-spawned White Sturgeon eggs and determine the timing and number of spawn events. The left downstream bank below Rock Island Dam is a known high-use area for White Sturgeon spawning and egg incubation. Spawned eggs will be collected by deploying metal-framed egg collection mats at locations where White Sturgeon eggs have previously been collected in large numbers (Golder 2003, 2011, 2014).

An egg collection mat consists of a welded 76 centimeter (cm) by 76 cm metal frame and metal insert panel used to hold a sheet of latex-cover fibrous air filter material within the frame. The coarse surface of the air filter (mat) material serves as an adherent surface to capture White Sturgeon eggs that are initially highly adhesive when released during spawning. The egg collection mats will be deployed in pairs, with both a float line and connected to shore by a length of rope, at 11 shore locations along a riprap embankment on the left bank below Rock Island Dam (Table 3). Due to high flow and the abrasive, angular substrate at the deployment locations, the sample gear can be subject to considerable wear and may require daily maintenance and frequent replacement. Depending on the magnitude of total river discharge, between 1 and 4 single egg collection mats will also be deployed at mid-channel locations along the left bank between the Rock Island Dam boat hazard sign and upstream of Haystack Eddy.

Table 3: Proposed Locations of Egg Collection Mats to be Deployed below Rock Island Dam (RI), 2015

SiteName	UTMZone	UTMEasting	UTMNorthing
RI1	10T	720088	5247190
RI2	10T	720184	5247089
RI3	10T	720273	5246953
RI4	10T	720327	5246859
RI4a	10T	720365	5246780
RI4b	10T	720393	5246722
RI5	10T	720413	5246656
RI6	10T	720445	5246499
RI6a	10T	720441	5246575
RI7	10T	720475	5246343
RI8	10T	719933	5246947

Egg collection mats will be deployed and inspected for 14 days from approximately June 20 to July 3, considered the peak period of White Sturgeon spawning activity, as river flows start to seasonally decrease and water temperature increase and exceed 14°C. In late May, the exact deployment period will be determined by Golder based on the strength of the 2015 Columbia River freshet and early spring water temperature. A Golder research vessel staffed with Golder and BLE crew will conduct the work.

All egg collection mats will be visually inspected daily for White Sturgeon eggs. If eggs are observed, eggs will be enumerated and a sub-sample (1 in every 10 eggs up to a maximum of 30 eggs) preserved in Prefer® for developmental stage identification. Developmental stage will be determined using a microscope to identified characteristic embryological features based on criteria developed by Beer (1981). Determination of developmental stages enables estimation of the number of spawning events and the date of spawning to be estimated based on known developmental rates in relation to ambient water temperature (Wang et al. 1985; Parsley et al. 2004).The remainder of the captured eggs will be placed within the *in situ* incubator until they hatch and develop into free-swimming larvae.

A portable floating *in situ* incubator was first developed and tested in 2013 as part of a pilot study to determine if sufficient numbers of wild spawned White Sturgeon eggs could be captured and incubated *in situ* to produce larvae for subsequent rearing in a hatchery (Golder 2014). Based on lessons learned, the 2015 redesigned incubator will consist of a square 76-cm wide floating chamber, approximately 100 cm deep (Figure 1). The incubator will be moored in an eddy approximately 3.5 kilometers (km) downstream of Rock Island Dam, near River Mile 451. In previous studies, captured White Sturgeon eggs were removed from the egg collection mat material by hand using tweezers – a time consuming and laborious process. Under the assumption egg hatch success will increase if handling time is reduced, egg-laden mat material will be removed from the metal mat frame and suspended within the incubator. Based on observations of free-swimming embryos within the 2013 incubator, embryos will swim up and eventually swim into one of two corners of the incubator where they will pass through a one-way exit and into a collection chamber. Once in the collection chamber, free embryos will eventually locate and reside within artificial substrate (i.e., high surface area bio-balls) at the bottom of the collection chambers. Solar-power battery operated water pumps will be used to maintain circulation flow within two McDonald incubation jars mounted inside the incubator, submerged below the water surface. Eggs captured on mats in low numbers will be removed by hand and temporarily placed within a cooler on the research vessel. These eggs will be transferred to the McDonald jars at the end of each day where they will incubate until hatching and exiting the McDonald jar. The free embryos will be reared in the incubator until all embryos absorb their yolk sac and develop into exogenously feeding larvae, at which point, the larvae will be transferred to MDH.

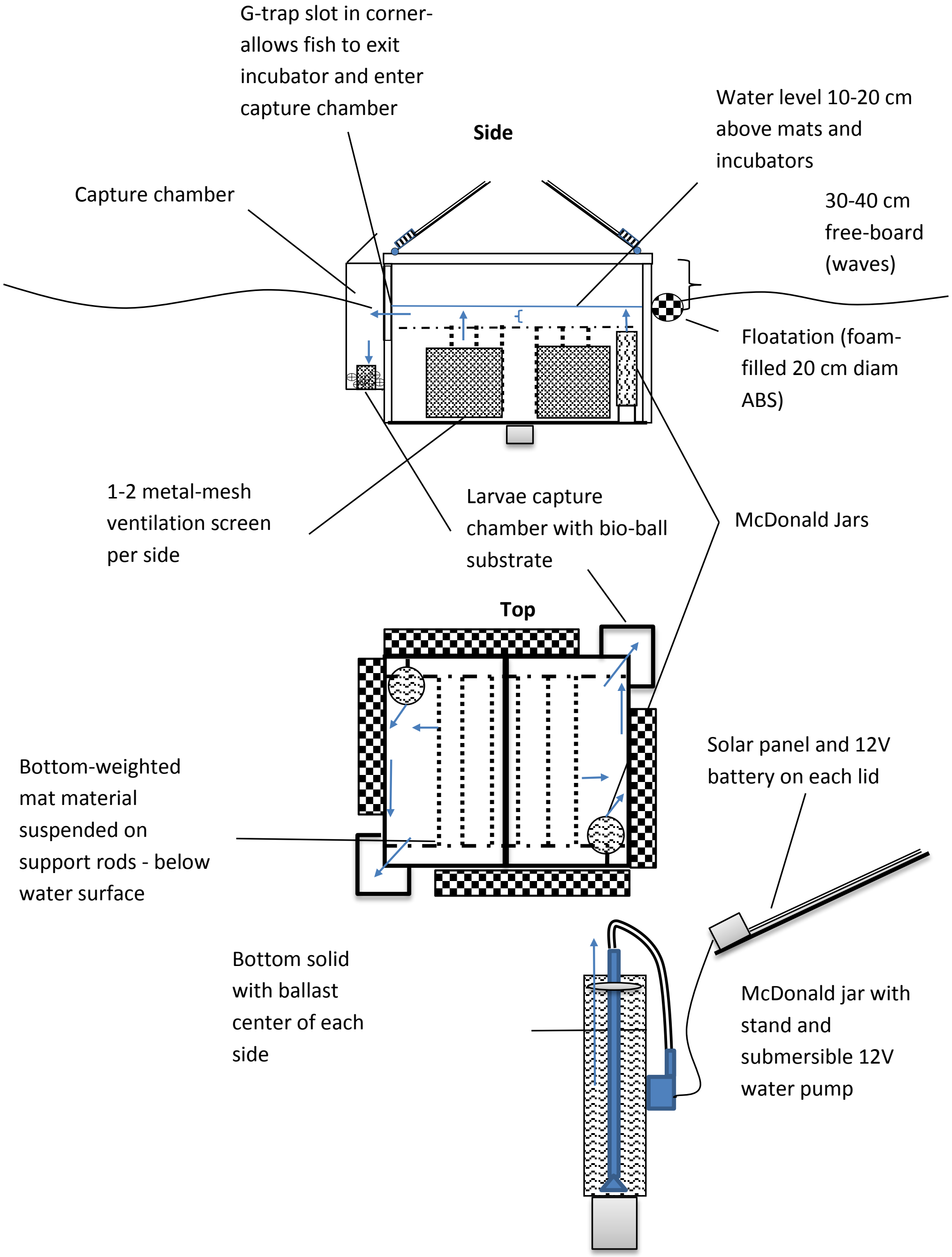

Figure 26: Design of the in situ incubator proposed for deployment during the 2015 White Sturgeon evaluation of existing spawning study component. Blue arrows indicate expected movement of free-embryos after hatch.

Assumptions: Objective 4 Task 1 Evaluation of Existing Spawning Use (2015)

Key assumptions of our proposed approach are:

1. Grant PUD will provide all egg mats frames, mat material, rope, floats, and mooring systems.
2. Golder and BLE will conduct sampling under the 2015 Grant PUD state and federal fish collection and transfer permits, applied for annually by Grant PUD.
3. Grant PUD will confirm with hatchery staff that the MDH is prepared and willing to receive wild-spawned larvae.
4. White Sturgeon larvae successfully incubated in the in-situ incubator will be transferred by Golder to MDH by mid-July.

Assets Allocated to this Task: Objective 4 Task 1 Evaluation of Existing Spawning Use (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	759	Sturgeon research boat Field computer *in situ* incubator DOT Truck	Egg collection mats Rope, cable, anchors, floats, hardware Coordinate larvae transfers with hatchery

Schedule: Late June to early July, 2015.

Objective 4 Task 2 – Hatchery White Sturgeon Growth, Survival, and Stocking Rate Adjustment (2015)

Golder has access to and is familiar with the White Sturgeon population modeling spreadsheet program developed for the Project. Larry Hildebrand was the principal developer of the Project WSMP and is familiar with the White Sturgeon population model. This model was used to establish the original stocking targets for the WSMP and Larry Hildebrand has demonstrated how the model works and explained the strengths and limitations of the model to the PRFF on several occasions.

The Project objectives and studies outlined in the WSMP are based upon an adaptive management approach and as such, are expected to require revisions to the study program based on data obtained from the monitoring programs. Recent data from the Upper Columbia River White Sturgeon Recovery Initiative program has suggested that first-survival rate of year-1 hatchery juveniles may be substantially higher than the initial rate on which stocking models were based (e.g., 80% vs 27% survival of the year-1 release; James Crossman, BC Hydro, TWG meeting, Oct 18, 2014, personal communication). Within the Project area, preliminary data collected since the first juvenile release of 2010BY fish in 2011 suggested that year-1 survival rate is likely low, but that survival may be highly dependent on release location. Stocking rates can also be influenced by other factors, such as long-term economic and cultural objectives.

Golder will continue to update the model with new data as it becomes available and accepted by the PRFF, to assist in the evaluation of stocking rates and help illustrate how adjustments in the stocking rates may affect recovery targets. Any changes to the stocking rate will require review and approval by the PRFF. As these potential changes cannot be predicted in advance, this task has been identified to provide professional advice and opinion as required by Grant PUD and the members of the PRFF. In this role, Golder's services may take the form of one or more of the following:

- attendance at PRFF or other meetings;
- opinion or advice related to the implementation of the WSMP or questions raised by the PRFF;
- general correspondence and preparation of memorandums;
- review and interpretation of new genetic information; and,
- provide advice related to sturgeon culture issues.

However, should a major revision of the model be required, a change in scope and budget would be required to recompile the model.

Assumptions: Objective 4 Task 2 – Hatchery White Sturgeon Growth, Survival, and Stocking Rate Adjustment (2015)

Key assumptions of our proposed approach are:

1. Model parameters are currently valid and based on the best available data.
2. The inclusion of new empirical data in the model will be based on study findings; any changes to stocking rates that are suggested by the revised model output will require approval from the PRFF and this may involve the development of supporting documentation or the preparation of "white papers." If this requires in-person attendance at additional meetings beyond the one in-person per year already budgeted in Objective 1 Task 2, then a change order will be required.
3. Major model revisions are beyond the contract work scope, but can be provided upon receipt of an approved change order and revised work scope.

Assets Allocated to this Task: Objective 4 Task 2 – Hatchery White Sturgeon Growth, Survival, and Suggest Adjustment to Stocking Rates (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	Grant PUD Provided Equipment and Support
2015	12	n/a	n/a

Schedule: Services provided in conjunction with PRFF meetings.

Objective 4 Task 3 –Database Management and Development Requirements (2015)

Golder will modify and update its existing field and office White Sturgeon databases to meet specific 2015 data collection obligations for adult White Sturgeon capture, juvenile release tracking, and acoustic telemetry tracking. All indexing databases allow field entry of the following variables:

1. Annual stocking data (fish lengths, weights, deformities, scute marks, PIT tag number).
2. Annual index monitoring results (lengths, weights, deformities, capture location, scute marks, PIT or sonic tag number).
3. Annual results obtained from tracking actively tagged juveniles (location records).

In addition to being a repository for the data collected under this Project, the database system will be used to provide data for specific reports to assist with provision of quarterly and annual data summaries, fish movement summaries, and allow upload of release and capture data to external databases (e.g., PTAGIS).

Assumptions: Objective 4 Task 3 –Database Management and Development Requirements (2015)

Key assumptions of our proposed approach are:

1. LGL and BLE staff will collect and provide Golder with tagging, processing, and release data for each White Sturgeon juvenile brood-year raised in the MDH and released into the Project area.
2. Golder will continue to serve as a PTAGIS coordinator for Grant PUD and upload White Sturgeon PIT-tag data to PTAGIS.
3. Grant PUD owns all data collected during the study, but the database structure, design, and VBA QA/QC and error trapping code are propriety to Golder.

Assets Allocated to this Task: Objective 4 Task 3 –Database Management and Development Requirements (2015)

Study Year	**Total Effort (hr)**	**Consultant Provided Equipment**	**Grant PUD Provided Equipment and Support**
2015	40	Field laptop Digital Entry device	n/a

Schedule: As required throughout each study year.

Objective 4 Task 4 –Annual WSMP Report (2015)

To facilitate effective management of data from the monitoring programs and support the requirements of the PRFF, annual technical reports will be prepared in 2015. The technical reports will:

- describe the methods used to address the statement of work;
- provide tabular and/or graphical summaries (as appropriate) of the data collected and briefly describe the results of field investigations;
- discuss key findings of the investigations; and,
- provide the proposed study program for the following year.

The report format will follow the existing Grant PUD reporting template. We will also provide Grant PUD with data necessary to comply with Federal and State sampling permits.

Assumptions: Objective 4 Task 4 Annual WSMP Report (2015)

Key assumptions of our proposed approach are:

1. Deliverable date for the annual technical reports will be January 30 following the study year, with the final report deliverable pending timely receipt of client comments.

Assets Allocated to this Task: Objective 4 Task 4 Annual WSMP Report (2015)

Study Year	Total Effort (hr)	Consultant Provided Equipment	GRANT PUD Provided Equipment and Support
2015	168	Word processing Data analysis GIS	n/a

Schedule: Draft technical annual report delivered by January 30 the following calendar year.

CLOSURE

We trust that the information in the 2015 WSMP Study Plan and Schedule meets your current requirements. If you have any questions or require clarification, please do not hesitate to contact the Brian Mattax or Paul Grutter.

REFERENCES

Beer, K.E. 1981. Embryonic and larval development of white sturgeon (Acipenser transmontanus). Unpublished Master's Thesis, University of California, Davis, CA. 93pp.)

Golder Associates Ltd. (Golder). 2003. White sturgeon investigations in Priest Rapids and the Wanapum reservoirs on the Middle Columbia River, Washington, U.S.A. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 002-8817F: 82pp. + 5 app.

Golder. 2011. White sturgeon monitoring and evaluation program annual report 2010. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0300: 42pp. + 7 app.

Golder. 2013. White sturgeon monitoring and evaluation program annual report 2012. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0302: 67pp. + 6 app.

Golder. 2014. White sturgeon management plan annual data report 2013. Report prepared for Public Utility District No. 2 of Grant County, Ephrata, Washington. Golder Associates Ltd. Report No. 10-3930-0303: 25pp. + 5 app.

Parsley, M.J., D.M. Gadomski, and P. Kofoot. 2004. White sturgeon mitigation and restoration in the Columbia and Snake rivers upstream from Bonneville Dam: Annual Progress Report. U.S. Geological Survey, Western Fisheries Research Center. Report C: 10pp.

Wang, Y.L., F.P. Binkowski, and S.I. Doroshov. 1985. Effect of temperature on early development of white and lake sturgeon, Acipenser transmontanus and A. fulvescens. Environmental Biology of Fishes 14:43-50.

Appendix E
WDOE Letter Approving the 2014 White Sturgeon Management Plan Annual Report

Appendix F
Summary of PRFF Comments on Draft 2014 WSMP Annual Report and Grant PUD Response

Summary of PRFF Comments on 2014 WSMP Annual Report and 2015 WSMP Annual Work Plan and Grant PUD Responses

Submitting Entity	Date Received	Paragraph	Agency Comment	Grant PUD Response

Priest Rapids Hydroelectric Project (P-2114)

AQUATIC INVASIVE SPECIES CONTROL AND PREVENTION PLAN: 2014 ANNUAL REPORT

License Article 401(a)(22)

By Carson Keeler

Public Utility District No. 2 of Grant County, Washington
Priest Rapids Hydroelectric Project
FERC Project No. 2114

February 2015

Executive Summary

The Aquatic Invasive Species Control and Prevention Program (AISP Program) activities for 2014 were conducted in accordance with the management plan titled, *Aquatic Invasive Species Control and Prevention Plan* (AISP; Grant PUD 2010). The AISP was developed by the Public Utility District No. 2 of Grant County, Washington (Grant PUD) in consultation with the Priest Rapids Fish Forum (PRFF), the Washington Department of Ecology's (WDOE's) Freshwater Aquatic Weed Control Program, the Washington Department of Fish and Wildlife's (WDFW's) Aquatic Invasive Species Program, and in accordance with Section 6.6.4 of the WDOE 401 Water Quality Certification (WQC; WDOE 2007) and License Article 401(a)(22) of the Federal Energy Regulatory Commission's (FERC's) license for operation of the Priest Rapids Hydroelectric Project (Project; FERC 2008). The AISP was submitted to FERC on March 3, 2010 and approved by FERC on July 7, 2010.

Key components of the AISP include education and monitoring that are designed to help manage, regulate, and potentially prevent introduction and/or spread of existing/new aquatic invasive species (AIS) within the Project.

During 2014, the Wanapum Reservoir was drawn down more than 20 feet below its normal minimum operating level (and up to 26 feet below its normal operating levels) for repairs to be made to the spillway sections of Wanapum Dam (a fracture was discovered in February of 2014 and the reservoir behind Wanapum Dam was lowered to prevent further damage). Furthermore, due to the fracture and associated drawdown, the entire Wanapum Reservoir was closed to the public, including all boat launches and recreation sites, for safety and cultural protection reasons. This unanticipated drawdown stranded a number of relatively immobile benthic organisms, including freshwater mussels, snails, fishes, and other organisms. In response, Grant PUD initiated land- and water-based surveys to characterize benthic communities potentially affected by the water-level reduction in the Wanapum Reservoir. This incident provided a unique opportunity to preform surveys in areas previously underwater within the Wanapum Reservoir, to estimate species composition and densities of stranded freshwater mollusks (mussels, clams, and snails) and to search for any potential AIS species of concern. Included in these survey efforts was the potential to find AIS, including zebra/quagga mussels, and New Zealand mud snails. Twelve taxa of snails and seven species of bivalve, including three native freshwater mussels and one non-native clam were found in the Wanapum Reservoir. No AIS species were encountered. Additionally, because of the drawdown conditions in Wanapum Reservoir, some of the educational and monitoring components of the AISP Program were limited to the Priest Rapids Reservoir of the Project. For instance, boater surveys/self-surveys were conducted solely within the Priest Rapids Reservoir and exclusively at the Priest Rapids Recreational Area (PRRA or Desert Aire) boat launch. Additionally, boat launch transect monitoring were only conducted within the Priest Rapids Reservoir at the Lower Wanapum, Huntzinger (new for 2014), Buckshot, and the PRRA/Desert Aire boat launches. Not only was the Wanapum Reservoir closed for a majority of 2014 to recreational activities, but any boat launch transect monitoring would not have been consistent with past and/or future monitoring results and thus not representative of "normal" water levels and aquatic plant presence/absence.

Educational activities for 2014 included placement of outreach materials and signage at four Project boat launches, placement of outreach material at major recreational outlet stores, a poster presentation and outreach material distributed at Grant PUD's Archaeology Days, and conducting voluntary boater surveys at the PRRA boat launch during high-use periods.

Boater surveys/self-surveys were conducted on a total of forty-nine boats. Cities of residence were varied throughout and included Mattawa/Desert Aire (seven instances), Yakima (four instances), Kirkland, Renton, Auburn, Seattle, Monroe, Ellensburg, and Royal City (two instances each), with all other cities as single occurrences. Waterbodies noted as having "been there" or "going there" during survey efforts included Lake Roosevelt (five times), Lake Washington and the Columbia River (six times), Moses Lake, Potholes Reservoir and Banks Lake (three times), Klickitat River, Puget Sound and the Snake River (two times), with all other waterbodies noted once. No interviewees were noted as having AIS present on their vessel and/or trailer.

Monitoring activities during 2014 consisted of zebra/quagga mussel sampling (Project-wide), and invasive aquatic plant surveys along with passive-monitoring of riparian/wetland invasive plants conducted at Priest Rapids Reservoir boat launches.

Results from the monitoring efforts in 2014 reported no zebra/quagga mussel veliger identified in any samples and no presence of zebra/quagga mussels or other macroinvertebrate AIS including New Zealand mudsnail (NZMS) on any artificial substrates within the Project. Eurasian milfoil was present at all but one of the boat launches surveyed in 2014. Lower Wanapum did not have any submergent vegetation, which is consistent with previous survey results. However, Eurasian milfoil was rarely dominant (at only one transect point at the Huntzinger boat launch) and boat launches were generally dominated by native species. Curlyleaf pondweed was present at two of the four boat launches (Huntzinger and PRRA) and was never dominant. Native species observed at boat launch transects typically included the following species, which were not recorded on a point-specific basis: coontail (*Ceratophyllum demersum*), common waterweeds (*Elodea* spp.), and native pondweed species (*Potamogeton* spp.). Transect results from 2014 are generally consistent with data gathered in 2013. Eurasian milfoil had a similar distribution as in 2013, with presence at the same launches (of those surveyed in 2014) and rarely exhibiting dominance. Curlyleaf pondweed was observed somewhat less in 2014 than this species had been in previous years. For example, it was not observed at the Buckshot boat launch in 2014, as it had been in previous years and, though present at PRRA, it did not exhibit dominance in 2014 as it had in prior years. As with prior years, native species remain dominant at most transect points at most boat launches. In 2014, native species were dominant at all transect points that had vegetation except one, which occurred at Huntzinger and was dominated by Eurasian milfoil.

Local and regional coordination activities in 2014 involved participation in the Columbia River Basin Team (CRBT) meeting and hosting Grant PUD's Annual Aquatic Invasive Species meeting.

The annual AIS meeting was held on April 24, 2014. Two small modifications were deemed necessary by Grant PUD and the stakeholders because of the drawdown of Wanapum Reservoir throughout the recreational season. One change was to move all boater survey efforts to the Priest Rapids Reservoir (preformed at the PRRA/Desert Aire boat launch), while the second change was to the aquatic vegetation boat launch surveys in the Wanapum Reservoir. Since the drawdown in 2014 continued to leave the Wanapum Reservoir boat launches void of water, aquatic vegetation surveys were not be feasible during the 2014 implementation season. These issues were both agreed upon by the stakeholder group. With these slight changes, Grant PUD continued implementation in 2014 in accordance with the AISP that was approved by FERC on July 7, 2010.

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Terms and Abbreviations

AIS	Aquatic Invasive Species
AISP	Aquatic Invasive Species Control and Prevention Plan
AISP Program	Aquatic Invasive Species Control and Prevention Plan Program
CDFG	California Department of Fish and Game
CRBT	Columbia River Basin Team
FERC	Federal Energy Regulatory Committee
Grant PUD	Public Utility District No. 2 of Grant County, Washington
GeoEngineers	GeoEngineers, Inc.
GIS	Geographic Information Systems
GPS	Global Positioning System
license	FERC license
NZMS	New Zealand Mudsnail
OHWM	Ordinary High Water Mark
PRFB	Priest Rapids Fish Bypass
PRFF	Priest Rapids Fish Forum
PRRA	Priest Rapids Recreation Area
Project	Priest Rapids Hydroelectric Project
RM	River Mile
USFWS	United States Fish and Wildlife Service
VMP	Vegetation Management Plan
WFB	Wanapum Fish Bypass
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WQC	Water Quality Certification

1.0 Introduction

The Public Utility District No. 2 of Grant County, Washington (Grant PUD) owns and operates the Priest Rapids Hydroelectric Project (Project), located along the mid-Columbia River in central Washington State. The Project is authorized by the Federal Energy Regulatory Commission (FERC) under Project No. 2114[1] and includes the Wanapum and Priest Rapids developments. A 401 Water Quality Certification (WQC) for the operation of the Project was issued by the Washington Department of Ecology (WDOE) on April 3, 2007and amended on March 6, 2008 (WDOE 2007). The 401 WQC's terms and conditions were directly incorporated into the FERC license (license) to operate the Project issued on April 17, 2008 (FERC 2008).

The Aquatic Invasive Species Control and Prevention Program (AISP Program) activities for 2014 were conducted in accordance with the management plan titled, *Aquatic Invasive Species Control and Prevention Plan* (AISP; Grant PUD 2010). The AISP was developed by Grant PUD in consultation with the Priest Rapids Fish Forum (PRFF), the WDOE's Freshwater Aquatic Weed Control Program, the Washington Department of Fish and Wildlife's (WDFW's) Aquatic Invasive Species Program, and in accordance with Section 6.6.4 of the 401 WQC (WDOE 2007) and Article 401(a)(22) of the license (FERC 2008). The AISP was submitted to FERC on March 3, 2010 and approved by FERC on July 7, 2010.

During 2014, the Wanapum Reservoir was drawn down more than 20 feet below its normal minimum operating level (and up to 26 feet below its normal operating level) for repairs to be made to the spillway sections of Wanapum Dam (a fracture was discovered in February of 2014 and the reservoir behind Wanapum Dam was lowered to prevent further damage). This unanticipated drawdown stranded a number of relatively immobile benthic organisms, including freshwater mussels, snails, fishes, and other organisms. In response, Grant PUD initiated land- and water-based surveys to characterize benthic communities potentially affected by the water-level reduction in the Wanapum Reservoir. This incident provided a unique opportunity to preform surveys in areas previously underwater within the Wanapum Reservoir, to estimate species composition and densities of stranded freshwater mollusks (mussels, clams, and snails) and to search for any potential AIS species of concern. Included in these survey efforts was the potential to find AIS, including zebra/quagga mussels, and New Zealand mud snails. Twelve taxa of snails and seven species of bivalve, including three native freshwater mussels and one non-native clam were found in the Wanapum Reservoir. No AIS species were encountered. Additionally, because of the drawdown conditions of Wanapum Reservoir, some educational and monitoring components of the AISP Program were limited to the Priest Rapids Reservoir of the Project. For instance, boater surveys/self-surveys was conducted solely within the Priest Rapids Reservoir and almost exclusively at the Priest Rapids Recreational Area (PRRA or Desert Aire boat launch). Additionally, boat launch transect monitoring was only conducted within the Priest Rapids Reservoir at the Lower Wanapum, Huntzinger (new for 2014), Buckshot, and PRRA boat launches. Not only was the Wanapum Reservoir closed for a majority of 2014 to recreational activities, any boat launch transect monitoring would not have been consistent with past and/or future monitoring results and thus not representative of "normal" water levels and aquatic plant presence/absence.

This annual report summarizes activities conducted in implementation year 2014 under the AISP Program.

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[1] 123FERC¶61,049

1.1 Objectives

As identified in the AISP, the primary objective is to address methods to monitor and manage aquatic invasive flora and fauna in the Project. Key components of the AISP include education and monitoring that are designed to help manage, regulate, and potentially prevent introduction and/or spread of new/existing aquatic invasive species (AIS) within the Project.

1.2 Priest Rapids Hydroelectric Project Description

The downstream boundary of the Project is located approximately three miles below Priest Rapids Dam (river mile [RM] 397.1) and extends upriver to the Rock Island Dam tailrace at RM 453.5 (Figure 1).

The Priest Rapids development consists of a 7,725-acre reservoir and a 10,103-foot-long by 179.5-foot-high dam spanning the Columbia River. The dam consists of left and right embankment sections; left and right concrete gravity dam sections; a left and right fish passage structure, each with an upstream fish ladder; a gated spillway section; a downstream fish passage structure (the Priest Rapids Fish Bypass (PRFB)); and a powerhouse containing ten vertical shaft integrated Kaplan turbine/generator sets with a total authorized installed capacity (best gate) of 675 MW (Figure 2).

The Wanapum development consists of a 14,680-acre reservoir and an 8,637-foot-long by 186.5-foot-high dam spanning the Columbia River. The dam consists of left and right embankment sections; left and right concrete gravity dam sections; a left and right fish passage structure, each with an upstream fish ladder; a gated spillway; a downstream fish passage structure (the Wanapum Fish Bypass (WFB)); and a powerhouse containing ten vertical shaft integrated Kaplan turbine/generator sets with a total authorized installed capacity (best gate) of 735 MW (Figure 3).

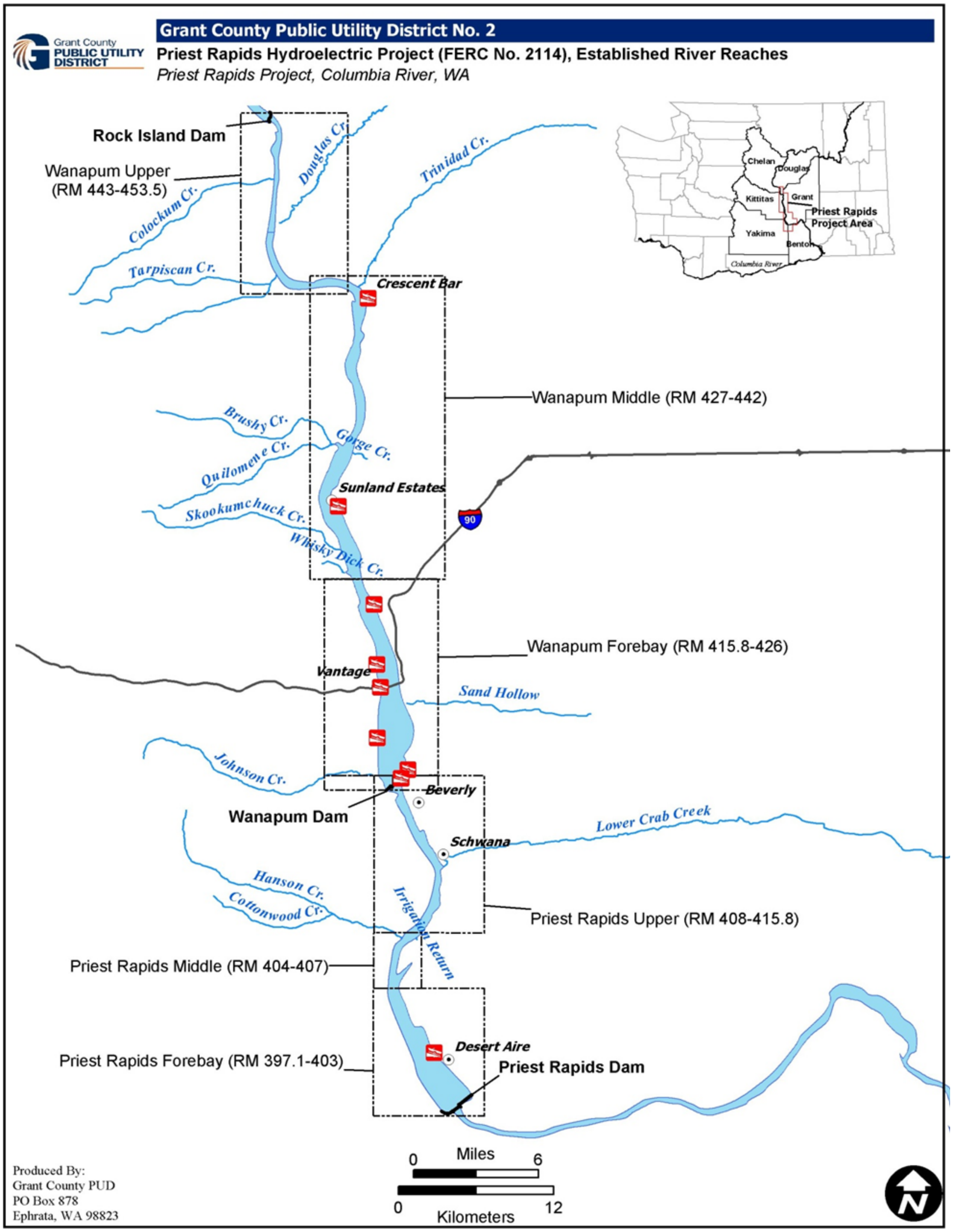


Figure 1 The Priest Rapids Hydroelectric Project and established river reaches presented by river mile (RM), mid-Columbia River, WA.

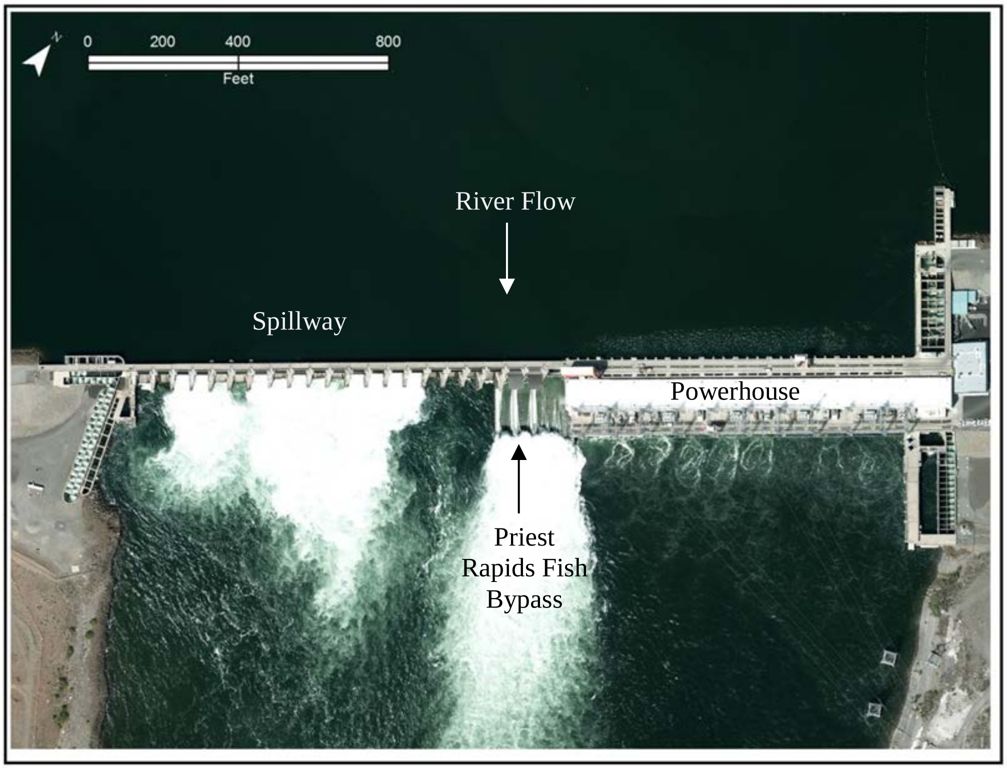


Figure 2 **Aerial photograph of Priest Rapids Dam, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.**

Figure 3 **Aerial photograph of Wanapum Dam, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.**

2.0 Activities

The following sections provide a summary of the activities conducted in 2014 for the AISP, which included elements of education, monitoring, and local and regional coordination. Each of these activities is discussed below in more detail.

2.1 Education

The educational activities implemented as part of the AISP for 2014 included placement of outreach materials and educational signage at four Project boat launches, placement of outreach material at major recreational outlet stores, a poster presentation and outreach materials distributed at Grant PUD's Archaeology Days, and voluntary boater surveys. These educational activities are discussed in the following sections.

2.1.1 Outreach Material and Educational Signage

Four Project boat launches were supplied with outreach materials and educational signage prior to the Memorial Day holiday (May 24, 2014). As stated above (see Section 1.0), the Wanapum Reservoir was operated at a drawndown level during the 2014 recreational season. Therefore all Project boat launches within the Wanapum Reservoir were closed to the public and thus not supplied with outreach materials. Supplied boat launches were solely located within the Priest Rapids Reservoir and consisted of the Lower Wanapum, Huntzinger (new for 2014), Buckshot, and Desert Aire (Priest Rapids Recreation Area (PRRA)) on the Priest Rapids Reservoir. Outreach materials consisted of the 100th Meridian Initiative's *Zap the Zebra* brochure (100th Meridian Initiative 2011; Appendix A) and boater self-survey forms (100th Meridian Initiative 2011a; Appendix B). Educational signage was comprised of the WDFW's AIS poster (WDFW 2011; Appendix D) and the WDOE advisory poster for Eurasian watermilfoil (WDOE 2011; Appendix E) (see Figure 4).

Additionally, prior to May 1, recreational outlet stores and/or businesses were supplied with outreach material (in the form of the *Zap the Zebra* brochure) for distribution, which included the Wal-Mart® sporting goods sections in Ephrata and Moses Lake, Washington, Tri-State Outfitters in Moses Lake, Washington, Big Wally's near Banks Lake, MarDon Resort on the Potholes Reservoir, and Pollywog's in Desert Aire, Washington. Furthermore, outreach materials were distributed (in the form of the *Zap the Zebra* brochure, WDFW's *Stop Aquatic Invasive Species* float keychain, and the United States Fish and Wildlife Service's (USFWS's) *Stop Aquatic Hitchhikers!* stickers) and an AIS poster (titled "*AIS in the Priest Rapids Hydroelectric Project;*" Appendix F) were presented at Grant PUD's annual Archaeology Days.

It is important to note that all Grant PUD Project boat launches, including newly developed launches that are in the process of being updated and/or constructed, will be outfitted with kiosks that will contain information about boater safety, boater regulations, recreational opportunities, wildlife, and AIS in the Project. All Project boat launches during 2014 consisted of the configuration of outreach materials and educational signage as the example displayed in Figure 4 below.

Figure 4 Outreach materials and educational signage configuration at the Upper Wanapum boat launch, Wanapum Reservoir, Priest Rapids Hydroelectric Project, mid-Columbia River ,WA.

2.1.2 Voluntary Boater Surveys

Because of the closure of boat launches on the Wanapum Reservoir during the 2014 recreational season, all voluntary boater surveys were conducted at the PRRA (Desert Aire) boat launch. All voluntary boater surveys were conducted using the 100th Meridian Institute's boater survey form (100th Meridian Initiative 2011c; Appendix C). The surveys were conducted during the Memorial Day holiday weekend, the 4th of July holiday weekend, and on the Labor Day holiday weekend. According to previously conducted vehicle count surveys (Harshman 2011), a majority of the boats launched at Project boat launches occurred between the hours of 0900hrs to 1400hrs, therefore the voluntary boater surveys were generally conducted during this timeframe (~3-6hrs each day). Results from these surveys are presented in Section 3.3 below.

2.2 Monitoring

The monitoring activities implemented as part of the AISP for 2014 included zebra/quagga mussel sampling and aquatic plant surveys at each Project boat launch. Descriptions of the monitoring activities applied during 2014 are presented in the following sections.

2.2.1 Zebra/Quagga Mussel

Zebra/quagga mussels were monitored throughout the Project by use of a plankton tow net and deployment of artificial substrates (only in the Priest Rapids Reservoir during 2014 because of the drawdown conditions of Wanapum Reservoir). Zebra/Quagga mussel and other potential AIS species were also surveyed along exposed shorelines and in-river during the drawdown period. Each of these monitoring methods is covered in the following sections.

2.2.1.1 Plankton Tow Net

Horizontal and vertical plankton tow net samples were collected at six locations throughout the Project. Samples were collected at Crescent Bar (RM 440.5), Sunland Estates (RM 426.0), Wanapum forebay (RM 417.0), Crab Creek (RM 412), Lake Geneva (RM 407.0), and Priest Rapids forebay (RM 399.0). Samples were collected three times throughout the monitoring season (once in July, August, and September respectively).

Sample methods included the use of a Wisconsin plankton net (363µ mesh net) that was drifted for a distance of 40-100 ft. at a depth of approximately 20 ft. for each location. The plankton tow net was thoroughly rinsed and all sample materials were transferred to a 250 ml Teflon bottle and preserved with 70 % isopropyl alcohol. A label was affixed to the sample bottle and appropriately filled out. Methods for collecting vertical tow samples were almost identical to the horizontal tow sampling method as described above, except that samples were taken from one meter above the bottom of the river up through the entire water column without drifting. The sampling procedures followed protocols developed by WDFW (Pamela Meacham, WDFW, pers. com and Jesse Shultz, WDFW, pers. com).

After collection, the samples were cataloged and shipped to Cameron Lange, a Senior Environmental Scientist located in the Great Lakes region of the United States whom is familiar with the identification of zebra/quagga mussel veliger, for analysis. Results and more information of these analyses are presented in Section 3.1.1 and Appendix G.

2.2.1.2 Artificial Substrates

An additional monitoring technique implemented during 2014, and in order to monitor for zebra and quagga mussels near areas with high boat traffic, Grant PUD deployed artificial substrates at some high-traffic Project boat launch areas. Boat launches selected for substrate deployment included only the PRRA (Desert Aire) in the Priest Rapids Reservoir due to the drawdown conditions of Wanapum Reservoir. Grant PUD followed the artificial substrate monitoring protocols as established by the California Department of Fish and Game (CDFG 2008) and provided by the WDFW (Jesse Shultz, WDFW, pers com). A single substrate was deployed at the PRRA boat launch. The substrates were kept at least one meter above the bottom of the river and were examined on the same schedule as the plankton tow net samples. Results from the artificial substrate monitoring are presented in Section 3.1.2.

2.2.1.3 Benthic Fauna Surveys

The unanticipated drawdown of Wanapum Reservoir stranded a number of relatively immobile benthic organisms, including freshwater mussels, snails, fishes, and other organisms. In response, Grant PUD initiated land- and water-based surveys to characterize benthic communities potentially affected by the water-level reduction in the Wanapum Reservoir. This incident provided a unique opportunity to preform surveys in areas previously underwater within the Wanapum Reservoir, to estimate species composition and densities of stranded freshwater mollusks (mussels, clams, and snails) and to search for any potential AIS species of concern. Included in these survey efforts was the potential to find AIS, including zebra/quagga mussels, and New Zealand mud snails. Results from these surveys are presented in Section 3.1.3.

2.2.2 Aquatic Vegetation Surveys

Grant PUD contracted GeoEngineers, Inc. (GeoEngineers) to perform aquatic vegetation boat launch surveys during 2014. Aquatic vegetation surveys conducted in 2014 focused on assessing aquatic plant distribution and species composition at four of the ten Project boat launches (all boat launches in the Wanapum Reservoir were not surveyed due to the drawdown conditions of Wanapum Reservoir). Aquatic plant assessment transect locations were established in 2011 at each Project boat launch (Keeler 2012). For 2014, the Huntzinger boat launch, which was newly constructed, was added to the existing database.

For the 2014 aquatic vegetation surveys, geospatial data layers were compiled into a geodatabase, which included: the Project boundary, aerial imagery, bathymetric data, road information, Project boat launch locations, and survey results from past field efforts, including the transects that were established at each boat launch. This geodatabase was uploaded on to a field computer running geographic information systems (GIS) and mobile Global Positioning System (GPS) and taken in the field to perform the surveys for the 2014 effort. Field surveys were completed on August 12, 2014. Methods used to complete these surveys are discussed below.

2.2.2.1 Boat Launch Transect Survey Methods

The boat launch transect survey methodology generally followed the protocols described in the AISP (Grant PUD 2010). The AISP (Grant PUD 2010) states that boat launch surveys will:

> *"…be conducted by traveling three 50-meter transects out from the boat launch, or until visual contact with the macrophytes is lost. The first transect will be 30m upstream of the launch, the second will be even with the middle of the launch, and the third transect will be 30 meters downstream of the launch."*

In practice, transect configurations were adapted to local conditions based on the presence of adjacent shorelines, jetties, and/or other structures.

Boat-based field surveys were conducted using a small field crew consisting of three biologists travelling in a sixteen-foot motorized vessel. A field computer running GIS and mobile GPS software loaded with boat launch transect locations were used to record data along each transect. Aquatic vegetation sampling was conducted either visually or by the use of a sampling rake to depict samples from regularly spaced data points along each transect. At each of the sample locations, a GPS point with associated aquatic plant presence/absence and species composition data were recorded using the mobile GPS device. Rake samples were also examined for presence of potential macroinvertebrate AIS including quagga /zebra mussels and/or New Zealand mudsnails.

During the 2014 surveys, aquatic vegetation presence was recorded at each transect point as follows:

- Dominant species at each point were recorded as Eurasian milfoil, curlyleaf pondweed, native species, or no vegetation.
- Secondary and tertiary co-dominant species, if present, were also recorded (Eurasian milfoil, curlyleaf pondweed, and/or native species).

Results for the 2014 aquatic vegetation surveys are discussed in Section 3.2 and displayed in Figures I-1 through I-4 in Appendix I of this annual report.

2.3 Local and Regional Coordination

Local and regional coordination activities implemented as part of the AISP for 2014 included participation in the Columbia River Basin Team (CRBT) meeting and hosting Grant PUD’s Annual Aquatic Invasive Species meeting. A summary of each activity are presented in the following sections.

2.3.1 Columbia River Basin Team Meeting

Grant PUD attended and participated in the CRBT meeting held in Spokane, Washington on May 13-14, 2014. Meeting minutes are made available at the 100th meridian initiative website at: http://www.100thmeridian.org/Columbia_RBT.asp.

2.3.2 Annual Aquatic Invasive Species Meeting

On April 24, 2014 and in accordance with the AISP, Grant PUD hosted the annual AIS meeting at the Phase II Maintanence Center Building, conference room 123. Per the AISP, the purposes of this meeting is to discuss the upcoming monitoring and educational season, any needed/warranted changes to AIS education, monitoring, and/or control methods or other changes to the AISP based on results from the previous year, new technologies, new AIS threats and/or introductions, new AIS pathways, etc. A PowerPoint was presented by Grant PUD on the results from the 2013 season and the planned efforts for 2014. Two small changes were deemed necessary by Grant PUD and the stakeholders because of the drawdown of Wanapum Reservoir through the recreational season. One change was to move all boater survey efforts to the Priest Rapids Reservoir (i.e. PRRA/Desert Aire), while the second change was to the aquatic vegetation boat launch surveys in the Wanapum Reservoir. The next meeting was scheduled for spring 2015 after the implementation of the 2014 monitoring and educational season.

3.0 Results

The following sections provide results from the activities conducted as part of the AISP in 2014, which includes outcomes from the zebra/quagga mussel sampling (both plankton tows and artificial substrate), boat launch transect surveys, and the voluntary boater surveys.

3.1 Zebra/Quagga Mussel Monitoring

As stated above in Section 2.2.1, zebra/quagga mussels were monitored by use of plankton tow nets and artificial substrates throughout the Project. Results from each method are discussed in the following sections.

3.1.1 Plankton Tow Net Results

A total of 18 samples were collected from July – September, cataloged, and sent to Cameron Lange, a Senior Environmental Scientist located in the Great Lakes region of the United States whom is familiar with the identification of zebra/quagga mussel veliger and is recognized as an expert by WDFW (Jesse Shultz, WDFW, pers com), for analysis. The 18 samples were analyzed using standardized techniques that are accepted for zebra mussel analyses. These techniques included the use of a dissecting style microscope fitted with polarizing filters used to examine the samples under 40x-120x magnification. Since zebra mussels have not previously been found at the sample locations within the Project, the entire settled contents of each sample were examined. If samples contained a lot of phytoplankton or plankton, they were prescreened through a 425-micron mesh sieve (Lange 2014).

No zebra mussels were found in any of the samples analyzed. A copy of each analysis was sent via email to WDFW during the 2014 season. Appendix G of this annual report displays all results from samples analyzed during 2014.

3.1.2 Artificial Substrate Results

During the same timeframe as the plankton tow samples were collected (July - September), artificial substrates were checked for presence/absence of zebra/quagga mussels or other AIS macroinvertebrate. A standardize form were supplied by WDFW to check for presence/absence of mussels (WDFW 2010; Appendix H). No presences of zebra/quagga mussels on any other macroinvertebrate AIS during the 2014 season were detected. Results were cataloged and sent via email to WDFW.

3.1.3 Benthic Fauna Survey Results

Twelve taxa of snails and seven species of bivalve, including three native freshwater mussels and one non-native clam were found in the Wanapum Reservoir during the survey period. No AIS species were encountered during the surveys of the Wanapum Reservoir.

3.2 Aquatic Plant Survey Results

Results from the survey efforts put forth for mapping and tracking aquatic vegetation along three transects at each Project boat launch are depicted in the following sections. Survey efforts during 2014 concentrated primarily on the boat launch transects that were recorded during previous survey efforts (Keeler 2012-2014).

3.2.1 Boat-Launch Transects

Figures I-1 through I-4 in Appendix I of this report illustrate results of aquatic vegetation mapping along three transects established at each Project boat launch, while Table 1 includes a summary of results for each boat launch (including past survey results), plus notes regarding presence of aquatic AIS and/or native species.

Table 1 Summary of Results for Boat Launch Transect Monitoring 2011-2014, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.

Year	Crescent Bar			Sunland Estates			Frenchman Coulee			Kittitas County			State Park			Upper Wanapum			Lower Wanapum			Huntzinger			Buckshot			PRRA		
	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS	EM	CP	NS
2011	X	X		X			X	X		X	X		X	X		X	X								X			X		
2012	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X							X	X	X	X	X	X
2013	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X							X	X	X	X	X	X
2014																						X	X	X	X		X	X	X	X

Notes:

1. EM = Eurasian milfoil; CP = curlyleaf pondweed; NS = native species.
2. Native species were not recorded in 2011.
3. The following boat launches were not surveyed in 2014 due to drawdown: Crescent Bar, Sunland Estates, Frenchman Coulee, Kittitas County, State Park and Upper Wanapum
4. Huntzinger boat launch was formally established between the 2013 and 2014 survey seasons and was therefore not sampled prior to 2014.

Each GPS point location along these transects represent a single sampling point where presence or absence of AIS or native species was recorded. Sampling focused primarily on AIS, but native species distribution and presence were additionally recorded at these locations. In some cases, transects were terminated early as a result of loss of contact with aquatic vegetation, which was often correlated with a water depth greater than twenty feet and therefore beyond the littoral zone where aquatic vegetation could survive. This is consistent with the protocol for these surveys outlined in the AISP (Grant PUD 2010).

Eurasian milfoil was present at all but one of the boat launches surveyed in 2014. Lower Wanapum did not have any submergent vegetation, which is consistent with previous survey results. However, Eurasian milfoil was rarely dominant (at only one transect point at the Huntzinger boat launch) and boat launches were generally dominated by native species. Curlyleaf pondweed was present at two of the four boat launches (Huntzinger and PRRA) and was never dominant. Native species observed at boat launch transects typically included the following species, which were not recorded on a point-specific basis: coontail (*Ceratophyllum demersum*), common waterweeds (*Elodea* spp.), and native pondweed species (*Potamogeton* spp.). Transect results from 2014 are generally consistent with data gathered in 2013. Eurasian milfoil had a similar distribution as in 2013, with presence at the same launches (of those surveyed in 2014) and rarely exhibiting dominance. Curlyleaf pondweed was observed somewhat less in 2014 than this species had been in previous years. For example, it was not observed at the Buckshot boat launch in 2014, as it had been in previous years and, though present at PRRA, it did not exhibit dominance in 2014 as it had in prior years. As with prior years, native species remain dominant at most transect points at most boat launches. In 2014, native species were dominant at all transect points that had vegetation except one, which occurred at Huntzinger and was dominated by Eurasian milfoil.

Differences in data results between sampling years are likely a result of a couple of different circumstances. These circumstances include differences in timing of survey efforts and annual variation in phenology of submergent vegetation. In 2014, the fourth year of data collection at boat launches since implementation of the AISP, surveys were intentionally scheduled within one week of the dates that 2013 surveys were completed (August 12, 2014, versus August 5, 2013) to reduce potential differences due to survey timing. Data results from 2014 and 2013 are very similar, more so than they have been in years prior (boat launch transect surveys were completed in October in 2011 and September in 2012). Nevertheless, some differences between years were observed. For example, at the PRRA boat launch, curlyleaf pondweed was less prevalent, which could be the result of the aquatic vegetation community at the PRRA boat launch still maturing since the boat launch was reconfigured and dredged in 2012, and vegetation has only had the opportunity to establish and mature for two seasons. However, there is no explanation or record of any changes/modifications to the boat launch at Buckshot that would explain the absence of curlyleaf pondweed there in 2014.

3.3 Boater Survey/Self-Survey Results

As stated in Section 2.2.1, voluntary boater surveys were all conducted at the PRRA boat launch on key recreational weekends (Memorial Day, 4th of July, and Labor Day) during 2014 because of the drawdown of Wanapum Reservoir. Self-survey forms were available at most boat launches during the recreational season.

A total of forty-nine boaters (forty-seven voluntary surveys and two self-surveys) were interviewed/surveyed during the voluntary/self-survey periods. Of the boaters interviewed/surveyed during the recreation season, all claimed the state of Washington as their home state. Cities of residence are noted in Table 2 from the boater surveys. The results where and even split for the 2014 survey season, with each side of the state being represented twenty-three times.

Table 2 Cities of Residence Noted from the Boater Survey conducted at the PRRA Boat Launch during major weekends, 2014, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.

Cities of Residence	No. of Occurrences
Mattawa/Desert Aire	7
Yakima	4
East Wenatchee	3
Kirkland, Renton, Auburn, Seattle, Monroe, Ellensburg, Royal City	2
Gig Harbor, Bellevue, Carnation, Enumclaw, Lynnwood, Kent, Woodinville, Sammamish, Bellingham, Marysville, Snohomish, Bremerton, Bonney Lake, Ephrata, Warden, Moxee, Selah and Pasco	1

Several other water bodies were noted as having “been there” or “going there” when asked during the interview or noted on the self-survey form. The waterbodies noted are included in Table 3 below including the number of occurrence of the waterbody.

Table 3 Waterbodies noted as having “been there” or “going there” from boater surveys, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.

Waterbody	No. of Occurrences
Lake Roosevelt	5
Lake Washington, Columbia River	4
Moses Lake, Potholes Reservoir, Banks Lake	3
Klickitat River, Puget Sound, Snake River	2
Lake Sammamish, American Lake, Crawfish Lake, Duck Lake, Lake Chelan, Lake Union, Rimrock Reservoir, Billy Clap Lake, Wind River, Duwamish Slough	1

4.0 Summary

In 2014, and in accordance with the AISP (Grant PUD 2010), Grant PUD conducted activities that included education, monitoring, local and regional coordination.

Educational activities for 2014 included placement of outreach materials and signage at four Project boat launches, placement of outreach material at major recreational outlet stores, a poster presentation and outreach material distributed at Grant PUD's Archaeology Days, and conducting voluntary boater surveys at the PRRA boat launch during high use periods.

Boater surveys/self-surveys were conducted on a total of forty-nine boats. Cities of residence were varied throughout and included Mattawa/Desert Aire (seven instances), Yakima (four instances), Kirkland, Renton, Auburn, Seattle, Monroe, Ellensburg, and Royal City (two instances each), with all other cities as single occurrences. Waterbodies noted as having "been there" or "going there" during survey efforts included Lake Roosevelt (five times), Lake Washington and the Columbia River (six times), Moses Lake, Potholes Reservoir and Banks Lake (three times), Klickitat River, Puget Sound and the Snake River (two times), with all other waterbodies noted once. No interviewees were noted as having AIS present on their vessel and/or trailer.

Monitoring activities during 2014 consisted of zebra/quagga mussel sampling/surveying, and invasive aquatic plant surveys along with passive-monitoring of riparian/wetland invasive plants conducted at Project boat launches.

Results from the monitoring efforts in 2014 reported no zebra/quagga mussel veliger identified in any samples and no presence of zebra/quagga mussels or other macroinvertebrate AIS including NZMS on any artificial substrates within the Project. Addtionally, during the benthic fauna surveys preformed within Wanapum Reservoir, no AIS species were found. Eurasian milfoil was present at all but one of the boat launches surveyed in 2014. Lower Wanapum did not have any submergent vegetation, which is consistent with previous survey results. However, Eurasian milfoil was rarely dominant (at only one transect point at the Huntzinger boat launch) and boat launches were generally dominated by native species. Curlyleaf pondweed was present at two of the four boat launches (Huntzinger and PRRA) and was never dominant. Native species observed at boat launch transects typically included the following species, which were not recorded on a point-specific basis: coontail (*Ceratophyllum demersum*), common waterweeds (*Elodea* spp.), and native pondweed species (*Potamogeton* spp.). Transect results from 2014 are generally consistent with data gathered in 2013. Eurasian milfoil had a similar distribution as in 2013, with presence at the same launches (of those surveyed in 2014) and rarely exhibiting dominance. Curlyleaf pondweed was observed somewhat less in 2014 than this species had been in previous years. For example, it was not observed at the Buckshot boat launch in 2014, as it had been in previous years and, though present at PRRA, it did not exhibit dominance in 2014 as it had in prior years. As with prior years, native species remain dominant at most transect points at most boat launches. In 2014, native species were dominant at all transect points that had vegetation except one, which occurred at Huntzinger and was dominated by Eurasian milfoil.

Local and regional coordination activities in 2014 consisted of participation in the CRBT meeting and hosting Grant PUD's Annual Aquatic Invasive Species meeting.

The annual AIS meeting will be held sometime mid-late April, 2015. Any modifications, changes, etc. will be noted in the final annual report submitted to FERC by June 1, 2015.

Literature Cited

100th Meridian Initiative. 2011a. *Zap the Zebra* Brochure. A partnership between the U.S. Fish and Wildlife Service and the University of Texas – Arlington. Accessed at http://www.100thmeridian.org/ZTZ2010.asp. March 2011.

100th Meridian Initiative. 2011b. Boater self-survey form. A partnership between the U.S. Fish and Wildlife Service and the University of Texas – Arlington. Accessed at http://www.100thmeridian.org/SurveyForms/SIF.pdf. March 2011.

100th Meridian Initiative. 2011c. Boater survey form. A partnership between the U.S. Fish and Wildlife Service and the University of Texas – Arlington. Accessed at http://www.100thmeridian.org/Documents/100MI_Survey_Form_2010.pdf. March 2011.

CDFG (California Department of Fish and Game), 2008. Zebra and Quagga Mussel Artificial Substrate Monitoring Protocol. Adopted from the California Department of Water Resources Monitoring Instructions for Zebra/Quagga Mussel Plate Samplers, April 2, 2008.

FERC (Federal Energy Regulatory Commission). 2008. Order Issuing New License for Public Utility District No. 2 of Grant County, 123 FERC ¶ 61,049, Washington D.C.

Grant PUD (Public Utility District No. 2 of Grant County, Washington). 2010. Aquatic Invasive Species Control and Prevention Plan. Public Utility District No. 2 of Grant County, Ephrata, Washington. http://www.gcpud.org/pudDocuments/naturalResourcesDocs/Aquatic%20Invasive%20Species%20Control%20%20Prevention%20Plan.pdf

Harshman, B. 2011. Vehicle Count Data from June 30, 2009 to September 7, 2010. Unpublished data from the Public Utility District No. 2 of Grant County, Washington. Ephrata, Washington.

Keeler, C. 2012-2014. Aquatic Invasive Species Control and Prevention Plan: 2011-2014 Annual Report. Public Utility District No. 2 of Grant County, Washington. June, 2012-2014.

Lange, C. 2014. Letter to Mr. Carson Keeler, Grant County PUD, Wanapum Dam, Beverly, Washington.

Meacham, P. 2009. Aquatic Nuisance Species Management Program. Washington Department of Fish and Wildlife. Personnel Communication.

Shultz, J. 2010-2014. Aquatic Nuisance Species Management Program Biologist. Washington Department of Fish and Wildlife. Personnel Communication.

WDOE (Washington Department of Ecology). 2007. Section 401 Water Quality Certification Terms and Conditions for the Priest Rapids Hydroelectric Project, FERC Project No. 2114, Spokane, Washington.

WDOE. 2011. Advisory poster for Eurasian watermilfoil. Lacey, Washington. January 2011.

WDFW (Washington Department of Fish and Wildlife). 2010. Artificial Substrate Monitoring Data Collection Form. Olympia, Washington.

WDFW. 2011. Aquatic Invasive Species Poster. Olympia, Washington. Accessed at http://wdfw.wa.gov/ais/ais_poster.pdf. January 2011.

Appendix A
100th Meridian Institute's *Zap the Zebra* Brochure

STOP AQUATIC HITCHHIKERS!™

www.ProtectYourWaters.net

Follow these simple steps:

☑ Clean

Remove all plants, animals, mud and thoroughly wash everything, especially all crevices and other hidden areas.

☑ Drain

Eliminate all water before leaving the area, including wells, ballast, and engine cooling water.

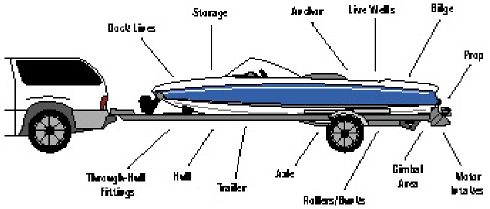
☑ Dry

Allow sufficient time for your boat to completely dry before launching in other waters.

If your boat has been in infested waters for an extended period of time, or if you cannot perform the required steps above, you should have your boat *professionally* cleaned with high-pressure scalding hot water (>140 °F) before transporting to any body of water.

Before launching and before leaving...

Inspect everything!



100th Meridian Initiative

ZAP THE ZEBRA

www.100thMeridian.org


Quagga mussels encrusting a boat motor

Zebra and quagga mussels are a nuisance for anglers and boaters. They can ruin your equipment, clog motor cooling systems, foul hulls, and jam the centerboard wells under sailboats.

Please report any sighting by calling our National Hotline:

1-877-STOP-ANS

1-877-786-7267

Image Credits: *Zebra Mussels on a Fishing Lure* by Marc Murrell, Kansas Department of Wildlife and Parks • *Zebra Mussels, Zebra Mussels on a Beer Can, Zebra Mussels on a Native Mussel, Bait Bucket, Quagga Mussels, Zebra/Quagga Mussel Distribution January 2009* by David Britton, U.S. Fish & Wildlife Service • *Zebra Mussels in a Cut-Away Pipe* by Don Schloesser, Great Lakes Science Center • *Zebra Mussels in a Pipe* by Craig Czarnecki, Michigan Sea Grant • *Quagga Mussels Encrusting a Boat Motor* by Matt Watson, The University of Texas at Arlington • The distribution map is based on data compiled by the U.S. Geological Survey's Nonindigenous Aquatic Species Program (http://nas.er.usgs.gov).

Invasive Mussels: Expensive Damage!

When zebra and/or quagga mussels invade our local waters they clog power-plant and public-water intakes and pipes. Routine treatment is necessary and very expensive. This leads to increased utility bills. If you use water and electricity, you do not want these mussels.


Zebra mussels in a cut-away pipe

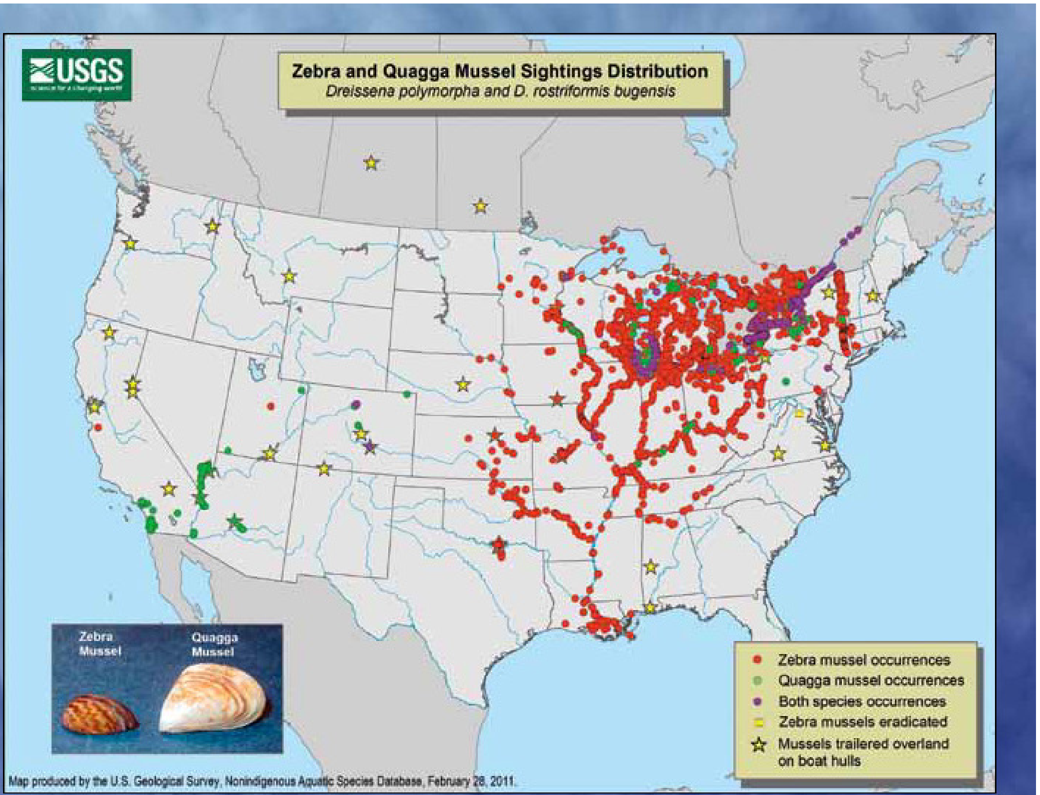

Zebra mussels blocking a pipe

Zebra/Quagga Mussels May Use Your Boat to Invade Additional Waters!

Once a boat has been in infested waters, it could carry invasive mussels. These mussels can spread to new habitats on boats trailered by commercial haulers or the public. Zebra and quagga mussels attach to boats and aquatic plants carried by boats. These mussels also commonly attach to bait buckets and other aquatic recreational equipment. An adult female zebra mussel can release up to a million eggs in a year. Please take precautions outlined in this brochure to help reduce the chance that zebra or quagga mussels will spread from your boat or equipment to uninfested areas.


Before zebra mussels


After zebra mussels



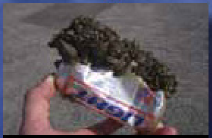
Map produced by the U.S. Geological Survey, Nonindigenous Aquatic Species Database, February 28, 2011.

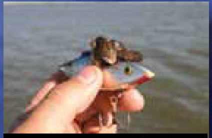
Zebra/Quagga Mussels Harm Native Aquatic Life


Zebra mussels on a crayfish


Zebra mussels on a native mussel

Zebra/Quagga Mussels Encrust Any Hard Surface


Zebra mussels on a beer can


Zebra mussels on a fishing lure

Zebra Mussels / Quagga Mussels

What are they?

Both are closely related, invasive, freshwater bivalve (mollusk) species that encrust hard surfaces.

Where do they come from?

These species came from the Black and Caspian Sea Drainages in Eurasia.

What size are they?

Larvae are microscopic and adults may be up to two inches long. They are usually found in clusters.

Why "Zebra" mussels?

Both species are sometimes referred to as "zebra" mussels because they both have light and dark alternating stripes. Quagga mussels are actually a distinct (but similar) species named after an extinct animal related to zebras.

Appendix B
100th Meridian Institute's Boater Self-Survey Form

LOCATION ______________________________ STATE _______________ DATE _______________

The Zebra Mussel

100TH MERIDIAN INITIATIVE TO PREVENT THE WESTWARD EXPANSION OF ZEBRA MUSSELS
BOATER SELF-SURVEY

The 100th Meridian Initiative is a multi-agency partnership effort to prevent the westward spread of zebra mussels and other aquatic nuisance species to western North American waters. The U.S. Fish & Wildlife Service is sponsoring and coordinating education outreach and voluntary trailered boat surveys with other agencies in the states on the 100th meridian. Surveys similar to this are being conducted in Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota and the Canadian Province of Manitoba. This survey is now being extended to the Colorado River. You as a boater are being asked to voluntarily inspect your trailer, boat and related equipment for any transported aquatic species, such as the **zebra mussel**, which may be carried accidentally to new locations. Your assistance and participation is appreciated in completing this survey and returning it in the provided, stamped envelope to the agency that is conducting this survey for the U.S. Fish and Wildlife Service. Please review the enclosed information on introduced aquatic species and boat and trailer inspections. Be sure to clean your boat, trailer and equipment after hauling-out the boat and before leaving the ramp area. Thanks for your help!

The following instructions will help you complete the survey.

Part One – Where are you from? (Any information provided is voluntary and anonymous.)

Please state the purpose of your visit, and fill in the boxes relating to your boat and home state. Your most recent launches are very important information, so please be as complete as possible.

Part Two – Where are you going?

Please indicate where you will be launching next **after you leave this lake**. Do not list further launchings at this lake. Again, please be as complete as possible in filling out this section.

Part Three – Returning the survey.

That's all there is to it! All you need to do is place this page in the provided, stamped, return envelope, seal it, and drop it in the mail.

SURVEY INFORMATION (Please Print)

PART ONE: Where are you from?

Home State:	Zip Code:

Type of Boat: ☐ Angling ☐ Pleasure ☐ Jet Ski ☐ Canoe ☐ Other explain

How many times have you launched in the last year?

Do you always launch in the same water body? ☐ Yes ☐ No

If no, please list below where else you have launched recently.

Water Body:	State:	County:	Date:
1.			
2.			
3.			

PART TWO: Where are you going? Please list below where you plan to launch next.

Water Body:	State:	County:	Date:
1.			
2.			

Are you already aware of threats of zebra mussels? ☐ Yes ☐ No

Or any other aquatic nuisance species? ☐ Yes ☐ No

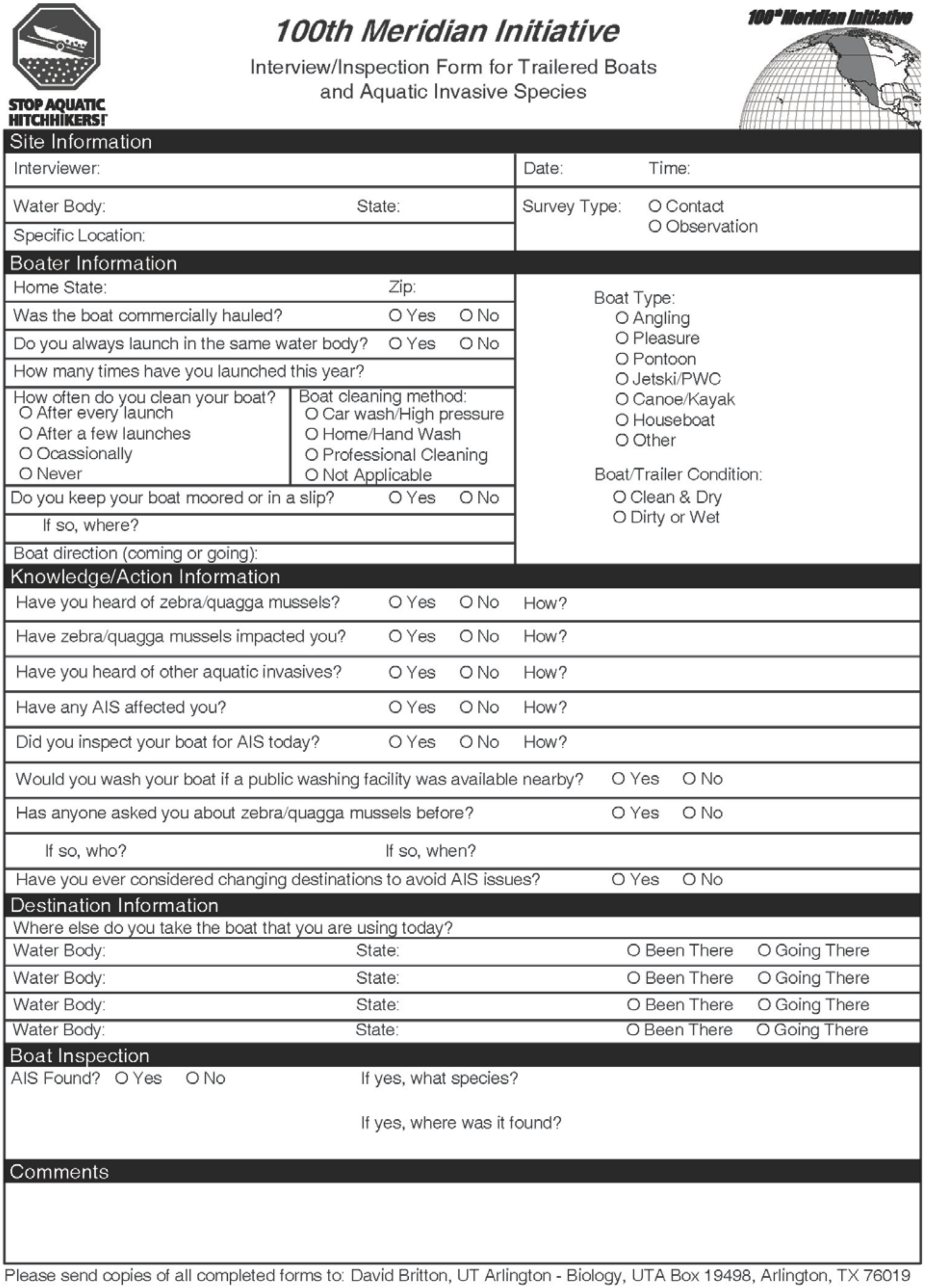
Do you clean your boat and trailer between launchings? ☐ Yes ☐ No

Is you boat kept on land or in water when not in use? ☐ On Land ☐ In Water

If in water, where is it kept? Water body: State:

Any Comments:

Appendix C
100th Meridian Institute's Boater Survey Form



STOP AQUATIC HITCHHIKERS!

100th Meridian Initiative

Interview/Inspection Form for Trailered Boats
and Aquatic Invasive Species

100th Meridian Initiative

Site Information

Interviewer:

Date: Time:

Water Body: State:

Specific Location:

Survey Type: ○ Contact ○ Observation

Boater Information

Home State: Zip:

Was the boat commercially hauled? ○ Yes ○ No

Do you always launch in the same water body? ○ Yes ○ No

How many times have you launched this year?

How often do you clean your boat?
- ○ After every launch
- ○ After a few launches
- ○ Ocassionally
- ○ Never

Boat cleaning method:
- ○ Car wash/High pressure
- ○ Home/Hand Wash
- ○ Professional Cleaning
- ○ Not Applicable

Do you keep your boat moored or in a slip? ○ Yes ○ No

If so, where?

Boat direction (coming or going):

Boat Type:
- ○ Angling
- ○ Pleasure
- ○ Pontoon
- ○ Jetski/PWC
- ○ Canoe/Kayak
- ○ Houseboat
- ○ Other

Boat/Trailer Condition:
- ○ Clean & Dry
- ○ Dirty or Wet

Knowledge/Action Information

Have you heard of zebra/quagga mussels? ○ Yes ○ No How?

Have zebra/quagga mussels impacted you? ○ Yes ○ No How?

Have you heard of other aquatic invasives? ○ Yes ○ No How?

Have any AIS affected you? ○ Yes ○ No How?

Did you inspect your boat for AIS today? ○ Yes ○ No How?

Would you wash your boat if a public washing facility was available nearby? ○ Yes ○ No

Has anyone asked you about zebra/quagga mussels before? ○ Yes ○ No

If so, who? If so, when?

Have you ever considered changing destinations to avoid AIS issues? ○ Yes ○ No

Destination Information

Where else do you take the boat that you are using today?

Water Body: State: ○ Been There ○ Going There

Water Body: State: ○ Been There ○ Going There

Water Body: State: ○ Been There ○ Going There

Water Body: State: ○ Been There ○ Going There

Boat Inspection

AIS Found? ○ Yes ○ No

If yes, what species?

If yes, where was it found?

Comments

Please send copies of all completed forms to: David Britton, UT Arlington - Biology, UTA Box 19498, Arlington, TX 76019

Appendix D
The Washington Department of Fish and Wildlife's Aquatic Invasive Species Poster displayed at Project Boat Launches

STOP

It is ***ILLEGAL*** to transport or spread Aquatic Invasive Species!

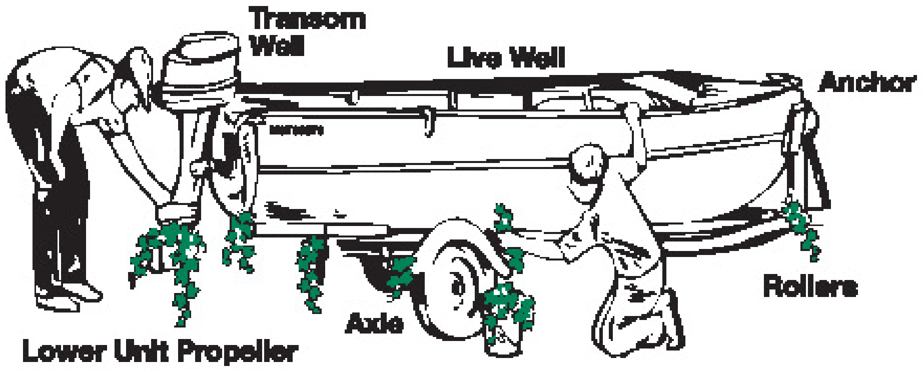
Before Launching & Before Leaving

You Must Remove ALL

Plants & Animals from Watercraft, Trailer and Gear.

You Must Drain ALL

Water from Fish/Live Wells, Holds and Bilges.



Unlawful to Transport Aquatic Plants - R.C.W. 77.15.290
Unlawful Use of Prohibited Aquatic Animal Species - R.C.W. 77.15.253
Unlawful Release of Fish, Shellfish or Wildlife - R.C.W. 77.15.250

To obtain information on free boat inspections, Report a sighting or Find out more about Aquatic Invasive Species:
Call 1-888-WDFW-AIS (933-9247) or go to www.WDFW.WA.GOV

Washington Department of FISH and WILDLIFE

STOP AQUATIC HITCHHIKERS!

Appendix E
The Washington Department of Ecology's Eurasian Water Milfoil Advisory Poster displayed at Project Boat Launches

ALERT!!

These waters contain

Under Washington law
transport or distribution of these species is

PROHIBITED

PLEASE! Clean your boat
and trailer before leaving the area:

- **Remove *ALL* aquatic plants and animals**
- **Drain *ALL* water**
- ***NEVER* empty aquariums or bait.**

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY
(360) 407-6562

Boats and trailers carrying
these species are subject
to criminal and civil penalties.

Washington Department of FISH and WILDLIFE
(360) 902-2200

Appendix F
AIS Poster titled “*Aquatic Invasive Species in the Priest Rapids Project*” presented at Grant PUD’s Archaeology Days, October 14-15, 2014

Aquatic Invasive Species in the Priest Rapids Project

What are Aquatic Invasive Species?

Any nonnative animal or plant species that live in, on, or next to water that are likely to cause harm to the economy, environment or human health. Invasive species are highly competitive, highly adaptive, and successful at reproducing in large numbers.

What is Grant PUD's role in helping stop the spread of Aquatic Invasive Species?

The Aquatic Invasive Species Control and Prevention Plan (AISP) includes educational, monitoring, and rapid response components intended to help reduce the potential for new AIS to be introduced into and become established within the Priest Rapids Project.

What is your role in helping the spread of Aquatic Invasive Species?

Follow these steps to reduce the spread of aquatic invasive species when taking your watercraft from the water:

- •Remove any visible plants, mud, fish or animals
- •Eliminate water from equipment & boat hull
- •Clean and dry anything that came in contact with water
- •Never release plants, fish or animals into a body of water unless they came out of that body of water

Websites for more information on AIS

Grant PUD's AIS: http://www.gcpud.org/naturalResources
/fishWaterWildlife/aquaticInvasiveSpecies.html

Washington Invasive Species Education: http://www.wise.wa.gov/

100th Meridian Initiative: http://www.100thmeridian.org/

Protect Your Waters: http://www.protectyourwaters.net/

WDFW Aquatic Invasive Species: http://wdfw.wa.gov/ais/

Examples of Aquatic Invasive Species

Photo courtesy of 100th Meridian Initiative

Zebra Mussels

Photo courtesy of U.S. Geological Survey

Quagga Mussels

Photo courtesy of D.L. Gustafson

New Zealand Mud Snail

Photo courtesy of Washington State Department of Ecology

Eurasian Watermilfoil

Examples of Aquatic Invasive Species Signage

STOP

Milfoil

Zebra Mussel

It is *ILLEGAL* to transport or spread Aquatic Invasive Species!

Before Launching & Before Leaving

You Must Remove ALL
Plants & Animals from Watercraft, Trailer and Gear.
You Must Drain ALL
Water from Fish/Live Wells, Holds and Bilges.

To obtain information on free boat inspections, Report a sighting or Find out more about Aquatic Invasive Species:
Call 1-888-WDFW-AIS (933-9247) or go to www.WDFW.WA.GOV

ALERT!!

These waters contain

Under Washington law
transport or distribution of these species is

PROHIBITED

PLEASE! Clean your boat and trailer before leaving the area:

- Remove ALL aquatic plants and animals
- Drain ALL water
- NEVER empty aquariums or bait.

Boats and trailers carrying these species are subject to criminal and civil penalties.

STOP the invasion

Invasive species are everyone's problem

Invasive species threaten Washington's most valuable industries and pristine ecosystems.

Get involved!

- Landscape and garden with native plants.
- Do not release pets, aquatic plants, or aquarium water into the wild.
- Clean your watercraft, trailer, and fishing equipment.
- Control the spread of invasive seeds.
- Learn to identify invasive species.

To report invasive species, call
1-877-9-INFEST

To learn more, visit:
www.InvasiveSpecies.wa.gov

Protect Washington from invasive species

Grant County
PUBLIC UTILITY DISTRICT
Excellence in Service and Leadership

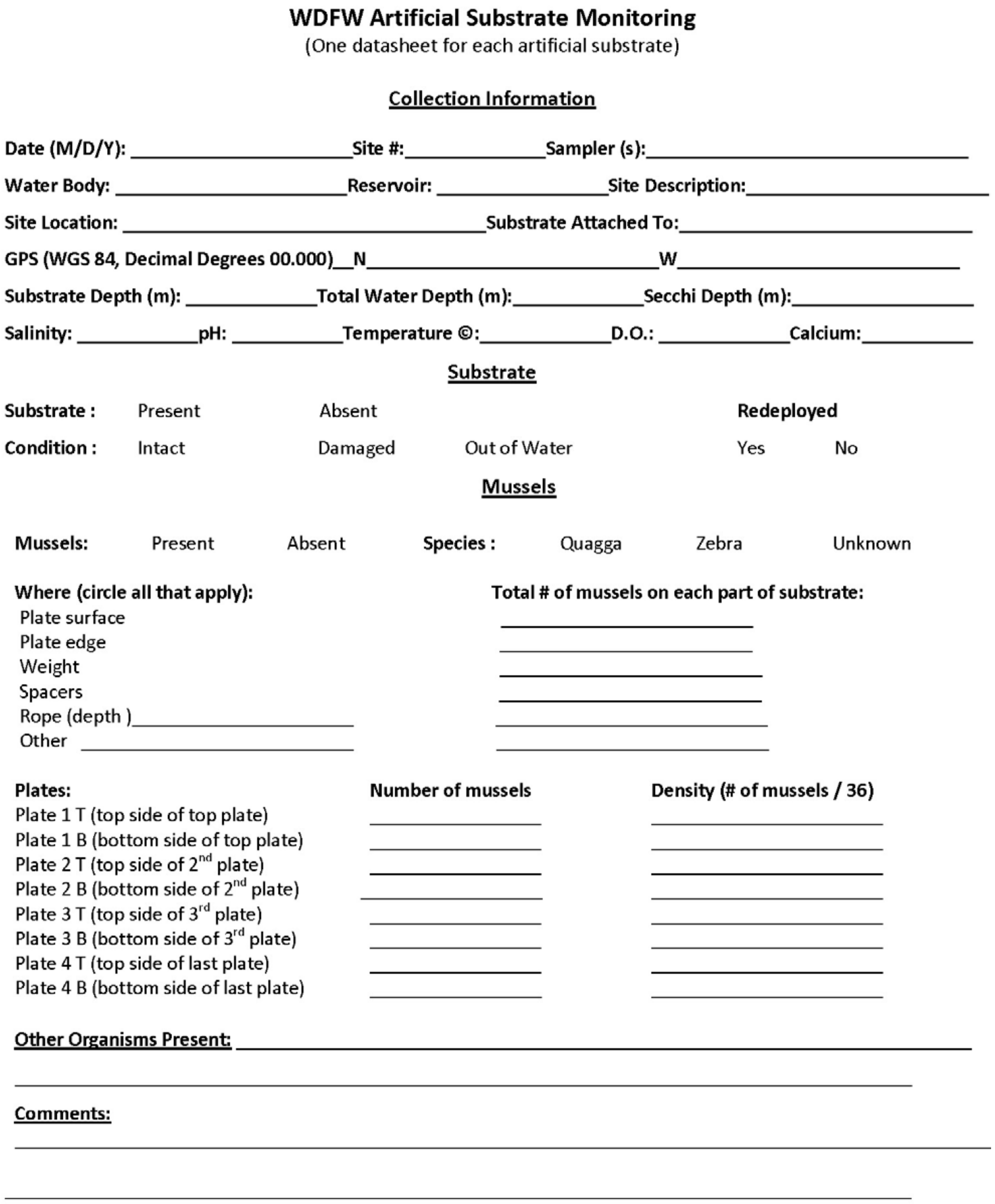
Appendix G

Zebra/Quagga Mussel veliger sample results during 2014, Priest Rapids Hydroelectric Project, mid-Columbia River, WA

Date	Reservoir	Location[1]	Collection Method	Zebra Mussels	*Corbicula*	Prescreened	Comments
7/7/14	Wanapum	WF	Both	No	No	No	Heavy Phytoplankton
7/7/14	Priest Rapids	CC	Both	No	Few	No	Heavy Phytoplankton
7/7/14	Wanapum	SE	Both	No	No	No	Heavy Phytoplankton
7/7/14	Priest Rapids	LG	Both	No	No	No	Heavy Phytoplankton
7/7/14	Wanapum	CB	Both	No	Some	No	
7/7/14	Priest Rapids	PRF	Both	No	Many	No	
8/26/14	Wanapum	WF	Both	No	No	No	
8/26/14	Priest Rapids	CC	Both	No	Many	No	Heavy Phytoplankton
8/26/14	Wanapum	SE	Both	No	No	No	
8/26/14	Priest Rapids	LG	Both	No	Few	No	
8/26/14	Wanapum	CB	Both	No	No	No	
8/26/14	Priest Rapids	PRF	Both	No	No	No	Heavy Phytoplankton
9/30/14	Wanapum	WF	Both	No	No	No	
9/30/14	Priest Rapids	CC	Both	No	Some	No	Some Ostracodes
9/30/14	Wanapum	SE	Both	No	Many	No	
9/30/14	Priest Rapids	LG	Both	No	No	No	
9/30/14	Wanapum	CB	Both	No	Many	No	
9/30/14	Priest Rapids	PRF	Both	No	No	No	

[1] CB=Crescent Bar, SE=Sunland Estates, WF=Wanapum Forebay, CC=Crab Creek, LG=Lake Geneva, PRF=Priest Rapids Forebay

Appendix H
Zebra/Quagga Mussel Artificial Substrate Datasheets



WDFW Artificial Substrate Monitoring

(One datasheet for each artificial substrate)

Collection Information

Date (M/D/Y): ____________________**Site #:**____________**Sampler (s):**______________________________

Water Body: ____________________**Reservoir:** ______________**Site Description:**______________________

Site Location: ______________________________**Substrate Attached To:**__________________________

GPS (WGS 84, Decimal Degrees 00.000)__N_________________________**W**_________________________

Substrate Depth (m): ___________**Total Water Depth (m):**___________**Secchi Depth (m):**________________

Salinity: __________**pH:** _________**Temperature ©:**___________**D.O.:** ___________**Calcium:**_________

Substrate

Substrate :	Present	Absent		**Redeployed**	
Condition :	Intact	Damaged	Out of Water	Yes	No

Mussels

Mussels: Present Absent **Species :** Quagga Zebra Unknown

Where (circle all that apply):	**Total # of mussels on each part of substrate:**
Plate surface	______________________
Plate edge	______________________
Weight	______________________
Spacers	______________________
Rope (depth)____________________	______________________
Other ________________________	______________________

Plates:	**Number of mussels**	**Density (# of mussels / 36)**
Plate 1 T (top side of top plate)	________________	____________________
Plate 1 B (bottom side of top plate)	________________	____________________
Plate 2 T (top side of 2nd plate)	________________	____________________
Plate 2 B (bottom side of 2nd plate)	________________	____________________
Plate 3 T (top side of 3rd plate)	________________	____________________
Plate 3 B (bottom side of 3rd plate)	________________	____________________
Plate 4 T (top side of last plate)	________________	____________________
Plate 4 B (bottom side of last plate)	________________	____________________

Other Organisms Present: ____

____

Comments:

____

____

Appendix I
Boat Launch Transect Maps for 2014

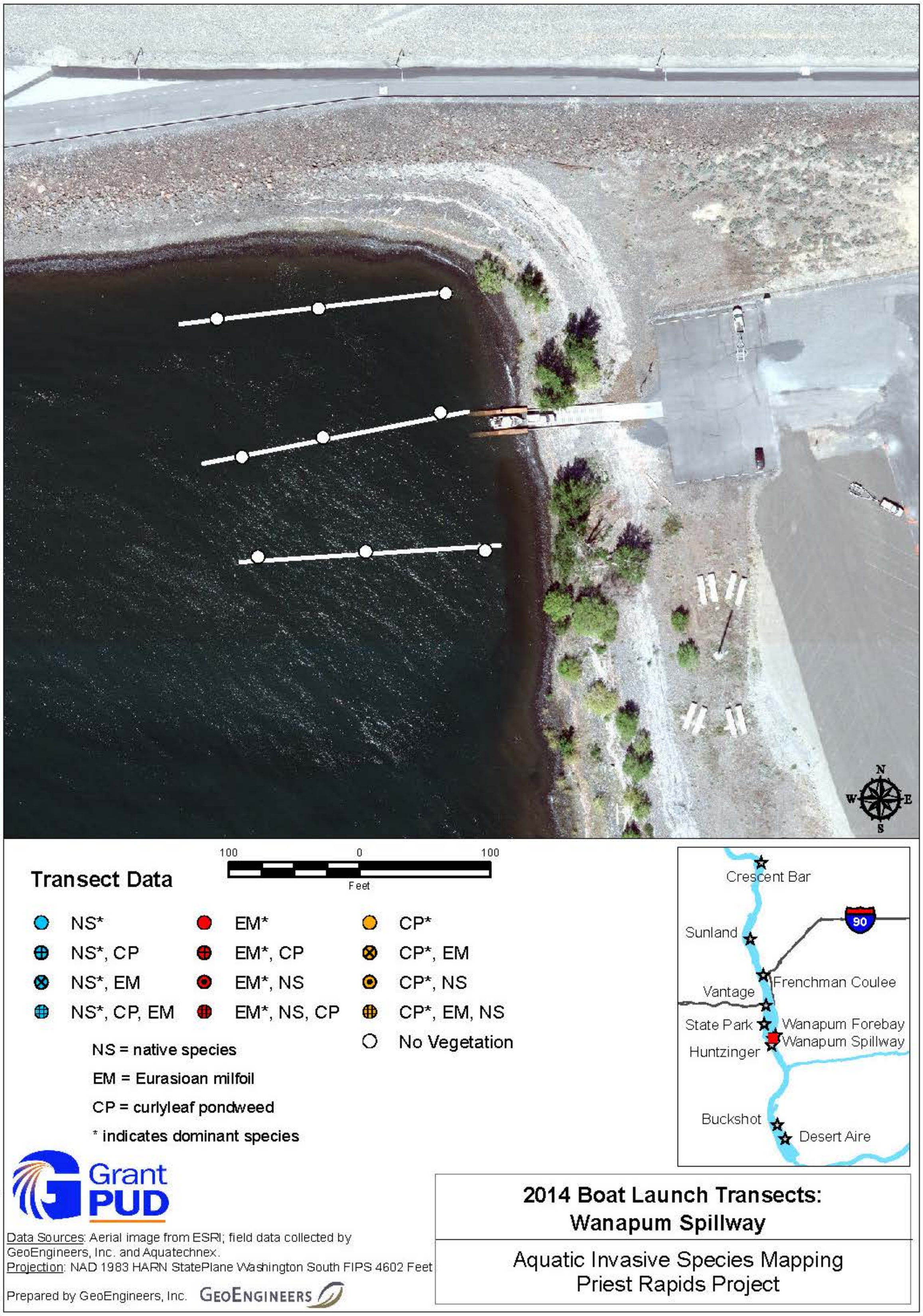


Figure I-1 Wanapum Tailrace Boat Launch Transects, Priest Rapids Reservoir, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.

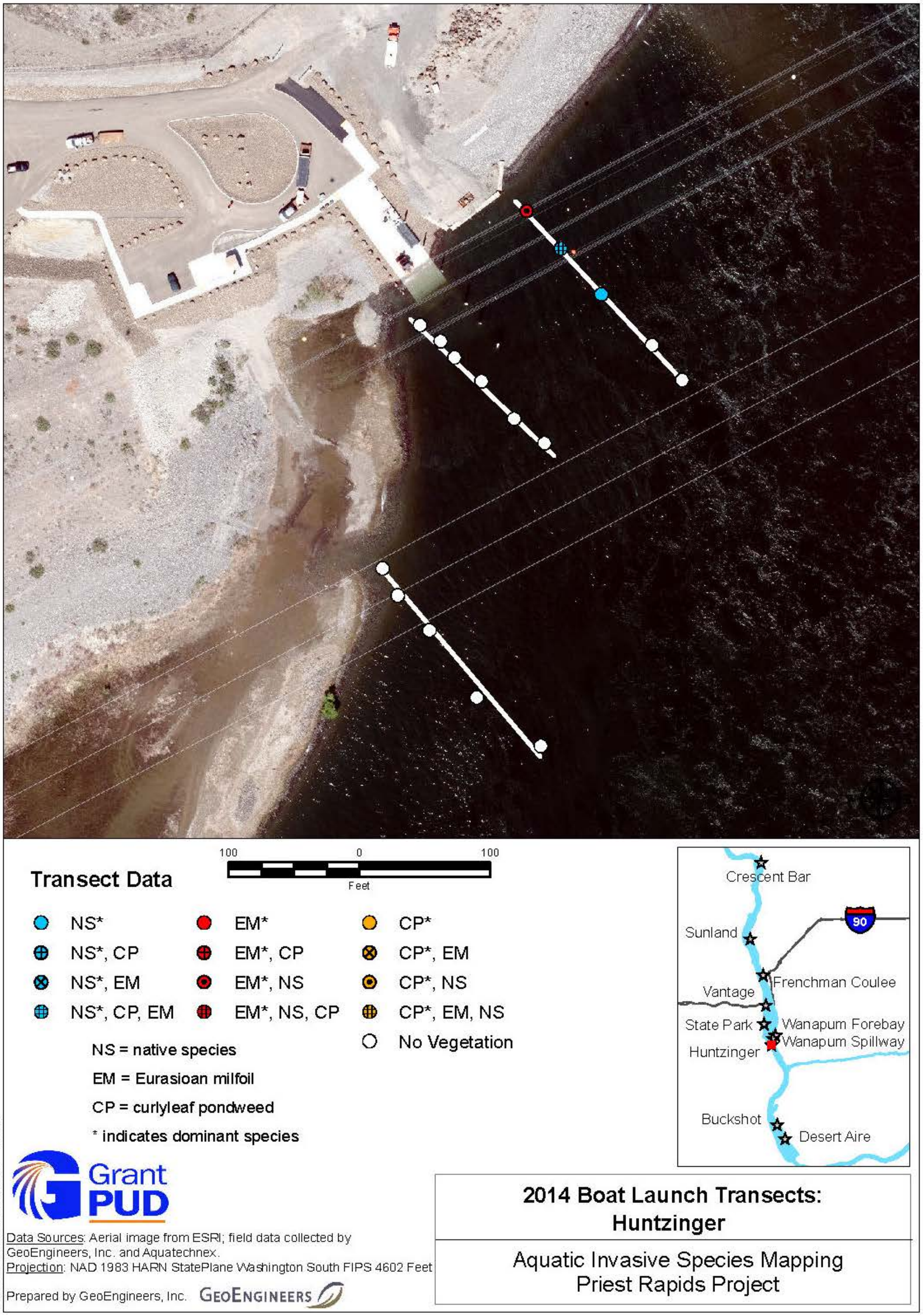


Figure I-2 **Huntzinger Boat Launch Transects Map, Priest Rapids Reservoir, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.**

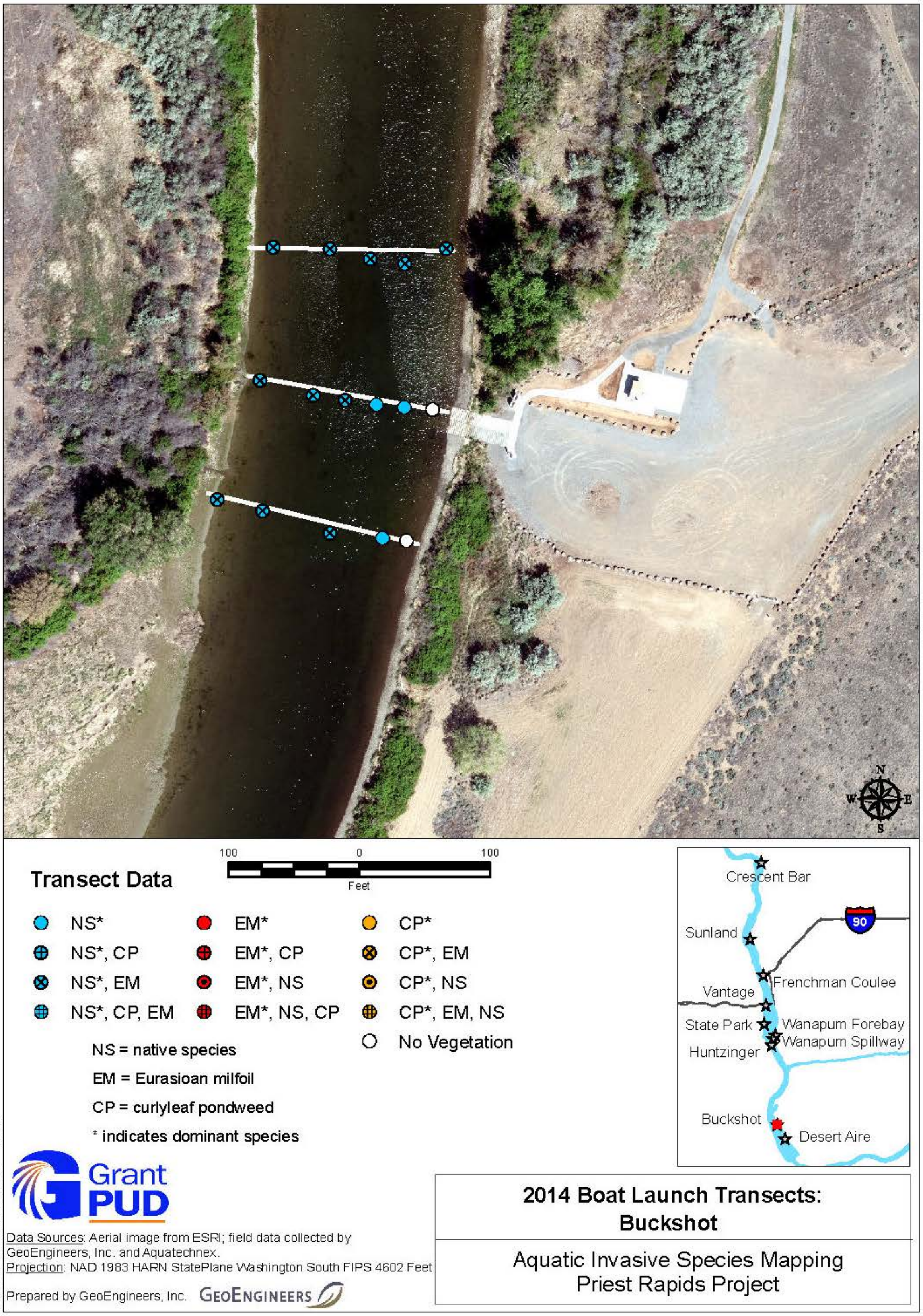


Figure I-3 Buckshot Boat Launch Transects Map, Priest Rapids Reservoir, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.

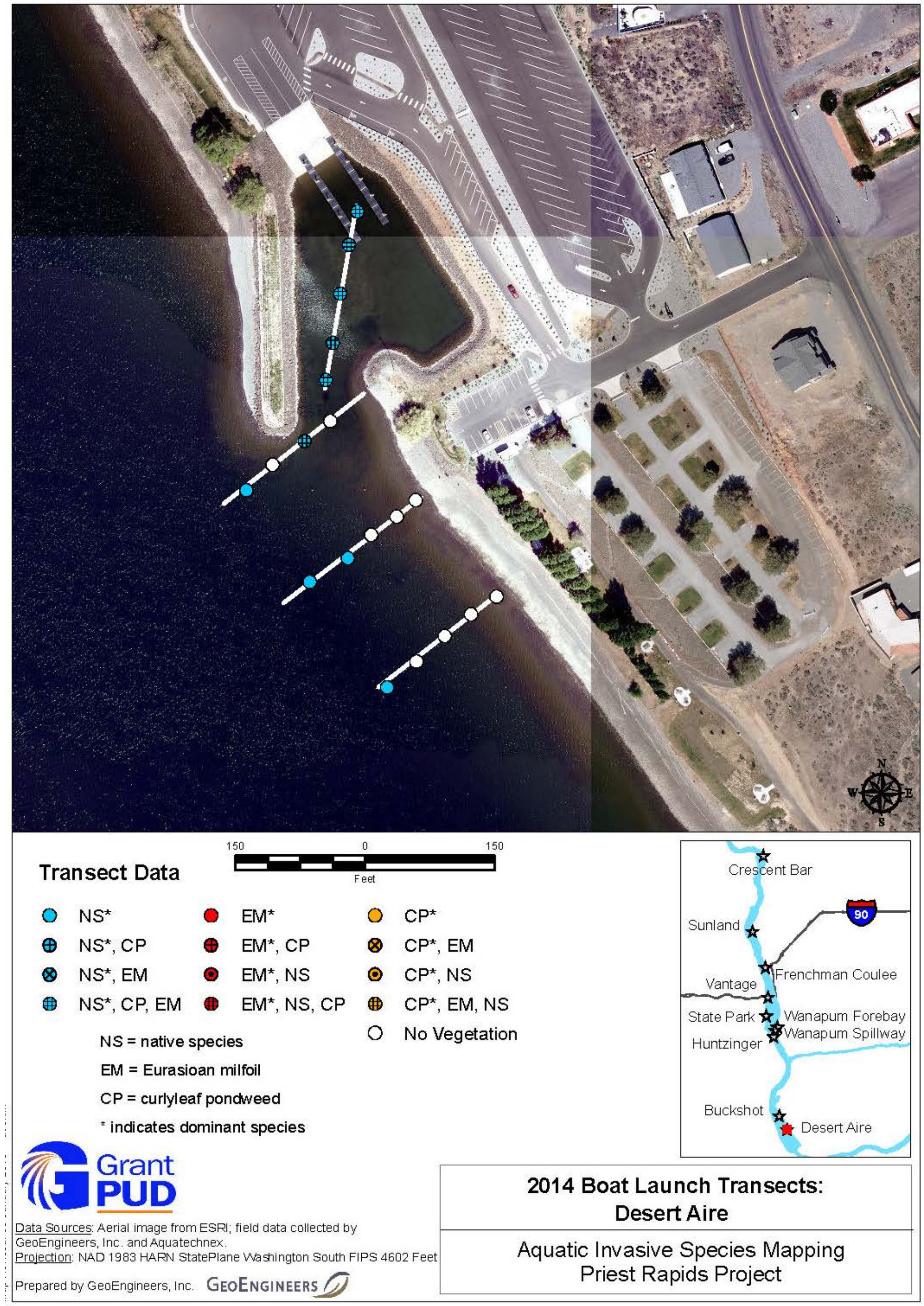


Figure I-4 **Priest Rapids Recreation Area (PRRA)/Desert Aire Boat Launch Transects Map, Priest Rapids Reservoir, Priest Rapids Hydroelectric Project, mid-Columbia River, WA.**

Assessment of the Emergency Drawdown Impact on the Mollusks and Other Organisms in Wanapum Lake, Columbia River, Grant County, Washington.

FIELD SURVEY SUMMARY REPORT

SUBMITTED TO:
Public Utility District No. 2 of Grant County

SUBMITTED BY:
Brett Tiller, Environmental Assessment Services
350 Hills St.
Richland, WA 99354

PRINCIPAL PROPONENTS:
Brett Tiller, Environmental Assessment Services
Mark Timko, Blue Leaf Environmental
Edward J. Johannes, Deixis Consultants

EAS ENVIRONMENTAL ASSESSMENT SERVICES RICHLAND, WASHINGTON   BLUE LEAF ENVIRONMENTAL   Deixis Consultants

March 20, 2015

EXECUTIVE SUMMARY

The discovery of a fracture in a spillway pier at Wanapum Dam on the Columbia River in February 2014 forced dam operators to conduct an emergency drawdown of Wanapum Lake (Reservoir), lowering it by as much as 27 ft (8.2 m). This unanticipated drawdown stranded a number of relatively immobile benthic organisms, including freshwater mussels, gastropods (snails), fishes (including juvenile lamprey), and other organisms. In response, Grant County Public Utility District (Grant PUD) initiated land- and water-based surveys to characterize benthic communities potentially affected by the water-level drop in the reservoir between Rock Island and Wanapum dams.

The purpose of this study was to determine the species present and estimate densities of stranded freshwater mollusks (mussels, clams, and snails) and provide a more general characterization of other stranded fauna, including fishes, crayfish, and amphibians. Specific objectives were to 1) characterize freshwater mollusk species composition and densities in dewatered areas; 2) assess freshwater mussel densities in areas unaffected by the water-level reduction; and 3) document fishes and other organisms present in the dewatered area, and describe potential effects of water-level reductions on these organisms.

Wanapum Lake was found to have diversity of roughly nineteen mollusk species. Twelve are gastropods (eleven native; one introduced) and seven are bivalves (six native, three unionids and four sphaeriacean clams [three sphaeriids or pea clams; and one non-native corbiculid]). Other than the corbiculid clam, no other invasive species considered harmful to the native molluscan fauna were encountered. However, several rare or sensitive snail species (in the genera *Fluminicola* and *Vorticifex*) and the formerly widespread western pearlshell (*Margaritifera falcata*) were found in the upper part of the study area just below Rock Island Dam. Their presence signifies the occurrence of a relatively unique and rare remnant of an upper Columbia preimpoundment riverine molluscan fauna and habitat (hard substrates and fast flowing well oxygenated cold water regime) that is also now found only in the downstream Hanford Reach.

A few state listed and former federally listed candidates were found during this survey. The ashy pebblesnail (*Fluminicola fuscus,* formerly *F. columbiana*) is a former federally listed candidate and a special status species in Washington State. The California floater (*Anodonta californiensis*; now placed under genetic Clade 1) is listed by the Washington Department of Fish and Wildlife (WDFW) as a Candidate for listing as Threatened or Endangered. The western pearlshell (*Margaritifera falcata*) is listed by WDFW as a Monitor species. Before this survey, *M. falcata* was suspected to be potentially extinct in the upper mainstem Columbia River.

Overall, freshwater mussel densities within the project area were relatively high compared to other areas reported along the Columbia River. Relatively high densities of mussels were noted to persist below the drawdown water line to a depth of at least 30 ft (~9 m).

Three juvenile lamprey (all Ammocoetes) were collected from one sampling site just upriver of Sunland Estates near river mile 431. Other species found stranded along the shorelines at selected sampling sites included redside shiner (*Richardsonius balteatus*) and three-spine stickleback (*Gasterosteus aculeatus*). Various sculpin (Cottidae) and crayfish (Cambaridae) also were observed.

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1.0 INTRODUCTION

On February 27, 2014, a fracture was discovered by Grant County Public Utility District (Grant PUD) personnel in one of the spillway piers at Wanapum Dam on the Columbia River, Washington. To relieve pressure on the pier, dam operators rapidly reduced the level of Wanapum Lake from a seasonal normal water level of ~570 ft to as low as 543 ft., leaving it at this level while the fracture was investigated and repaired. This drop in reservoir level exposed significant portions of the shoreline between Rock Island and Wanapum dams that had been inundated since 1963. As a result of the emergency drawdown, a number of relatively immobile benthic organisms such as freshwater mussels (unionid clams), sphaeriaceans (pea and Asian clams), and gastropods (snails) were stranded. Native and non-native species of fish such as Pacific lamprey (*Entosphenus tridentatus*) also may have been affected along with two non-native species of mollusks, the big-ear radix snail *Radix auricularia* and invasive Asian clam *Corbicula fluminea*.

In response, Grant PUD asked Environmental Assessment Services (EAS) and Blue Leaf Environmental to conduct land- and water-based surveys to characterize benthic communities potentially affected by the emergency drawdown. Deixis Consultants was subcontracted by EAS to identify and recommend a sampling protocol for the snails and sphaeriaceans clams.

Specific study objectives were to:

1) Characterize freshwater mollusk species composition and densities in areas that were dewatered by the emergency drawdown and describe potential effects of the drawdown on these organisms.

2) Assess freshwater mussel densities in areas not dewatered by the emergency drawdown (remaining unexposed regions and within shoreline areas where water levels fluctuate during routine hydropower operations).

3) Document stranded fishes and other organisms present in areas that were dewatered by the emergency drawdown.

1.1 Study Area

The study area included the full length of Wanapum Lake, which is approximately 37.2 miles (60 km) long and is bounded by Wanapum and Rock Island dams (Figure 1). A total of 10 tributaries enter the reservoir: Johnson, Skookumchuck, Whiskey Dick, Sand Hollow, Quilomene, Trinidad, Tarpiscan, Colockum, Douglas, and Brushy creeks. The reservoir mostly comprises of impounded water habitat with fine grained substrates near Wanapum Dam, transitioning in upstream reaches into relatively free-flowing water habitat with rocky substrates and some backwater areas below Rock Island Dam.

1.2 Potential Native Sensitive and Non-native Invasive Species

Globally freshwater mollusks have suffered the highest number of documented extinctions of any major taxonomic group and in North America, suffer much higher rates of imperilment than most terrestrial groups, including birds and mammals (Williams et al. 1992; Lydeard et al. 2004).

This is all too true for the freshwater Columbia River mollusks where they have been impacted by reservoirs behind numerous dams now populating the river. At least six Columbia River mollusks may be extinct, including several endemics (Frest & Johannes 1995, 2004).

Three genera of freshwater mussels, *Anodonta*, *Margaritifera*, and *Gonidea*, were identified, prior to the survey, as potentially occurring in Wanapum Lake area. *Margaritifera* and *Gonidea* have been found in this region in Native American midden deposits (Swanson 1962; Lyman 1980; Chance and Chance 1985; Salo 1985) and *Anodonta* in the nearby Lind and Grand coulees in Pleistocene deposits (Henderson 1929; Enbysk 1956; Landye 1973). Recent surveys found no live *Margaritifera* in stretches above or below Wanapum Lake and it was thought to be extinct in the upper Columbia River (DE&S and RL&L 2000; BioAnalysts 2006; Helmstetler 2008; Mueller et al. 2011; Lindsey et al. 2013). *Anodonta* spp. has been found live both upstream and downstream of Wanapum Lake in both impounded and "free" flowing areas of the Columbia River (Newell 1998; DE&S and RL&L 2000; BioAnalysts 2006; Helmstetler 2008; Mueller et al. 2011; Lindsey et al. 2013).

The western pearlshell (*Margaritifera falcata*) and western ridged mussel (*Gonidea angulata*) are listed by the Washington Department of Fish and Wildlife (WDFW) as Monitor species. Four species of *Anodonta* also are potentially present in the survey area: California floater (*A. californiensis*), Oregon floater (*A. oregonensis*), winged floater (*A. nuttalliana*), and western floater (*A. kennerlyi*) (Mueller et al. 2011). The California floater is identified by WDFW as a candidate for listing as threatened or endangered and was formerly considered as a candidate for listing federally (USFWS 1991). The other three unionids are WDFW Monitor species.

Recent genetic work on unionids has revealed the possibility that there are fewer western U.S. *Anodonta* species than originally thought (Chong et al. 2008, 2009; Mock et al. 2004, 2010). Three genetic clades have been identified but only two concern us here. Clade 1 contains the California floater and winged floater, while Clade 2 contains the Oregon floater and western floater (Chong et al. 2008). If these clades are accepted then only *A. nuttalliana* and *A. oregonensis* would be the recognized *Anodonta* species in Washington; the others being synonymized under their respective clade member.

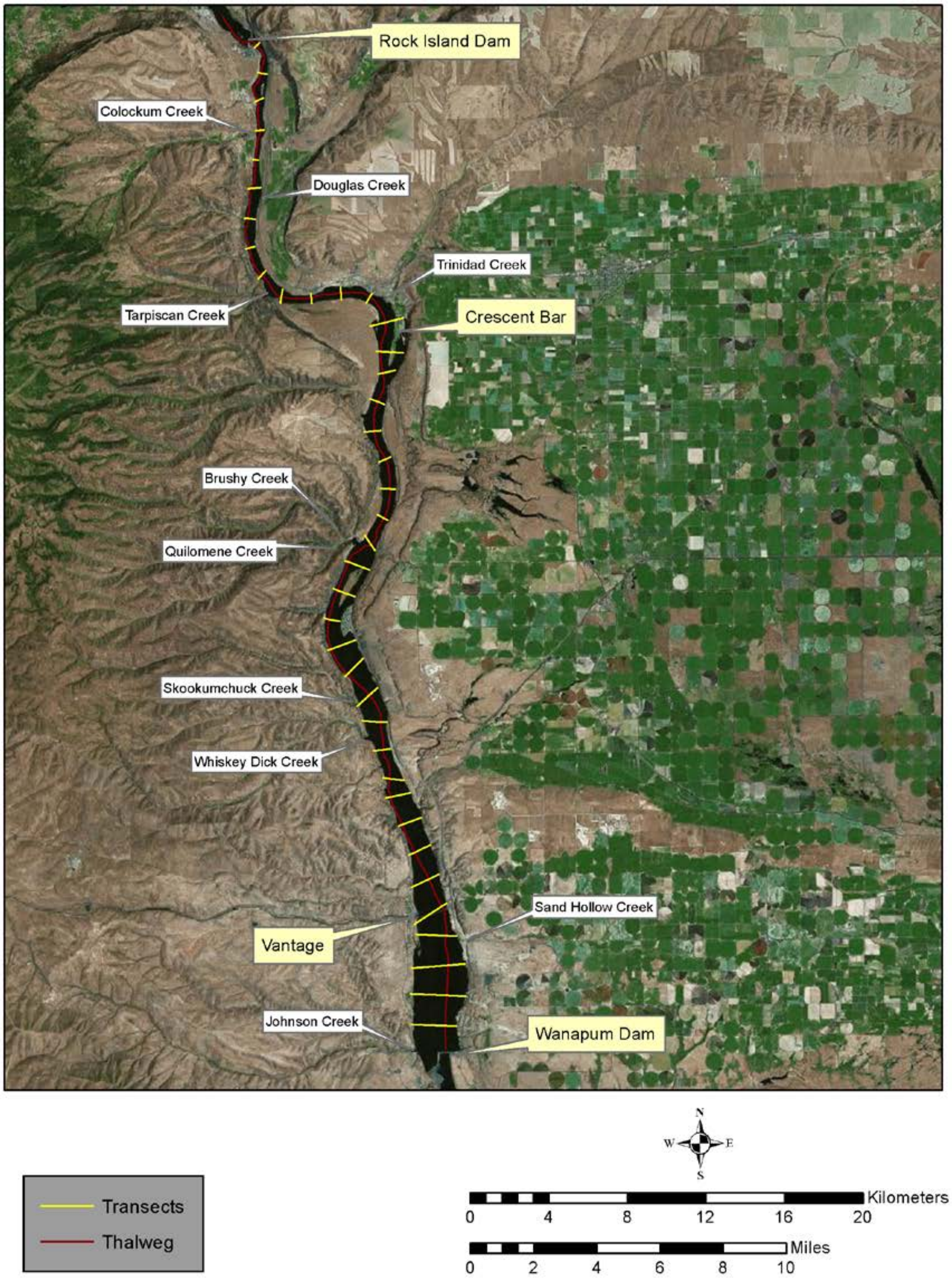


Figure 1. Wanapum Lake Cross-Channel Transects and River Segments

In addition to native freshwater mussels two special status snails, the ashy pebblesnail (*Fluminicola fuscus*), formerly Columbia pebblesnail (*Fluminicola columbiana*) (Hershler and Frest 1996), and the shortface lanx (*Fisherola nuttalli*), were expected to be found in the study area. These cold-water snail taxa have persisted in the Hanford Reach of the Columbia River and were former federal Candidate species (USFWS 1991). Currently, these species are considered rare, imperiled, and in decline (Frest and Johannes 1995; Frest et al. 2007). Despite this both are still listed as only state candidates by the State of Washington and are not at present listed federally.

In the survey area two invasive species that could potentially be found are the zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis bugensis*) while three others likely to be found are the New Zealand mud snail (*Potamopyrgus antipodarum*), Asiatic clam (*Corbicula fluminea*), and big-ear radix snail (*Radix auricularia*).

2.0 METHODS

Field surveys were performed between mid-March and early April 2014. Land-based surveys were conducted in the shoreline area exposed by the emergency drawdown to determine the species and density estimates of stranded mussels, clams, snails, fishes (including lamprey), and other organisms. Water-based surveys were performed to estimate the density of mussels found below the Wanapum Lake normal hydropower operations lowest water level determined by the ordinary low-water mark (OLWM) found evident along the shorelines.

2.1 Transect and Segment Delineation

Linear cross-channel transects (running perpendicular to the shoreline) covering the full length of Wanapum Lake was systematically established at 1.5 km intervals from Wanapum Dam to Rock Island Dam resulting in a total of 40 transects spread over a 60 km long study area (Figure 1). Generally, each transect extended perpendicular to the flow of the river from the OLWM on the right bank to the OLWM on the left bank.

The data from the transects were lumped into 10 river segments (each containing 4 transects) for the purposes of depicting patterns that could emerge associated with the varying hydro-geomorphic properties of this stretch of the Columbia River (Figure 2). Actual transects and survey plot locations for each river segment are provided in Appendix 5.1.

2.2 Substrate Classification

For both land- and water-based surveys, the surveyors noted on a field survey forms the dominant and subdominant substrate type, aquatic vegetation abundance, and embeddedness within each plot, following methodologies described by Platts et al. (1983) (Table 1). The relative amount of predator and human activity (footprints) was also noted when present because of the potential for predation and anthropogenic effects on plot data (scavenging, removal of mussels).

Table 1. Substrate Classification

Dominant Substrate	Subdominant Substrate	Embeddedness	Aquatic Vegetation
1) Fines, sand, silt, and mud	1) Fines, sand, silt, and mud	1) 0-25% fines	1) No vegetation present
2) Gravel-medium cobble	2) Gravel-medium cobble	2) 26-50% fines	2) Sparse vegetation; substrate completely evident
3) Large cobble	3) Large cobble	3) 51-75% fines	3) Vegetation common; substrate partially obscured
4) Boulder/bedrock	4) Boulder/bedrock	4) 76-100% fines	4) Dense vegetation substrate nearly or completely obscured

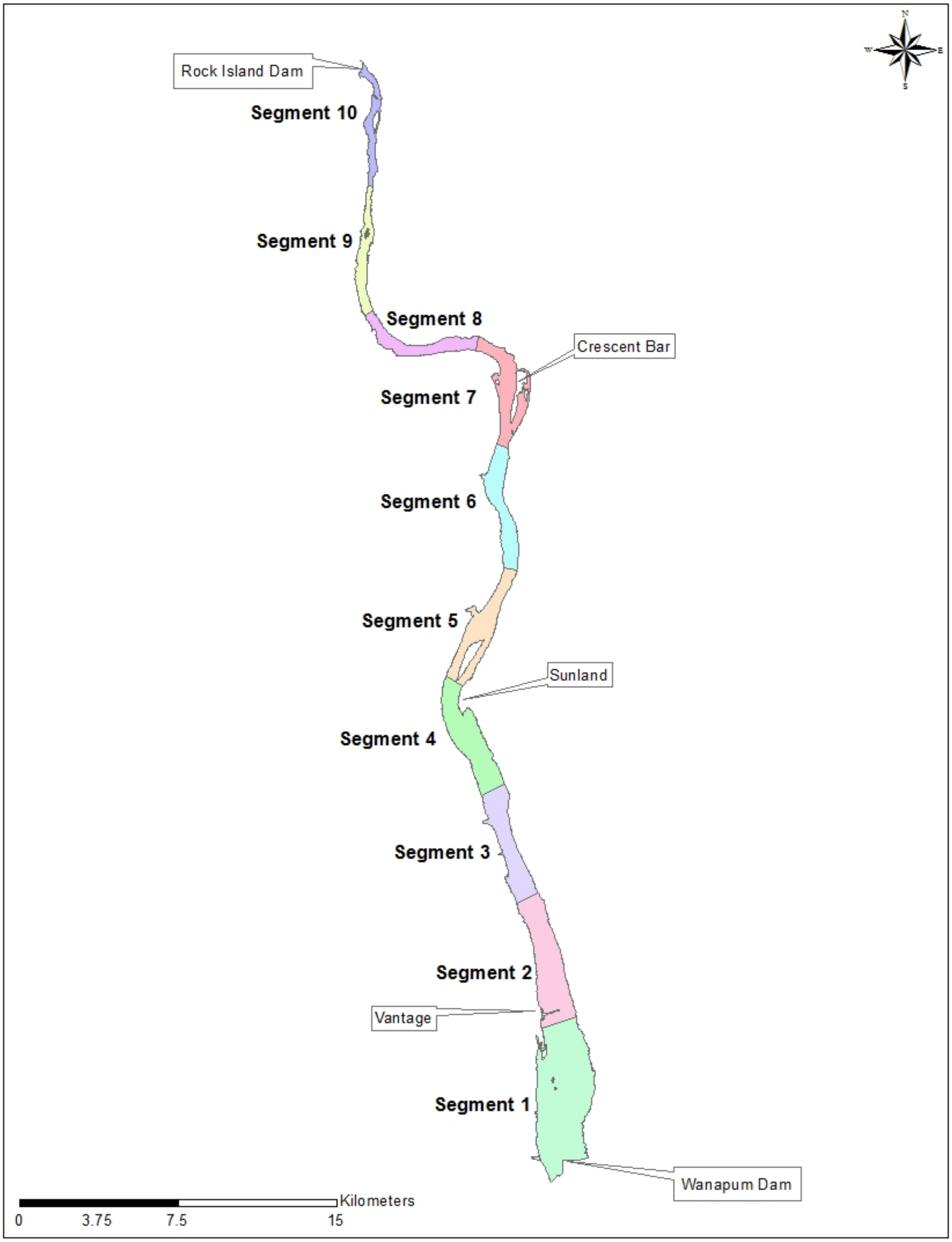


Figure 2. River Segments Used to Characterize Molluscan Fauna

2.3 Freshwater Mussel Species Presence and Density Surveys

Land- and water-based surveys were undertaken to determine the freshwater mussel taxa present and densities within each of the 10 river segments. Five survey zones were established and measured within each river segment; progressing from just below the emergency drawdown water line up to the lowest areas routinely dewatered during normal hydropower operations (Figure 3). To select the plot center points along each transect, surveyors determined the distance between the OLWM and current river level using a range finder or global positioning system (GPS) unit.

This linear distance was then divided by five, and the resulting intervals were used to designate the location of each plot along each transect (Figure 3). The center of the first and last plots were located one-half the length of an interval from the current river level and OLWM, respectively, to maintain even spacing. Resulting intervals were recorded and sub-meter accuracy GPS readings of each center point captured. Three circular plots were surveyed between the OLWM and the Wanapum Lake emergency drawdown water line found at the time of the survey (late March through early April) on both sides of the river along each transect. In some areas, plots were inaccessible due to steep slopes and not surveyed. A single plot also was established within the zone between the OLWM and ordinary high water mark to record mussel densities observed within the shoreline area routinely dewatered during routine hydropower operations. In-water surveys were also completed at every other transect, alternating between right bank and left bank. Because the unanticipated high densities of mussels encountered massively expanded field time at each survey plot site, de-watered plot points 2 and 4 were dropped after work commenced, to reduce total time in the field to an acceptable length. Even with this reduction

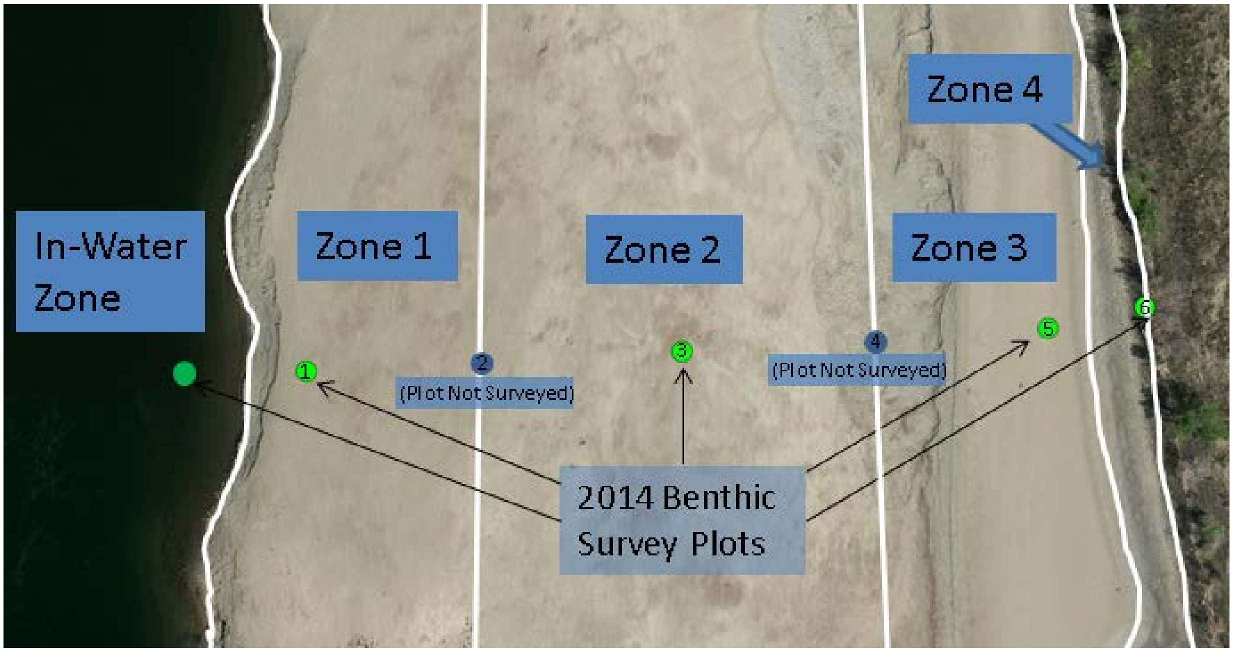


Figure 3. Illustration of Benthic Survey Plots along Transects and Inundation Zones

in surveyed plot sites a significant total of 233 plots were sampled for mussels (Table 2).

Underwater surveys were conducted using self-contained underwater breathing apparatus (SCUBA). Divers surveyed from within 1 m above the river bottom in a circular path around the center point of each plot and recorded any mussels present. The primary in-water survey plot river depth was 10 ft (3 m); however, additional surveys were conducted in five areas down to 30 ft (9.1 m) to examine potential changes in mussel densities in deeper water.

Each plot radius surveyed at each center point generally ranged between one (3.14 m^2) and four meters (50.3 m^2), depending on the relative abundance of native freshwater mussels encountered within each plot (1 m radius plots were used when more than 50 individuals were expected to be counted within the 4 m radius plot). In a few instances, the interval determined between plots was less than 1 m and in other instances, conditions such as steep slopes prevented the field team from measuring the entire plot area.

Any sign of a potentially burrowed mussel was inspected and excavated to no more than 25 cm depth to determine if a mussel was present. All mussels occurring within Plot 3 (Zone 2) were measured using calipers when less than 50 mussels were found there. When mussel densities were greater than 50 individuals per plot, only specimens within a 1 m radius of the center point were measured and recorded. The length, height, and width of each mussel within the selected plot radius was measured and recorded to the nearest millimeter on a field survey form. Any recently consumed mussel remnants observed within the plot were recorded as “depredated.”

2.4 Freshwater Gastropod and Sphaeriacean Clam Species Presence and Density Surveys

Freshwater gastropod (snail) and sphaeriacean clam (pea and Asian clams) species and densities were determined from within a 0.1 m^2 sub-plot measuring 30 cm x 30 cm in the dewatered areas. These were initially to be located within on-land transect plots 1, 3, and 5 (mid-level dewatered flow band) at every other transect (3 km intervals), alternating between left and right banks. A total of five transects were sampled this way. However, as the project progressed it became obvious that processing and picking these many samples would be prohibitive of time and budget; so for the remaining transects one random plot was chosen for each transect sampled for gastropods and sphaeriacean clams. A total of 28 plots spread over the 60 km study area were sampled for gastropods and sphaeriacean clams (Table 2; Appendix 5.4). Snail and sphaeriacean clam sub-plots were placed in the center of the larger mussel plot provided the entire plot frame occurs within the dominant substrate type found within the larger mussel plot. The material within the 0.1 m^2 sub-plot was removed to a depth of 2.5 cm and sieved. Sub-plot material was sieved using 10 mm or down to 600 μm mesh size, when necessary, to retain mollusks while reducing sediment sample size.

2.5 Laboratory Proceedures

The sediment samples containing snail and sphaeriacean clam specimens obtained from within each sub-plot were placed in containers and preserved with isopropyl alcohol and subsequently sent to a malacologist (Deixis Consultants) for proper identification and enumeration. To facilitate picking, each sample was run through a series of Taylor standard brass sieves, smallest being 40 mesh (<0.5 mm), to separate out different size classes of sediment and mollusks and remove more of the fine sediment. All sub-plot size classes were separately picked using either forceps or a fine brush depending on dimensions or fragility of the mollusks present. Picking was done at low power under a Leica MZ 7.5 binocular dissecting scope, The snails and sphaeriacean clams were then identified and segregated by species, enumerated, and stored in labeled bottles in 95% ethanol. The processed sediment and taxa not picked, such as insects, were retained in the original containers sent to Deixis in alcohol. Specimens were classified as dead or live based on the presence of soft tissue within the shell. While identifying and enumerating dead snail specimens was useful to characterize overall species richness within the project area, the cause of death for snail specimens classified as “dead” (i.e., no soft tissue present in the shell) would not likely to have been the result of the emergency drawdown because of the relatively short time period between the dewatering event and when the specimens were collected.

The molluscan datasets (mussels; gastropods and sphaeriacean clams) were entered into MS Excel® spreadsheets, checked for accuracy, and then summarized by river segment, inundation zone, and other associated physical characteristics such as substrate size class. Central tendencies and variations of the survey results were represented using means and standard errors (SE), respectively. The variance (SE) statistics were calculated using the mean of mean mussel densities measured for each transect (left and right banks combined) within each river segment. Each river segment had four transects, and each transect generally had six plots (three on the right bank and three on the left) for a total of 24 plots per river segment. In some cases, however, the transects occurred on steep cliffs and plots were inaccessible and so not surveyed. Variances for inundation Zone 3 were calculated using standard deviations because only two plots (n=2) were located in this zone in each transect. As a result it was not possible to more precisely calculate a mean of means for each river segment in Zone 3.

2.6 Identification Methods

The methodology for mussel identification described by Nedeau et al. (2009) was used for this study. Gastropod and sphaeriacean taxonomy was based on Burch (1975a, 1975b, 1989), modified where necessary by Taylor (1981) and Turgeon et al. (1998). The latter was used as the source for common names. The periodical literature not necessarily cited here also was used extensively to update all sources and reflect more recent taxonomic changes (see Appendix 5.3 for changes).

2.7 Extent of Dewatered Riverbed Area and Total Organisms Lost Determinations

The extent of riverbed areas dewatered during the February 2014 emergency drawdown within each river segment was calculated by creating a geographical information system (GIS) polygon feature class for the entire project area to quantify the dewatered area (Zones 1, 2, and 3). This effort was completed using high-resolution aerial imagery, breaklines, elevation contours, and terrain datasets of the Wanapum Dam Columbia River corridor collected during March 2014 (provided by Grant PUD). The GIS feature class polygons were built using a combination of water edge break lines, digital elevation contours, and rectified aerial imagery. The imagery showed the water’s edge immediately after the emergency drawdown event, the persistent riparian vegetation perimeter, and color contrast of the substrate routinely dewatered. The water edge was represented using the supplied water breaklines and adjusted to the imagery where needed. The upper water level was digitized by following the contrast line created by the routinely dewatered substrate. Cliff faces and/or persistent vegetation perimeters were used when the routinely dewatered surface was vertical or not clearly visible in the imagery. Islands of land and standing pools of water within the dewatered zone were not included in the surface area estimates.

Once the perimeter of the dewatered area exposed by the emergency drawdown was digitized, the ESRI 3D Analyst extension Interpolate Polygon To Multipatch tool was used to calculate the surface area of the dewatered zone. This tool creates a multipatch polygon feature class from the supplied terrain and calculates the surface area from the portions of the terrain dataset that fall within the polygon perimeter.

The aerial extent (surface area) of the dewatered regions (Zones 1-3) within each river segment was then multiplied by the density estimates (mean and 95% confidence intervals[+/- 2SE]) of mollusks to estimate the total number of organisms lost as a result of the river drawdown.

2.8 Fishes and Other Organisms Documented

Blue Leaf Environmental conducted a juvenile lamprey sampling and survey effort in early March 2014. Sampling locations were selected based on Grant PUD's pre-existing juvenile lamprey sampling sites. From these sites, Blue Leaf selected eight locations that were accessible by land and a few tributaries accessible by boat. Staff sampled four of eight sites between Rock Island and Wanapum dams using an ABP-2 Backpack Electrofisher set to 125 volts at 3 pulses/second. Sampling occurred in 20 minute increments using a wide sweeping pattern along the shoreline in 0-1 m depth at a slow walking pace. Sampling was completed by a three-person team: one to operate the backpack electrofisher and two to capture any lamprey observed using long-handled dip nets. Lamprey collected were measured and returned to the river.

In addition to juvenile lamprey, the sampling team recorded observations of pools and stranded fish from the OLWM to the water's edge. Species composition and abundance were recorded for all stranded vertebrates as well as the habitat.

3.0 RESULTS & DISCUSSION

Presented here are the results of land- and water-based field surveys conducted by EAS personnel in the study area between mid-March and early April 2014. This section covers actual plots and plot areas surveyed; snail and bivalve species encountered; their richness, densities, and distributions (in Wanapum Lake area and occurrences elsewhere in the Columbia River); and total area and numbers of mussels dewatered.

3.1 Plots Surveyed in Dewatered and In-Water Regions of the Study Area

Within the dewatered regions of the study area, a total of 233 plots encompassing 8,060 m^2 were surveyed for freshwater mussels. Twenty-eight plots encompassing a total of 2.8 m^2 were surveyed for snails and sphaeriacean clams (Tables 2 and 3; Appendix 5.4).

Table 2. Number of Plots Surveyed in Dewatered Regions of Wanapum Lake

	River Segment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Snails and fingernail clam Plots	6	0	3	1	4	2	4	3	3	2	28
Mussels Survey Plots	26	15	22	17	20	26	28	26	27	26	233

Table 3. Number of Freshwater Mussel Plots and Sum of Plot Area Surveyed in Dewatered Zones of Wanapum Lake

Zone	**# Plots**	**Sum of Plot Area (m^2)**
1	79	2499
2	68	2533
3	67	2714
4	19	314
Total	233	8060

In addition, SCUBA divers surveyed 39 plots encompassing 1,206 m^2 of in-water riverbed area for freshwater mussels (Table 4). Riverbed areas ranged from 10 ft (3 m) to 30 ft (9.1 m) depths.

Table 4. In-Water Freshwater Mussel Plots and Plot Area Surveyed in Wanapum Lake

Depth (ft) below Water Line	**# Plots**	**Sum of Plot Area (m^2)**
10	19	955
15	5	63
20	5	63
25	5	63
30	5	63
Total	39	1206

3.2 Mollusk Taxa Encountered

A total of 19 mollusk species were encountered (12 are snails, one introduced, and seven are bivalves including three unionids, three pea clams, and one non-native corbiculid clam) in the Wanapum Lake area (Tables 9 and 10; Appendix 5.4). This area has a much richer freshwater mollusk fauna than previously reported from nearby Columbia River impoundments and has a similar number of species as found in the “free” flowing Hanford Reach (Table 10).

Species richness of both gastropods and bivalves was consistently highest in the upper segments of the study area (Segments 6 through 10) (Tables 5 and 6). Species richness in these regions of the project area is likely due to the increased complexity of hydro-geomorphological characteristics (relatively narrow channels, asymmetrical thalweg, and variation of riffles and pools) of the upper river regions.

Table 5. Number of Freshwater Gastropod Taxa Encountered by River Segment

	Number of Gastropod Taxa		
River Segment	**Live**	**Dead**	**Combined**
1	5	6	6
2	0	0	0
3	2	6	6
4	0	1	1
5	5	5	6
6	6	5	6
7	6	8	8
8	5	8	8
9	6	9	9
10	8	9	9
Totals	9	12	12

Table 6. Number of Freshwater Bivalve Taxa Encountered by River Segment

	Number of Bivalve Taxa		
River Segment	**Live**	**Dead**	**Combined**
1	5	5	5
2	3	3	3
3	7	6	7
4	5	3	5
5	6	6	6
6	6	6	6
7	6	6	6
8	6	6	6
9	6	6	6
10	4	4	4
Totals	7	7	7

The presence of three relatively rare mollusk species also were documented: the ashy pebblesnail (*Fluminicola fuscus*, formerly *F. columbiana*), floater mussel Clade 1 (*Anodonta* Clade 1, formerly *A. californiensis*), and western pearlshell mussel, which was suspected to be extinct in the Columbia River system.

The ashy pebblesnail (as the Columbia pebblesnail) was a federally listed candidate species and currently is a special status species in Washington State. The western pearlshell is listed by WDFW as a monitor species. The WDFW considers the California floater (*Anodonta* Clade 1) as a candidate for listing as threatened or endangered.

Other than the Asian clam and the Big-ear radix, non-indigenous highly invasive species such as the New Zealand mudsnail, quagga mussel, or zebra mussel were not found in any samples collected. Further discussion of mollusk species, abundance, and distribution documented in the study area in 2014 is provided in the following sections.

3.3 Freshwater Mussel Species Richness, Densities, and Distributions

Three distinct freshwater mussels species were found in the project area: Clades 1 and 2 floater mussels (*Anodonta*) and the western pearlshell (Figure 4). Freshwater mussel abundance throughout the project area was relatively high, with average densities ranging between 1 and 8 individuals/m^2, but individual survey plot results ranged from 0 to approximately 22 individuals per square meter (m^2). In comparison, mussel densities recently recorded in the Hanford Reach ranged between 0 to 0.9 individuals/m^2 with an overall average density of approximately 0.3 individuals/m^2 (Lindsey et al. 2013). Although not detected during this effort, the Western ridged mussel (*Gonidea angulata*) was tentatively noted in a report on a limited field survey effort in the dewatered areas of Wanapum Lake carried out by the Yakama Nation Fisheries Resources Management Program personnel in early March (Yakama Nation 2014). It is unlikely that this riverine species would occur in areas impacted by the impoundment of Wanapum Dam. The shell (if correctly identified) likely is a wash down from a tributary into the reservoir or potentially from a Native American mussel midden deposit; one has been reported at Vantage adjacent to Wanapum Lake with *G. angulata* present (Swanson 1962). Since no permanent flowing creeks exits locally, this shell midden deposit likely indicates that *angulata* occurred in the Columbia River in this area before the current impoundment existed.

Floater Mussel Clade 1
Anodonta Clade 1
(formerly *A. californiensis* or *A. nattalliana*)

Floater Mussel Clade 2
Anodonta Clade 2
(formerly *A. kennerlyi* or *A. oregonensis*)

Western Pearlshell
Margaritifera falcata

Figure 4. Photographs of Freshwater Mussels Found in Wanapum Lake, Spring 2014

Mussel densities, including the special status floater mussel Clade 1 (formerly *Anodonta californiensis*), were consistently higher in river segments 2 through 5 (Figure 5). In contrast, western pearlshell were seldom found in downriver segments 1 through 6. However, substantial aggregations (beds) of this species were encountered in the upper regions (river segments 7 through 9) of the project area (Figure 6).

Mean densities of all three species were considerably greatest in dewatered Zones 1 and 2. And while mean densities of both Clade 1 and 2 of the *Anodonta* genera were lower in Zone 3, the western pearlshell mussel was completely absent in Zone 3 (Figure 7). No live mussel specimens were documented in Zone 4, an area routinely dewatered as part of typical hydropower operations.

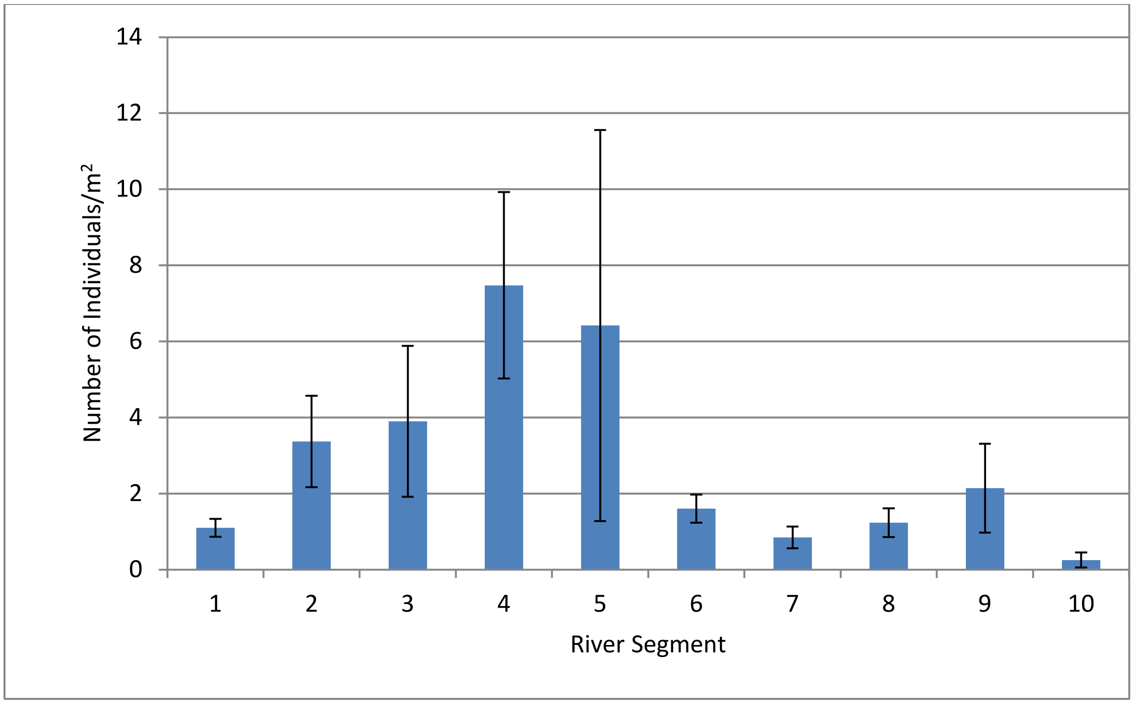


Figure 5. Mean (+/- 1 SE) Freshwater Mussel Densities by River Segment

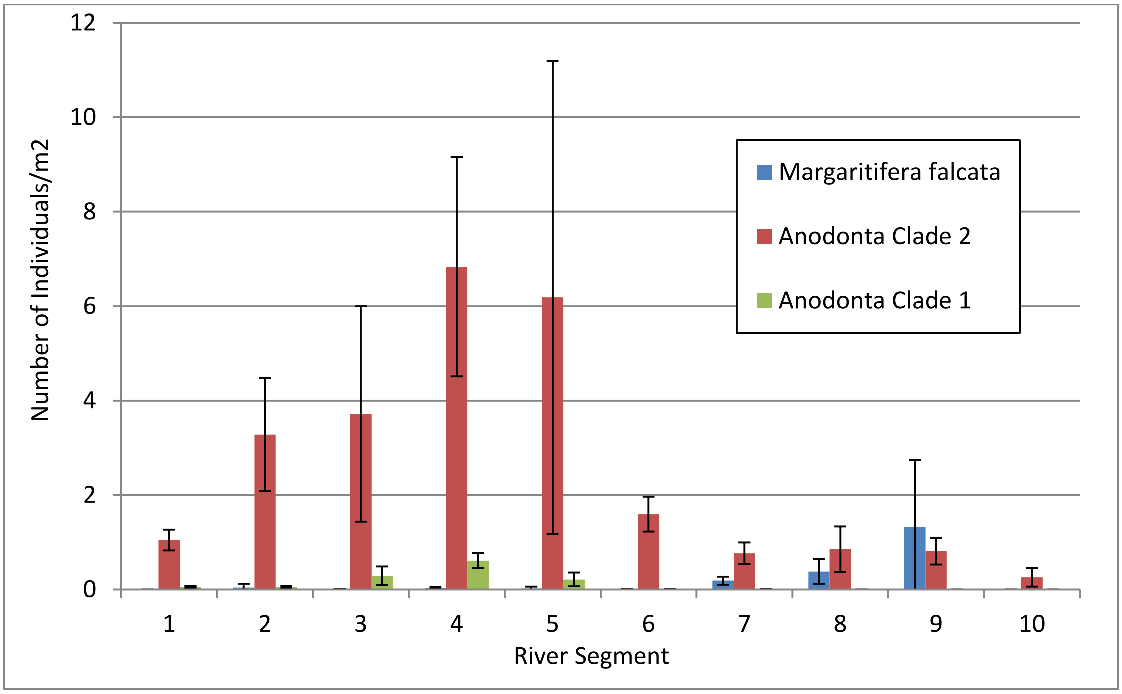


Figure 6. Mean (+/- 1 SE) Freshwater Mussel Densities by Species & River Segment

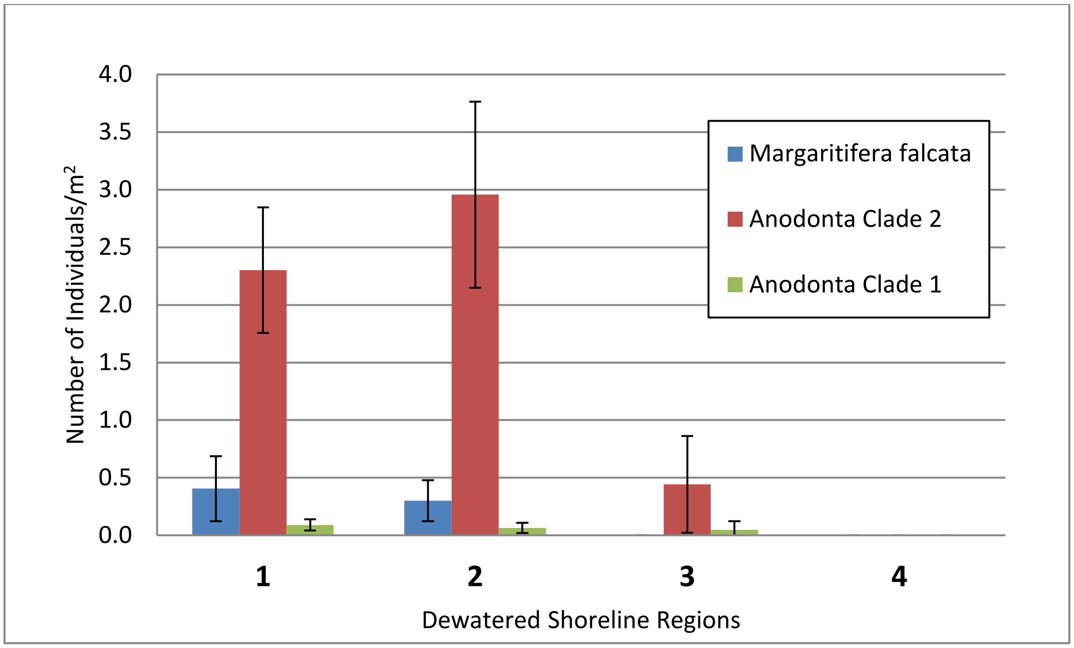


Figure 7. Mean (+/- 1SE) Freshwater Mussel Densities by Species & Dewatered Shoreline Zone

The preponderance of floater mussels (*Anodonta* Clade 1 and 2) documented in lower river segments 2 through 5 was expected because of the relatively wide river morphology and slowing of river flow there, which leads to increased sediment deposition in the area. As shown in Figure 8, mean mussel densities were highest for all three species when the dominant substrate type was sand/silt (Class 1).

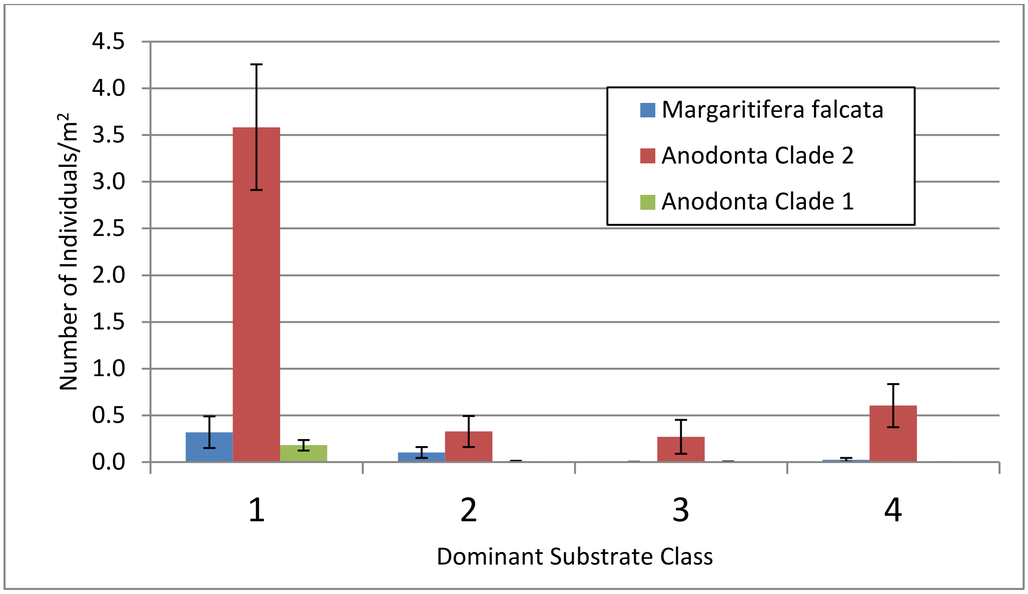


Figure 8. Mean (+/- 1 SE) Freshwater Mussel Densities by Species by Dominant Substrate Class

The preferred habitat of Clades 1 and 2 of the floater mussels includes sediment-dominated substrates. Surprisingly, survey results also showed slightly higher mean densities of the western pearlshell in sand/silt dominated substrates as compared to other larger substrate types. Gravel-dominated substrates are typically described as the preferred habitat of this riverine-type species (Nedeau et al. 2009).

Water-based surveys down to 30 ft (~9 m) below the dewatered water line showed that mean freshwater mussel densities ranged between 1 and 4 individuals/m^2 (Figure 9). Due to time limitations, high sediment levels obscuring the SCUBA diver's visibility, and the lack of flowing water at the selected water-based survey sites, divers were unable to distinguish species composition without disturbing the riverbed. This action would have adversely affected the dive team's ability to accurately count mussels in each plot.

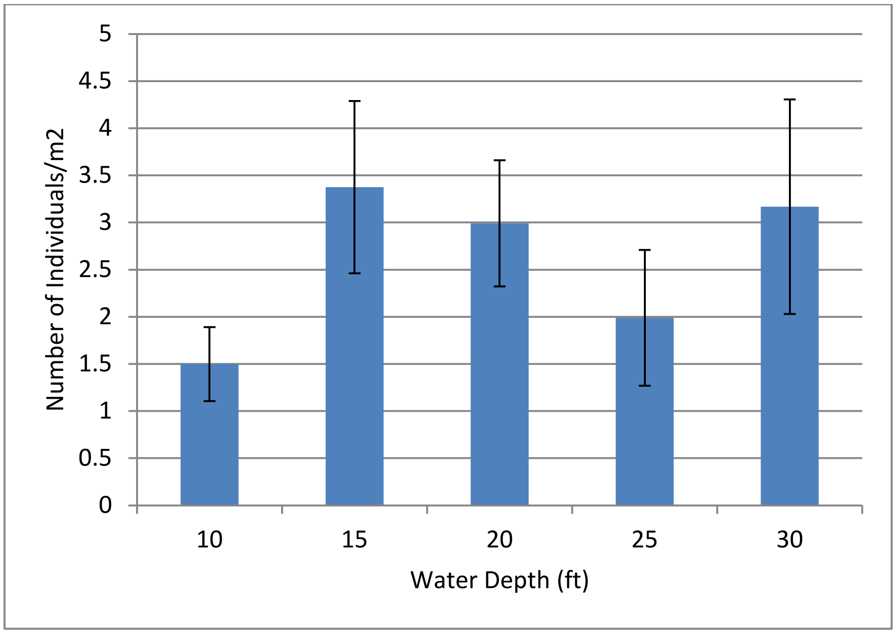


Figure 9. Mean (+/- 1 SE) Freshwater Mussel Densities in Varying Water Depths Down to 30 ft

3.4 Estimates of Total Area and Total Numbers of Mussels Dewatered

As described above, EAS staff generated three dimensional GIS-based polygons of the dewatered regions to estimate the spatial extent of land that was dewatered within each river segment. The area dewatered within inundation zones 1, 2, and 3 were represented as a single region (single GIS shape file polygon) for each river segment. This was necessary because digitizing these zones within the project area separately was highly complex and uncertain. Figure 10 provides an example illustration of the dewatered region mapped and measured within a portion of the project area. Appendix 5.1 contains maps of all ten river segments and shows actual transect lines and dewatered regions mapped. A total of 14.7 square kilometers (km^2) of land was estimated to have been dewatered during the 2014 emergency drawdown (Table 7).

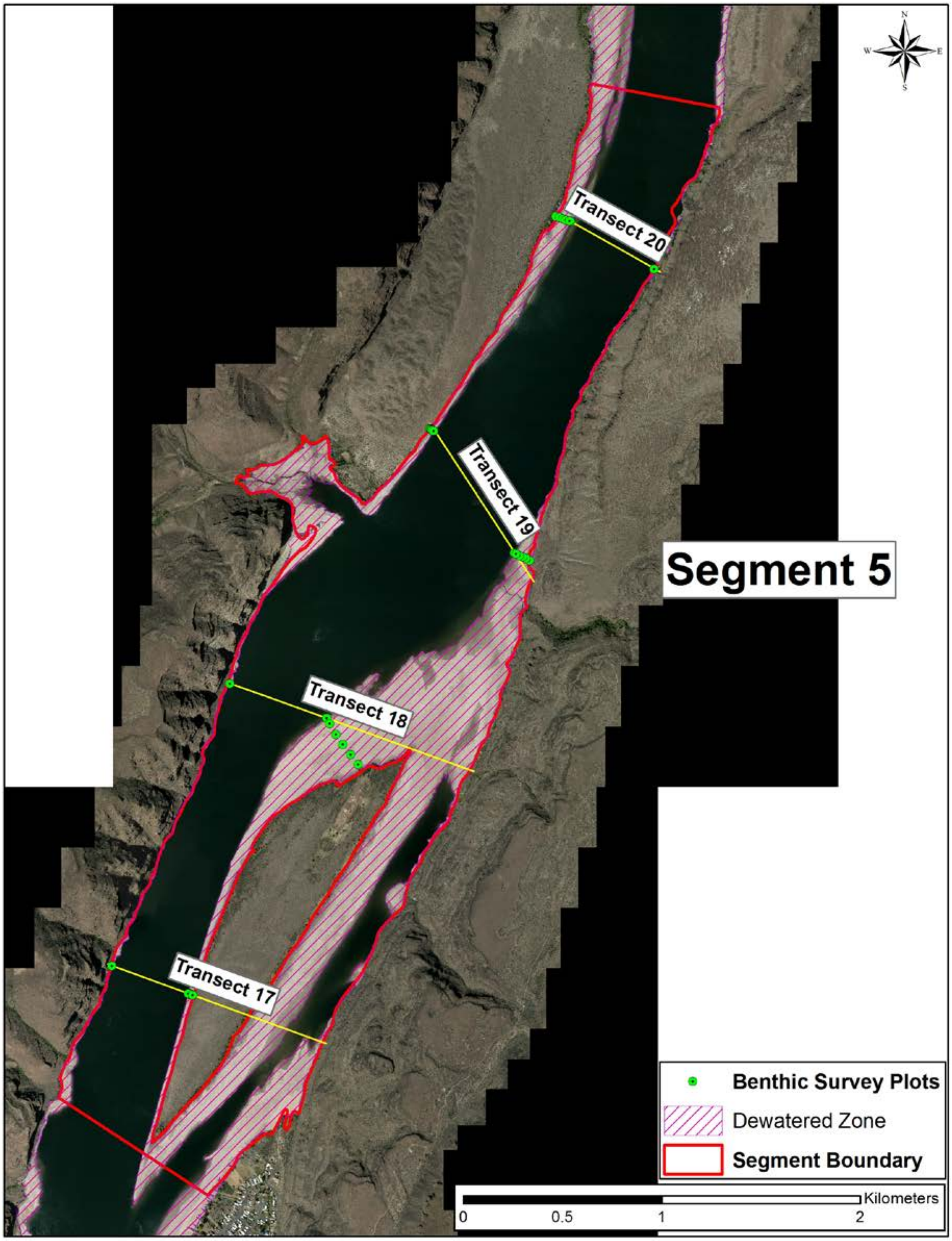


Figure 10. Illustration of GIS-based Mapping of Areas Dewatered during 2014

Table 7. Estimated Area (m2) of Wanapum Lake Dewatered in February 2014

Segment	Zones 1, 2, & 3
1	3,391,200
2	909,810
3	792,469
4	2,545,650
5	1,649,493
6	1,068,386
7	2,208,792
8	920,595
9	777,887
10	477,610
Totals	**14,741,890**

The total number of mussels dewatered during 2014 was then estimated based on densities (mean and 95% upper and low confidence intervals) determined for each species by river segment and multiplied by the total surface area dewatered (Table 8; Appendix 5.2). While mussel numbers were largely comprised of *Anondonta* Clade 2, (see Table 8 below), a total of approximately 37.1 million (range ~11 to 65.8 million) mussels were dewatered during the 2014 emergency drawdown.

Table 8. Estimated Number (Mean +/- 95% C.I.) of Freshwater Mussels Dewatered in Wanapum ReservoirLake, 2014

Statistic	*Anodonta* Clade 1	*Anodonta* Clade 2	Western Pearlshell
Lower 95% C.I.	**1,020,439**	**9,970,191**	**0**
Mean (Average)	**1,899,320**	**33,110,694**	**2,106,203**
Upper 95% C.I.	**3,087,308**	**57,735,437**	**4,996,622**

3.5 Freshwater Snail and Pea Clam Species Densities, Distributions and Habitats

Tables 9 and 10 lists the taxa of snails and sphaeriacean clams identified in the samples sieved and collected throughout the project area. Table 9 briefly summarizes preferred habitats of these species, their general geographic distribution, and likelihood of occurrence. Appendix 5.4 lists the number of specimens found at plot sites. Further life history characteristics of these taxa can be found in Frest and Johannes (1995, 2001) and Appendix 5.3.

Table 9. Snail and Clam Taxa Identified in Wanapum Lake, 2014

Common Name	Scientific Name	General Habitat Characteristic	Distribution	Relative Abundance
Ashy pebblesnail	*Fluminicola fuscus*	Riverine, swift flow, hard substrate, cold water	Eastern Washington	Rare
Unnamed pebblesnails	*Fluminicola n. sp.*	Riverine, swift flow, hard substrate, cold water	Eastern Washington	Rare to Common
Artemesian rams-horn	*Vorticifex effusa*	Riverine, swift flow, hard substrate, cold water	W. Washington, N. Oregon, N.W. California	Uncommon
Creeping ancylid	*Ferrissia rivularis*	Riverine & lacustrine	Central and eastern U.S., southern Canada	Uncommon
Glossy valvata	*Valvata humeralis*	Riverine & lacustrine	Pacific Northwest	Common
Three-ridge valvata	*Valvata tricarinata*	Riverine & lacustrine, soft substrate, macrophytes, cold water	North America; mostly east of the continental divide	Common
Big-ear radix	*Radix auricularia*	Riverine & lacustrine, soft substrate, macrophytes	Europe, Asia, Alaska?; likely introduced to N. America	Common
Prairie fossaria	*Bakerilymnaea bulimoides*	Riverine & lacustrine	U.S. and Canada	Common
Golden fossaria	*Galba obrussa*	Riverine & lacustrine	U.S. and Canada	Common
Unknown Lymnaeidae	*Lymnaeidae*	Riverine & lacustrine	World wide	Common
Tadpole physa	*Physella gyrina*	Pond/lakes, warm water	North America	Common
Button sprite	*Menetus opercularis*	Pond/lakes, warm water	W. Washington, N. Oregon, N.W. California	Common
Ash gyro	*Gyraulus parvus*	Pond/lakes, warm water	North America	Abundant
Ubiquitous peaclam	*Pisidium casertaneum*	Riverine & lacustrine	Northern Hemisphere	Abundant
Ridgebeak peaclam	*Pisidium compressum*	Riverine & Lacustrine	U.S., Southern Canada	Common
Triangular peaclam	*Pisidium variabile*	Riverine & lacustrine	U. S., Southern Canada	Common
Asian clam	*Corbicula fluminea*	Riverine & lacustrine, warm water	World wide	Common

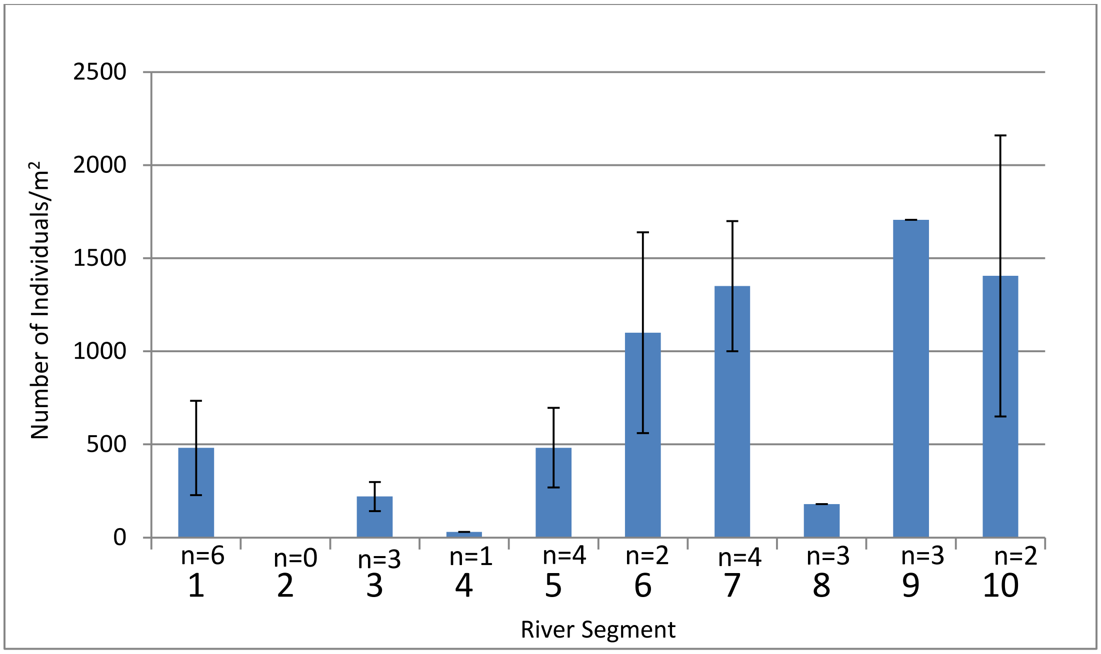


Figure 11. Mean (+/- 1 SE) Freshwater Snail and Pea Clam Densities by River Segment

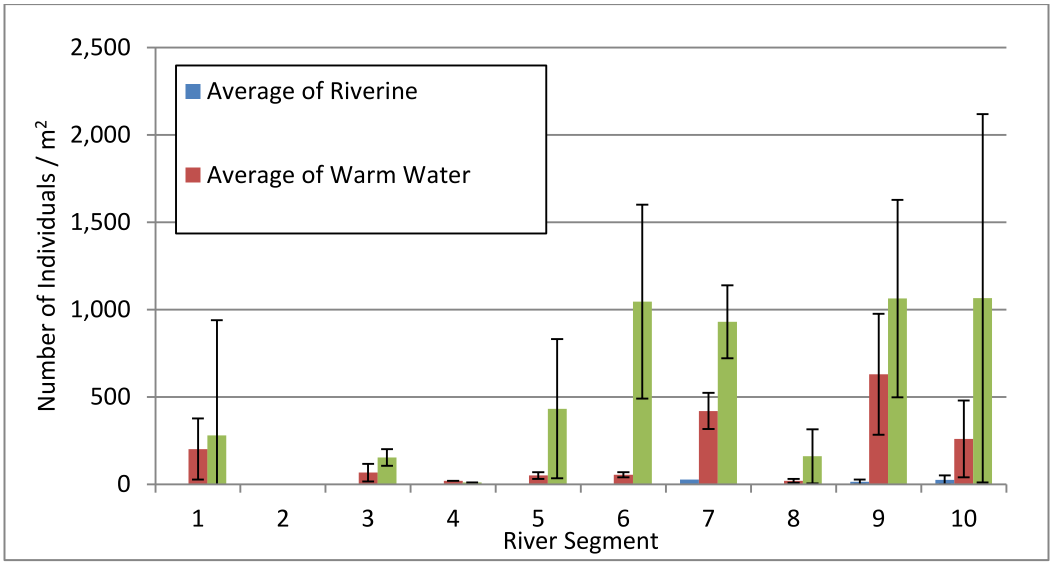


Figure 12. Mean (+/- 1SE) Freshwater Snail and Pea Clam Densities by Niche & River Segment

Mean densities of snails and pea clams (*Corbicula* was ignored) generally ranged between 180 and 1,700 individuals/m^2 with maximum density of 2,630 individuals/m^2 recorded in Segment 9. Densities of snails and pea clams showed a similar pattern as the western pearlshell mussels, where the highest mean densities were consistently noted in the upper river segments (6, 7, 9 and 10) (Figure 11).

Figure 12 further shows relatively high mean densities of riverine-type (hard substrate and fast flowing cold water) snails such as pebblesnails (*Fluminicola* spp.) measured in the upper regions of the project area. Snail and pea clam densities did not appear to vary substantially according to substrate type. Because snail and pea clam densities were measured only in plot 3 (Zone 2), no data were available to examine potential changes in mean densities according to the inundation zones defined in this report.

3.6 Preimpoundment Riverine Molluscan Fauna and Habitat

The area above Wanapum Lake below Rock Island Dam was found to contain remnants of a riverine fauna and habitat that historically existed in the Columbia River. Of particular interest was the occurrence of the unnamed pebblesnail (*Fluminicola sp*.), ashy pebblesnail (*Fluminicola fuscus*), Artemesian rams-horn (*Vorticifex effusa*), western pearlshell (*Margaritifera falcate*), and the widespread creeping ancylid (*Ferrissia rivularis*) within the upper regions of the project area (see “riverine” results in Figure 12 for river segments 7, 9, and 10). Their presence signifies the occurrence of a relatively unique and rare remnant of an upper Columbia preimpoundment riverine habitat (hard substrates and fast flowing, well oxygenated cold water regime) that is also now found only in the downstream Hanford Reach (Table 10).

The occurrence of these riverine taxa and habitat above Wanapum Lake is likely due to how Wanapum Dam and the upstream dams (Rock Island, Rocky Reach, Wells and Chief Joseph dams) are operated. All of these dams (unlike the Grand Coulee Dam) are run-of-the-river hydroelectricity facilities (ROR), either having no storage at all, or a limited amount of storage (referred to as pondage). This allows the Columbia River to flow more rapidly from one dam to the next with less chance of temperature increases and deoxygenation of the water. Reduced reservoir sizes found at these dams also allows for the possibility of the occurrence of riverine habitat between the upper end of a dam impoundment and the next upstream dam. Since these micro riverine areas have swift currents, fine sediments found in reservoirs have not covered these small stretches, preserving the original riverine substrate that riverine mollusks need, such as *Vorticifex* and *Ferrissia*.

Generally, the reported native Hanford Reach snails and unionid clams (no sphaeriid clams were noted though likely present) was similar to that observed in the project area with some notable differences (Table 10). No shortface lanx (*Fisherola nuttalli*) were found in the riverine stretch above Wanapum Lake despite known occurrences of this species upstream of this area (Neitzel and Frest 1993). The western pearlshell (thought locally extinct in the upper Columbia) was found above Wanapum Lake but surprisingly does not survive in the Hanford Reach despite the continued occurrence of the more sensitive shortface lanx in that stretch of the Columbia River.

Interestingly, this project has revealed that several gastropod species ranges end in the Wanapum Lake area. The north-most occurrence of *Vorticifex effusa* and the south-most occurrences of *Valvata humeralis* and *V. tricarinata* in the Columbia River are found here.

Table 10. Mollusk Faunal Comparison of Wanapum Lake with two Upstream Reservoirs and the Downstream Hanford Reach

TAXON NAME	Hanford Reach (RM 343-397)[3]	Wanapum Lake, Wanapum Dam (RM 415.8)	Lake Entiat, Rocky Reach Dam (RM 473.7)[1]	Wells Reservoir, Wells Dam (RM 515.8)[2]
°_Valvata humeralis_	-	X	X	-
°_Valvata tricarinata_	-	X	X	X
°[a]___Fluminicola fuscus___	X	X	-	-
°[a]___Fluminicola___ **n. sp.**	X	X	-	-
*_Potamopyrgus antipodarum_	X	-	-	-
°*___Pyrgulopsis robusta___	X[8]	-	-	-
°[a]___Fisherola nuttalli___	X	-	-	-
Bakerilymnaea bulimoides[5]	X	X	X[5]	X[5]
Galba obrussa[5]	X[5]	X	-	X[5]
*_Radix auricularia_	X	X	X	X
Stagnicola apicina	X	-	-	-
Stagnicola (H.) caperata		-	X	-
Stagnicola elodes	X	-	-	-
Stagnicola (S.) traski		-	X	-
Physella (P.) gyrina	X[4]	X	X	X[4]
Gyraulus (T.) parvus	X	X	-	X
Menetus (M.) callioglyptus	X	X	-	-
°[a]_Vorticifex effusus_	X	X	-	-
[a]_Ferrissia rivularis_	X[9]	X	-	-
Anodonta nuttalliana (Clade 1)	X	X	-	X[6]
Anodonta oregonensis (Clade 2)	X	X	X[7]	-
°[a]___Margaritifera falcata___	X†	X	-	-
°[a]_Gonidea angulata_	-	-	-	-
*_Corbicula fluminea_	X	X	X	X
Pisidium (C.) casertanum	-	X	-	-
Pisidium (C.) compressum	-	X	-	X
Pisidium sp.	-	-	X	-
Pisidium (C.) variabile	-	X	-	-
SPECIES OF CONCERN	5	3	0	0
COLD-WATER SPECIES	9	6	0	1
RIVERINE SPECIES	6	5	0	0
INTRODUCED SPECIES	4	2	2	2
TOTAL NATIVE SPECIES DIVERSITY	16	17	7	7
TOTAL SITE DIVERSITY	20	19	9	9

Table Explanation:

*=introduced species. _Pyrgulopsis robusta_, a native, likely introduced in the Columbia River from the upper Snake River sometime before 1988.

bold=Species Special of Concern (as defined in Frest and Johannes 1993, 1995); _Margaritifera_ should be considered a Species Special of Concern in the Columbia River.

°=cold-water species (see criteria in Frest and Johannes, 1992)

a=preferring stream environments or an amniphile

†=extinct in this stretch

1=DE&S and RL&L (2000)

2=BioAnalysts (2006)

3= Neitzel and Frest (1993); Newell (1998); Frest, et al. (2008); Mueller et al. (2011).

4=identified as _Physella propinqua propinqua_ in previous reports; synonym of _P. gyrina_ (Taylor, 2003).

5=formerly under the genus _Fossaria_

6=identified as _californensis_

7=also identified as _kennerlyi_

8=identified as _Pyrgulopsis_ n. sp.

9=identified as _Ferrissia_ spp. in Neitzel and Frest (1993).

3.7 Fishes and Other Organisms Documented

No other stranded fauna such as lamprey or other fishes were observed in any of the survey plots along the transects and inundation zones in dewatered regions of Wanapum Lake. While stranding of fishes and other organisms was likely in smaller pockets of standing water, little evidence was remaining due to scavenging and/or predation by herons, gulls, and other resident fauna prior to field teams conducting the surveys. However, one crayfish and several crayfish appendages were observed in survey plots.

A limited electrofishing effort was undertaken in March, 2014 to help identify the fish species composition and relative abundance of fishes found in some areas. In the eight selected juvenile lamprey sampling sites, only four were suitable for electroshocking because of the deep soft mud and steep banks. Three juvenile lamprey (all Ammocoetes) were collected from the four sites that were sampled. A variety of fish species and crayfish also were found stranded along the shorelines of the selected sampling sites. Species included redside shiner (*Richardsonius balteatus*), three-spine stickleback (*Gasterosteus aculeatus*), and Pacific lamprey (*Entosphenus tridentata*). Various sculpin (Cottidae) and crayfish (Cambaridae) also were recorded. All fish were collected from the sampling site just upriver of Sunland Estates near river mile 431. Some of these stranded fish and crustaceans were found in pools along the shorelines; however, the majority were found in patches of Eurasian milfoil (*Myriophyllum spicatum*) along the banks. An abundance of tracks from raccoons and various large birds were also observed in areas where stranded fishes and invertebrates occurred. These scavengers could have biased our observations.

A contemporaneous survey effort was carried out on March 5 at four locations by the Yakama Nation FRMP. Their field crews found a total of 10 Pacific lamprey (5 macrophthalmia and 5 larvae) that were desiccated on dry substrate. Other taxa they reported finding in the dewatered areas included sculpins, three-spine sticklebacks, dace, sturgeon, smallmouth bass, crayfish, and mollusks (Yakama Nation FRMP, Pacific Lamprey Project Report March 5, 2014).

An estimate of lamprey habitat dewatered during 2014 was made by cross-referencing substrate measurements made during this study to substrate habitat types considered useful for interpreting lamprey habitat preferences (Close and Aronsuu 2003, Hansen et al 2003) (Table 11). The proportion of plots exhibiting the lamprey habitat conditions were then represented for each river segment and the total area by multiplying the dewatered regions mapped during this project. River segments 1 through 7 contained relatively higher proportions of habitat preferred by lamprey (Figure 13) and comprised a total of approximately 10Km2 of Wanapum Lake dewatered during 2014 (Figure 14).

Table 11. Cross-reference of substrate typing used during the current project to Lamprey Habitat Types 1 through 3.

Lamprey Habitat Type	**Literature Based Lamprey Habitat Description (1Close and Aronsuu 2003, 2Hansen et al 2003)**	**2014 Field-Based Substrate Classifications (Platts et. al. 1983)**
Type 1	1) Mixture of soft sediment particles including silt, clay, fine organic matter, and some sand 2) Preferred larval habitat that usually consists of sand, fine organic matter, and cover (detritus, aquatic vegetation), which is usually formed in areas of deposition	Dominant and Subdominant Substrates were both Type 1 Substrates
Type 2	1) Similar to Type I habitat but with a larger component of sand 2) Acceptable, but not preferred, larval habitat that usually consists of shifting sand, gravel, or rubble, and very little or no fine organic matter, but is soft enough for larvae to burrow into	Either Dominant or Subdominant Substrate was classified as Type 1 Substrate or Substrate was Embedded 76-100% with Fines
Type 3	1) Bedrock, hard clay, cobble, or coarse gravel substrates 2) Cannot be penetrated by larvae, so is unacceptable habitat, and usually consists of bedrock or hardpan clay, with rubble and coarse gravel	All other substrate combinations not described in Lamprey Habitat Type 1 and 2

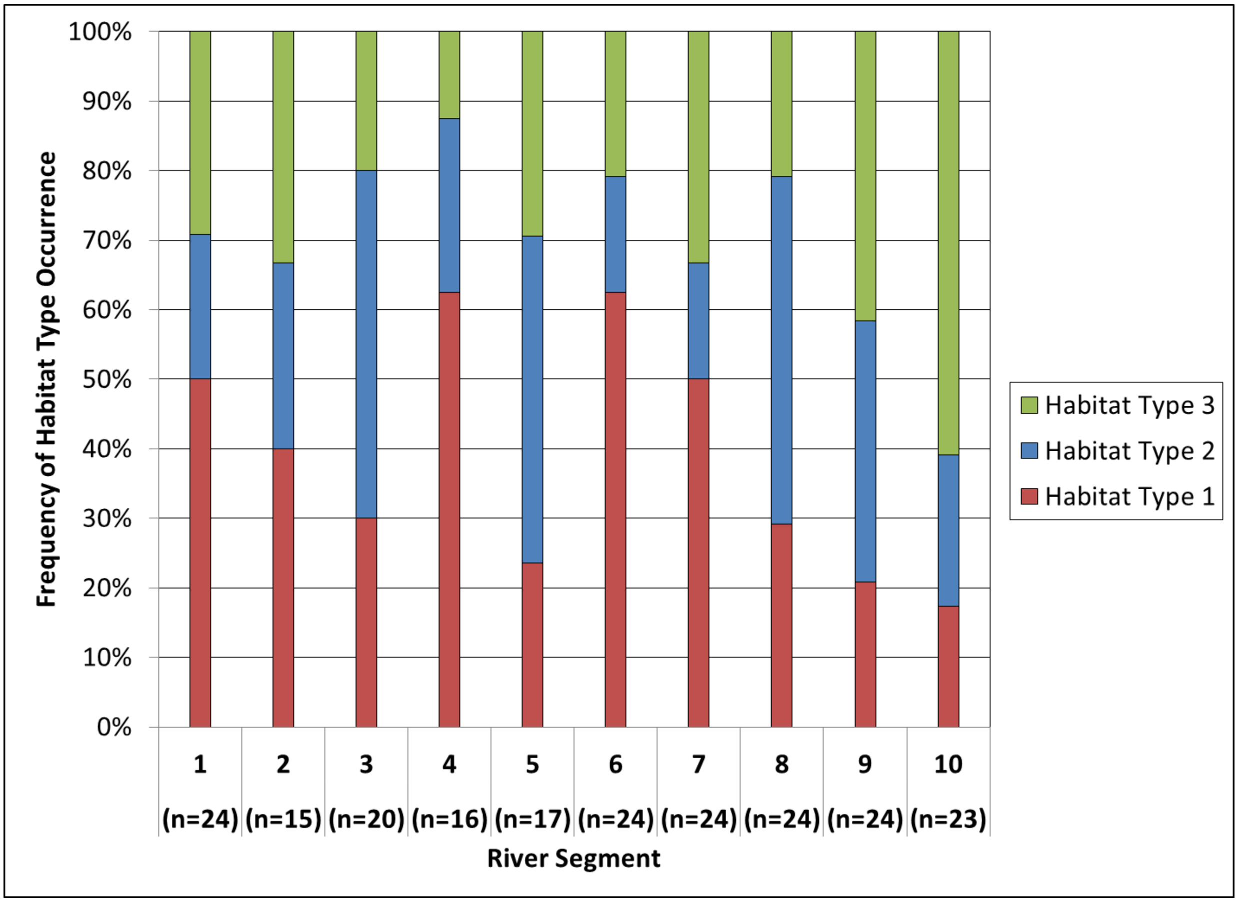


Figure 133. Rearing Lamprey Habitat Types by Wanapum Lake River Segment

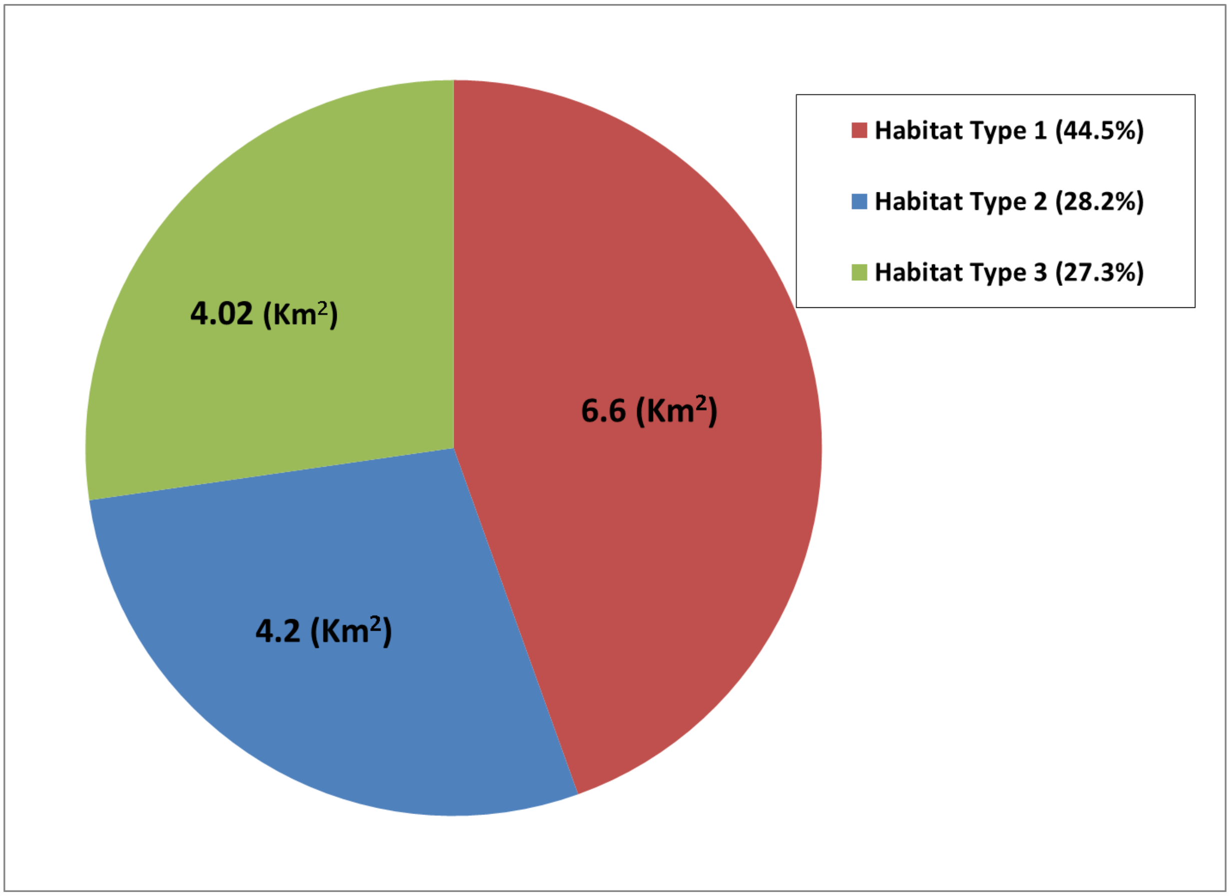


Figure 14. Cumulative Rearing Lamprey Habitat Types by Wanapum Lake, (Km2)

3.8 Discussion of Molluscan Recoveries

Studies on recovery of mollusks from reservoir drawdowns are essentially nonexistent, especially in the Columbia River basin. In the most simple terms, however, we know the ~14.7 km^2 Wanapum Lake shorelines exposed in the 2014 emergency drawdown had established a mussel population of ~ 37 million (estimated to be between 11 and 65 million) within a 50 year time frame (the dam was constructed and these river shoreline areas were inundated in 1964). This information suggests an overall annual mussel colonization rate during the past 50 years of approximately 740,000 individuals per year for the ~14.7 km^2 area, or roughly 0.05 individuals/m^2/yr. However, a number of unknown factors such as historical host species and mussel densities and carrying capacity of the area greatly limit our ability to predict mussel recovery rates following the emergence drawdown event. The next best that can be said, without recovery monitoring data in-hand, is to compare the relative dispersal abilities between the major groups of freshwater gastropods and bivalves and species within the gastropods and bivalves based on their life history characteristics. The dispersal rates of most freshwater mollusks are generally poorly known (Kappes & Haase 2012). Because invasive species dispersal can be easily tracked, knowledge of the dispersal capability of invasive species surpasses that known for native species (Kappes & Haase 2012).

Gastropods can be divided into three major groups, but only two, Prosobranchia and Pulmonata apply to freshwater snails. Though now considered not valid divisions because they are polyphyletic (Ponder & Lindberg 1997; Jorge et al. 2010), they are still useful to describe the dispersal and recovery potential of freshwater snails that occur in these two groups. Pulmonates are more often passively dispersed than prosobranchs, who most often actively disperse (Taylor 1988). Active dispersers (prosobranchs) move from one area to another through their own efforts and as a result consist of species with limited geographic ranges with high endemism (Taylor 1988). pulmonates more commonly rapidly disperse passively (i.e., by animals such as fish, birds, amphibians or mammals) to new areas and generally include species with widespread geographic ranges. Pulmonates may also be faster active dispersers than prosobranchs (Kappes & Haase 2012). The two groups can be easily separated. Unlike pulmonates, prosobranch snails generally have separate sexes (*Valvata* is a exception) and an operculum. Pulmonates are hermaphroditic and do not have separate sexes, allowing them to mate with any individual or in some cases to self fertilize, an advantage most prosobranchs lack. Despite the presence of an operculum, most prosobranchs are more sensitive to temperature extremes than pulmonates and are restricted to perennial water whereas pulmonates occur in perennial to seasonal water habitats. As a result prosobranchs are more likely to die of heat prostration when aerially transported out of water. However, because prosobranchs have an operculum, they have been observed to survive passage through the gut of fishes more readily than pulmonates and could be passively dispersed this way (Brown 2007).

Of the gastropods that occur in Wanapum Lake, *Fluminicola* and *Valvata* are prosobranchs while all the rest of the snails are pulmonates. Both *Fluminicola* and *Valvata* will likely have the slowest recovery rates from the drawdown of all the snails present, with *Fluminicola* being the slower of the two. No active dispersal rates have been determined for either genus in the scientific literature so estimates of their recovery rate is not possible with much accuracy. Among the pulmonates, both *Ferrissia* and *Vorticifex* will likely have the slowest rate of recovery but still will be faster than that seen for *Valvata* and *Fluminicola*. *Ferrissia* is a limpet and *Vorticifex* is nearly like a limpet. Both likely do not move very fast or far and generally stay on hard substrates (cobbles, boulder or bedrock) or sometimes as seen in *Ferrissia* on aquatic plants. Clear evidence of transport by birds is found with the occurrence of *Vorticifex* (likely through its eggs), along with *Menetus* and lymnaeids, in the landlocked Crater Lake, Oregon, created by the eruption of Mt. Mazama over 5600 years ago (Brode 1938; Zdanowicz et al. 1999). The rest of the pulmonates, *Bakerilymnaea*, *Galba*, *Stagnicola*, *Physella*, *Gyraulus* and *Menetus* are both quick active and passive (mostly by birds) dispersers. Dispersal is also facilitated in these snails by the presence of pallial lung instead of a gill. These snails have been observed to fill this lung with air allowing them to float on the surface of water bodies.

It is unlikely that any of these snails will be dispersed downstream by a flood event, especially in the upper “riverine” part of Wanapum Lake, as upstream dams tightly control the flow of the Columbia River. However, all these snails will display positive rheotaxis and will move against any flow, usually resulting in upstream movement.

Of the freshwater bivalves (clams and mussels) in Wanapum Lake, unionids (native freshwater mussels) will likely be the slowest to recover from the drawdown, possibly slower than that seen in prosobranch snails. Adult mussels are essentially sessile but have life spans ranging from roughly 20 years (*Anodonta*) to 60 years (*Gonidea*) to perhaps 120 years (*Margaratifera*).

Unionids typically have separate sexes (though individuals can be hermaphrodites), the exception, even for the genus, can be found in *Margartifera falcata*, which is strictly hermaphroditic (Heard 1970). Dispersal of these bivalves is dependent on specific host fish parasitized by their glochidium larval stage. The recovery of the unionids is closely tied to the distribution and or presence of its host fish or fishes. Sphaeriids, or in this case *Pisidium*, are found in many habitats and have species that are found with widespread ranges, a result of passive transport by birds and the ability to self-fertilize. Like pulmonates, sphaeriids recovery rate from the drawdown will be rapid. Sphaeriids have also been observed to survive passage through fish guts (Brown, 2007). Table 12 summarizes the expected relative rates of recovery for each of the gastropod groups detected in the 2014 Wanapum Lake survey efforts.

Table 12. Expected relative recovery rates of mollusks from the Wanapum Lake drawdown.

Taxon	Slow Recovery Rate	Intermediate Recovery Rate	Fast Recovery Rate
PROSOBRANCH GASTROPODS			
Fluminicola	X		
Valvata		X	
PULMONATE GASTROPODS			
Bakerilymnaea			X
Galba			X
Stagnicola			X
Physella			X
Gyraulus			X
Menetus			X
Vorticifex		X	
Ferrissia		X	
UNIONIDS			
Anodonta	X		
Margaritifera	X		
Gonidea	X		
SPHAERIIDS			
Pisidium			X

4.0 LITERATURE CITED

Bersine, K., V. E. Brenneis, R. C. Draheim, A. M. Wargo Rub, J. E. Zamon, R. K. Litton, S. A. Hinton, M. D. Sytsma, J. R. Cordell, and J. W. Chapman. 2008. *Distribution of the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*) in the Columbia River Estuary and its first recorded occurrence in the diet of juvenile Chinook salmon (*Oncorhynchus tshawytscha*).* Biological Invasions 10: 1381-1388.

BioAnalysts. 2006. *Aquatic Macroinvertebrate Inventory And RTE Assessment. Wells Hydroelectric Project, FERC No. 2149*. Final Report prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington. BioAnalysts, Inc., Boise, Idaho. iv + 21 pp., appendices.

Brode, J. S. 1938. *The denizens of Crater Lake.* Northwest Science 12(3): 50-57.

Brown R. J. 2007. *Freshwater mollusks survive fish gut passage.* Arctic 60: 124–128.

Burch, J. B 1975a. *Freshwater Sphaeriacean Clams (Mollusca: Pelecypoda) of North America*. Malacological Publications, Hamburg, Michigan. xi + 96 pp.

Burch, J. B 1975b. *Freshwater Unionacean Clams (Mollusca: Pelecypoda) of North America*. Malacological Publications, Hamburg, Michigan. xviii + 204 pp.

Burch, J. B. 1989. *North American Freshwater Snails*. Malacological Publications, Hamburg, Michigan. 365 pp.

Burch, J. Q. 1944. *Checklist of west American mollusks.* Minutes, Concological Club of Southern California 38:18.

Chance, D. H. and J. V. Chance. 1985. *Kettle Falls: 1978, further archaeological excavations in Lake Roosevelt*. Anthropological Reports (Research Manuscript Series) No. 84. Moscow: University of Idaho.

Chong, J. P., J. C. Brim Box, J. K. Howard, D. Wolf, T. L. Myers, and K. E. Mock. 2008. *Three deeply divided lineages of the freshwater mussel genus* Anodonta *in western North America*. Conservation Genetics 9(5): 1303-1309.

Chong J. P., J. C. Brim Box, D. A. Nez, and K. E. Mock. 2009. *Isolation and characterization of microsatellite loci in western North American* Anodonta *species.* Molecular Ecology Resources 9(3): 939-943.

Close, D. A. and K. K. Aronsuu. 2003. *Pacific lamprey research and restoration project; 2002 annual report.* Annual report to Bonneville Power Administration, Project #94-026, Portland, Oregon

Counts, C. L., III. 1985. Corbicula fluminea *(Bivalvia: Corbiculidae) in the state of Washington in 1937, and in Utah in 1975*. The Nautilius 99: 18-19.

Counts, C. L., III. 1986. *Zoogeography and History of the Invasion of the United States by* Corbicula fluminea *(Bivalvia: Corbiculidae).* American Malacological Bulletin, Special edition 2: 7-39.

DE&S and RL&L. 2000. *Benthic Macroinvertebrate Survey 1999. Final. Rocky Reach Hydroelectric Project FERC Project No. 2145.* Final Report prepared for Public Utility District No. 1 of Chelan County, Wenatchee, Washington. Duke Engineering & Services, Inc., Bellingham, Washington and RL&L Environmental Services Ltd., Edmonton, Alberta. ii + 29, appendices.

Enbysk, B. J. 1956. *Vertebrates and Mollusca from Lind Coulee, Washington.* Proceedings of the American Philosophical Society 100(3): 267-278.

Foster, M., P. Fuller, A. Benson, S. Constant, and D. Raikow. 2014. *Corbicula fluminea*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. Available at http://nas.er.usgs.gov/ queries/FactSheet.asp?speciesID=92.

Frest, T. J. and P. A. Bowler. 1993. *A Preliminary Checklist of the Aquatic and Terrestrial Mollusks of the Middle Snake River Sub-Basin.* Desert Fishes Council, Proceedings 24: 53-58.

Frest, T. J. and E. J. Johannes. 1992. *Distribution and Ecology of the Endemic and Relict Mollusc Fauna of Idaho TNC's Thousand Springs Preserve.* Deixis Consultants, Seattle, Washington. ii + 291 pp.

Frest, T. J. and E. J. Johannes. 1993. *Mollusc Species of Special Concern within the Range of the Northern Spotted Owl.* Deixis Consultants, Seattle, Washington. iv + 98 pp.; June, 1993 addendum ii + 39 pp.

Frest, T. J. and E. J. Johannes. 1995. *Interior Columbia Basin Mollusk Species of Special Concern*. Final Report prepared for Interior Columbia Basin Ecosystem Management Project, Walla Walla, Washington. Deixis Consultants, Seattle, Washington. xi + 274 pp., appendices.

Frest, T. J. and E. J. Johannes. 2001. *An Annotated Checklist of Idaho Land and Freshwater Mollusks*. Idaho Academy of Science, Journal, 36(2): 1-51.

Frest T. J. and E. [J.] Johannes. 2004. *Some freshwater mollusks of the Lower Columbia River, Oregon and Washington*, 69-88. *In* Sytsma M. D., J. R. Cordell, J. W. Chapman, and R. C. Draheim. *Lower Columbia River Aquatic Nonindigenous Species Survey 2001-2004.* Final Technical Report: Appendices. Prepared for the U. S. Coast Guard and the U. S. Fish and Wildlife Service. Center for Lakes and Reservoirs, Portland State University, Portland, Oregon. iii + 164 pp.

Frest, T. J., E. J. Johannes, and B. L. Tiller. 2008. *Mollusk Observations Along the Hanford Reach of the Columbia River: 100 and 300 Areas River Corridor Baseline Risk Assessment, Appendix F*. *In* Queen, J. M. *Inter-Areas Component of the River Corridor Baseline Risk Assessment Sampling Summary*. River Corridor Closure Contract. Washington Closure Hanford, Richland, Washington, WCH-274, rev. 0. vi + 68 pp., appendices.

Hanna, G. D. 1966. *Introduced Mollusks of Western North America.* California Academy of Sciences, Occasional Paper 48. 108 pp.

Hansen, M. J., J. V.Adams, D. W.Cuddy, J. M. Richards, M. F. Fodale, G. L. Larson, D. J. Ollila, J. W. Slade, T. B. Steeves, R. J. Young, and A Zerrenner. 2003. *Optimizing larval assessment to support sea lamprey control in the Great Lakes.* Journal of Great Lakes Research 29: 766-782.

Heard, W. H. 1970. *Hermaphroditism in* Margaritifera falcate *(Gould) (Pelecypods: Margaritiferidae)*. The Nautilus 83(3): 113-114.

Helmstetler, H. and D. L. Cowles. 2008. *Population Characteristics of Native Freshwater Mussels in the mid-Columbia and Clearwater Rivers, Washington State*. Northwest Science 82(3): 211-221.

Henderson, J. 1929. *Some Fossil Fresh-water Mollusca from Washington and Oregon.* The Nautilus 42(4): 119-123.

Hershler, R. and T. J. Frest. 1996. *A Review of the North American Freshwater Snail Genus* Fluminicola *(Hydrobiidae).* Smithsonian Contributions to Zoology 583. iii + 41 pp.

Hershler, R. and H.-P. Liu. 2004a. *Taxonomic Reappraisal of Species Assigned to the North American Freshwater Gastropod Subgenus* Natricola *(Rissooidea: Hydrobiidae).* The Veliger 47(1): 66-81.

Hershler, R. and Liu, H.-P. 2004b. *A molecular phylogeny of aquatic gastropods provides a new perspective on biogeographic history of the Snake River region.* Molecular Phylogenetics and Evolution, 32: 927–937.

Hershler, R. and H.-P. Liu. 2012. *Molecular Phylogeny of the Western North American Pebblesnails, Genus* Fluminicola *(Rissooidea: Lithoglyphidae), With Description of a new Species.* Journal of Molluscan Studies 78: 321–329.

Howard, J. 2010. *Sensitive freshwater mussel surveys in the Pacific Southwest Region: Assessment of conservation status.* Final Report submitted to the USFS PSW Regional Office, Vallejo, CA under contract #AG-91S8-P-07-0080. 61 pp.

Isom, B. G. 1986. *Historical review of Asiatic clam (*Corbicula*) invasion and biofouling of waters and industries in the Americas.* American Malacological Bulletin, Special Edition No. 2: 1-5.

Isom, B. G., C. F. Bowman, J. T. Johnson, and E. B. Rodgers. 1986. *Controlling* Corbicula *(Asiatic clams) in complex power plant and industrial water systems.* American Malacological Bulletin, Special Edition 2: 95-98.

Jörger, K. M, I. Stöger, Y. Kano; H. Fukuda, T. Knebelsberger, and M. Schrödl. 2010. *On the origin of Acochlidia and other enigmatic euthyneuran gastropods, with implications for the systematics of Heterobranchia.* BMC Evolutionary Biology 10(1): 323.

Kappes, H. and P. Haase. 2012. *Slow, but steady: dispersal of freshwater molluscs*. Aquatic Sciences 74: 1-14.

Landye, J. J. 1973. *Environmental Significance of Late Quaternary Nonmarine Mollusks from former Lake Bretz, Lower Grand Coulee, Washington.* M.A. Thesis, Washington State University, Pullman, Washington. xi + 109 pp.

Lindsey, C., J. Nugent, B. Tiller, and M. Filan. 2013. *Hanford Site Freshwater Mussel Monitoring Report for Calendar Year 2013*, Prepared for the U.S. Department of Energy by Mission Support Alliance, Richland, Washington. 20 pp.

Litton, R. K. 2000. *Youngs Bay benthic invertebrate survey study 2000.* Report to Oregon Department of Environmental Quality. Fisheries Biologist, Clatsop County Fisheries.

Lydeard, C., et al. 2004. *The Global Decline of Nonmarine Mollusks.* Bioscience 54(4): 321-330.

Lyman, R. L. 1980. *Freshwater Bivalve Molluscs and Southern Plateau Prehistory: A Discussion and Description of Three Genera*. Northwest Science 54(2): 121-136.

McMahon, R. F. 1999. *Invasive characteristics of the freshwater bivalve* Corbicula fluminea, pp. 315-343, *in* Claudi, R., and J. H. Leach, *Nonindigenous freshwater organisms: vectors, biology, and impacts*. Lewis Publishers: Boca Raton, Florida. 8 unnumbered + 464 pp.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. *Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions.* Journal of Great Lakes Research 19: 1-54.

Mueller, R. P., G. K. Turner, B. L. Tiller, I. D. Welch, and M. D. Bleich. 2011. *Assessment of the Species Composition, Densities, and Distribution of Native Freshwater Mussels Along the Benton County Shoreline of the Hanford Reach, Columbia River, 2004*. PNNL-19933, Pacific Northwest National Laboratory, Richland, Washington. x + 24 pp., appendices.

Nedeau, E. J., A. K. Smith, J. Stone, and S. Jepsen. 2009. *Freshwater Mussels of the Pacific Northwest.* Second Edition. The Xerces Society for Invertebrate Conservation, Portland, Oregon. 51 pp.

Neitzel, D. and T. Frest. 1993. *Survey of Columbia River Basin Streams for Columbia Pebblesnail* Fluminicola columbiana *and Shortface Lanx* Fisherola nuttalli. Battelle Pacific Northwest Laboratory PNL-8229. Rev. 1. ix + 29 pp., appendices.

Newell, R. I. 1998. *Diversity of Aquatic Invertebrates of the Hanford Reach of the Columbia River, some Tributaries and their Adjacent Springs, Washington State, U. S. A.* Report to the Nature Conservancy of Washington, 34 pp.

Platts, W. S., W. F. Megaham, and H. W. Minshall. 1983. *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. U.S. Forest Service, General Technical Report INT-138, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Salo, L. V. 1985. *Large-Scale Analytic Units: Chronological Periods and Sites*. In *Summary of Results, Chief Joseph Dam Cultural Resources Project, Washington*, edited by S. K. Campbell, pp. 183 - 222. University of Washington, Office of Public Archaeology, Seattle.

Smith, D. G. 2001. *Systematics and Distribution of the Recent Margaritiferidae,* pp. 33-49, *in* G. Bauer and K. Wächtler (eds.), *Ecology and Evolution of the Freshwater Mussels Unionoida*. Ecological Studies 145. Springer-Verlag, Berlin. XXII + 394 pp.

Swanson, E. 1962. *The Emergence of Plateau Culture*. Occasional Papers of the Idaho State College Museum 8. 89 pp.

Taylor, D. W. 1981. *Freshwater Mollusks of California: A Distributional Checklist*. California Department of Fish and Game 67(3):140-163.

Taylor, D. W. 1985. *Evolution of freshwater drainages and molluscs in western North America*, pp. 265-321, *in* Smiley, C. J. (*ed*.), *Late Cenozoic History of the Pacific Northwest*. Pacific Division AAAS and California Academy of Science, San Francisco. 417 pp.

Taylor, D. W. 1987. *Thousand Springs Preserve threatened or endangered snails.* Unpublished Report to The Nature Conservancy, Sun Valley, Idaho, 2 pp.

Taylor, D. W. 1988. *Aspects of freshwater mollusc ecological biogeography.* Paleogeography, Paleoclimatology, Paleoecology 62: 511-576.

Taylor, D. W. 2003. *Introduction to Physidae (Gastropoda: Hygrophila);. biogeography, classification, and morphology*. Revista de Biologîa Tropical, vol. 51 supplement 1, 287 pp.

Taylor, D. W. and R. C. Bright. 1987. *Drainage History of the Bonneville Basin*, pp. 239-256, in R. S. Kopp and R. E. Cohenour (*eds*.), *Cenozoic Geology of Western Utah. Sites for Precious Metal and Hydrocarbon Accumulations*. Utah Geological Association Publication 16, 684 pp.

Turgeon, D. D. et al. 1998. *Common and Scientific Names of Aquatic Invertebrates from the United States and Canada. Mollusks*. Second Edition. American Fisheries Society, Special Publication 26. 526 pp.

Yakama Nation. 2014. *Wanapum Pool Draw Down Lamprey Sampling.* Yakama Nation FRMP, Pacific Lamprey Project. Yakama Nation Fisheries Resources Management Program, Toppenish, WA. 34 pp.

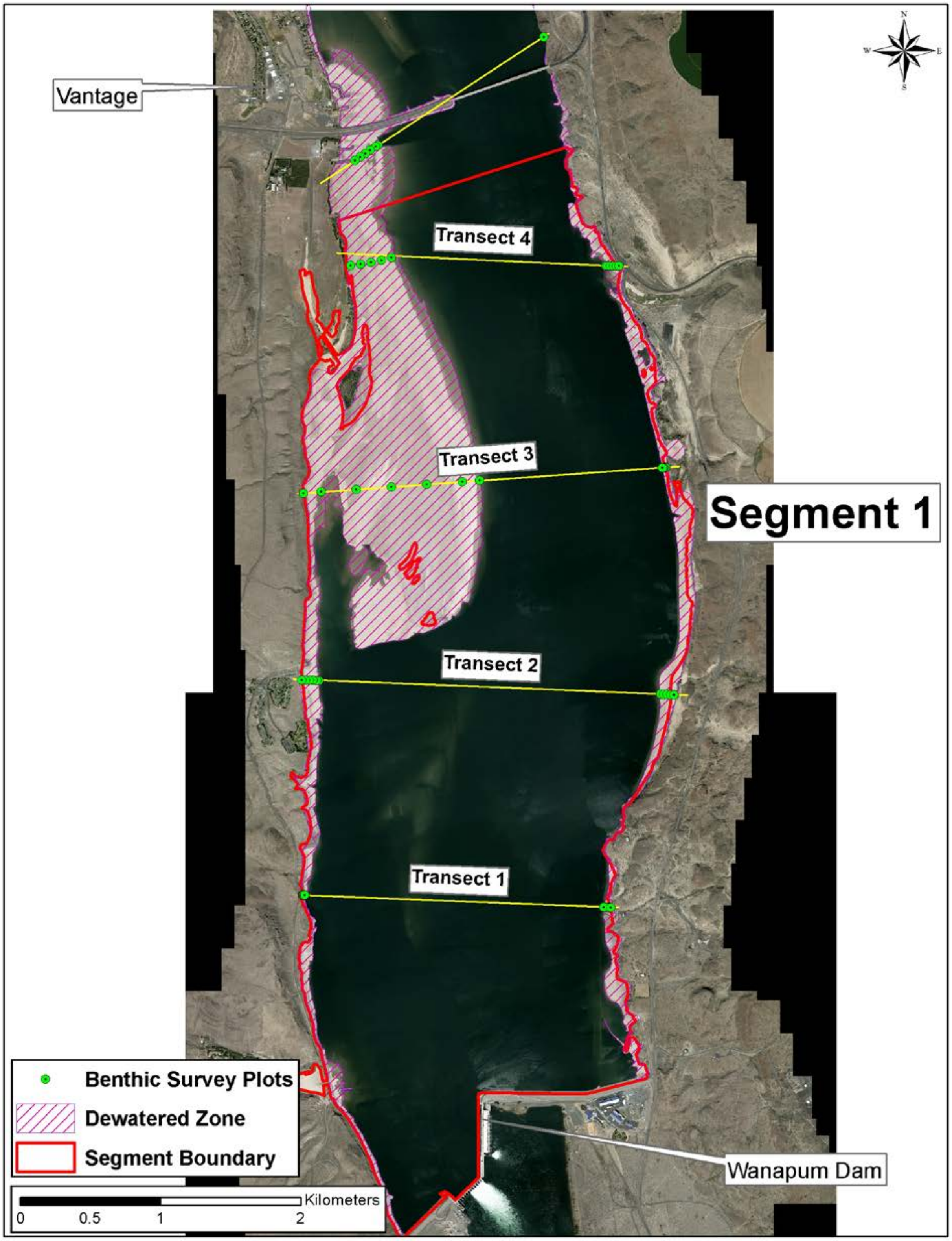
USFWS. 1991. *Endangered and Threatened Wildlife and Plants; Animal Candidate Review for Listing as Endangered or Threatened Species, Proposed Rule*. Federal Register 56: 58804-58836.

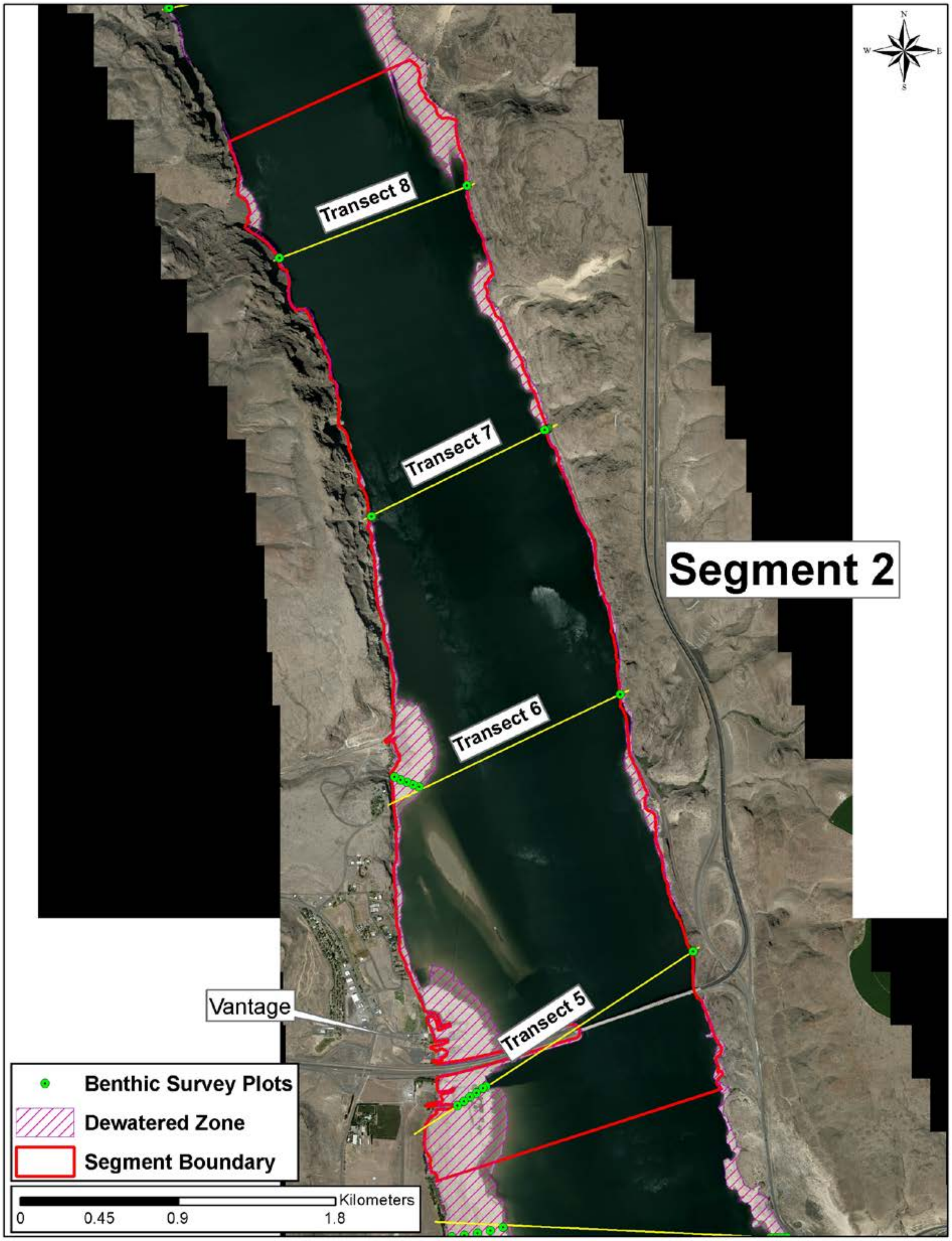
Williams, J. D., M. L. Warren, jr., K. S. Cummings, J. L. Harris and R. J. Neves. 1992. *Conservation Status of Freshwater Mussels of the United States and Canada.* Fisheries 18: 6-22.

Zdanowicz, C. M., G. A. Zielinski, and M. S. Germani. 1999. *Mount Mazama eruption; calendrical age verified and atmospheric impact assessed*. Geology 27(7): 621–624.

APPENDICES

4.1 APPENDIX Maps of Transects and Survey Plots for each River Segment

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Segment 2
Transect 6
Vantage
Transect 5
Benthic Survey Plots
Dewatered Zone
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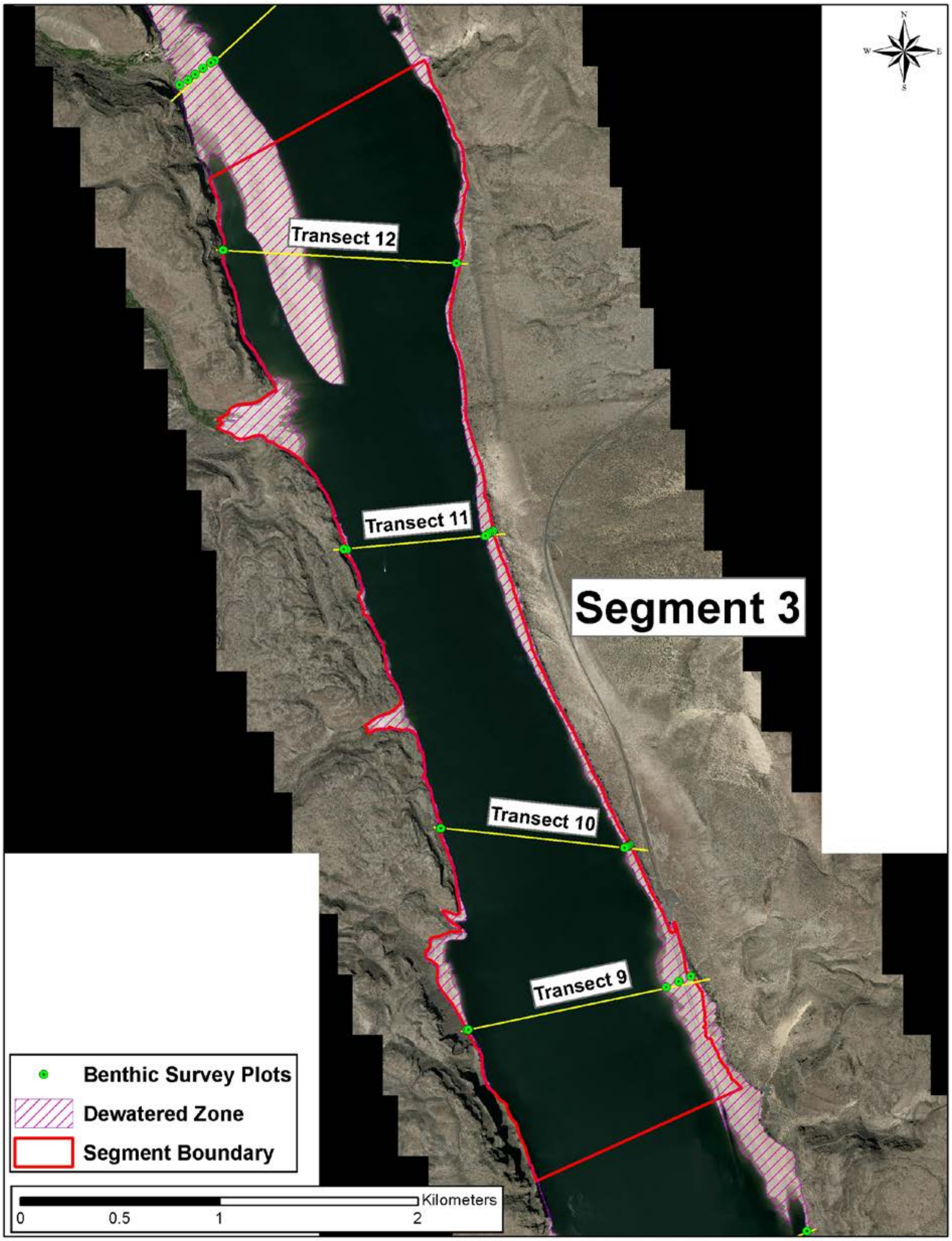
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E
S
Transect 12
Transect 11
Segment 3
Transect 10
Transect 9
Benthic Survey Plots
Dewatered Zone
Segment Boundary
Kilometers
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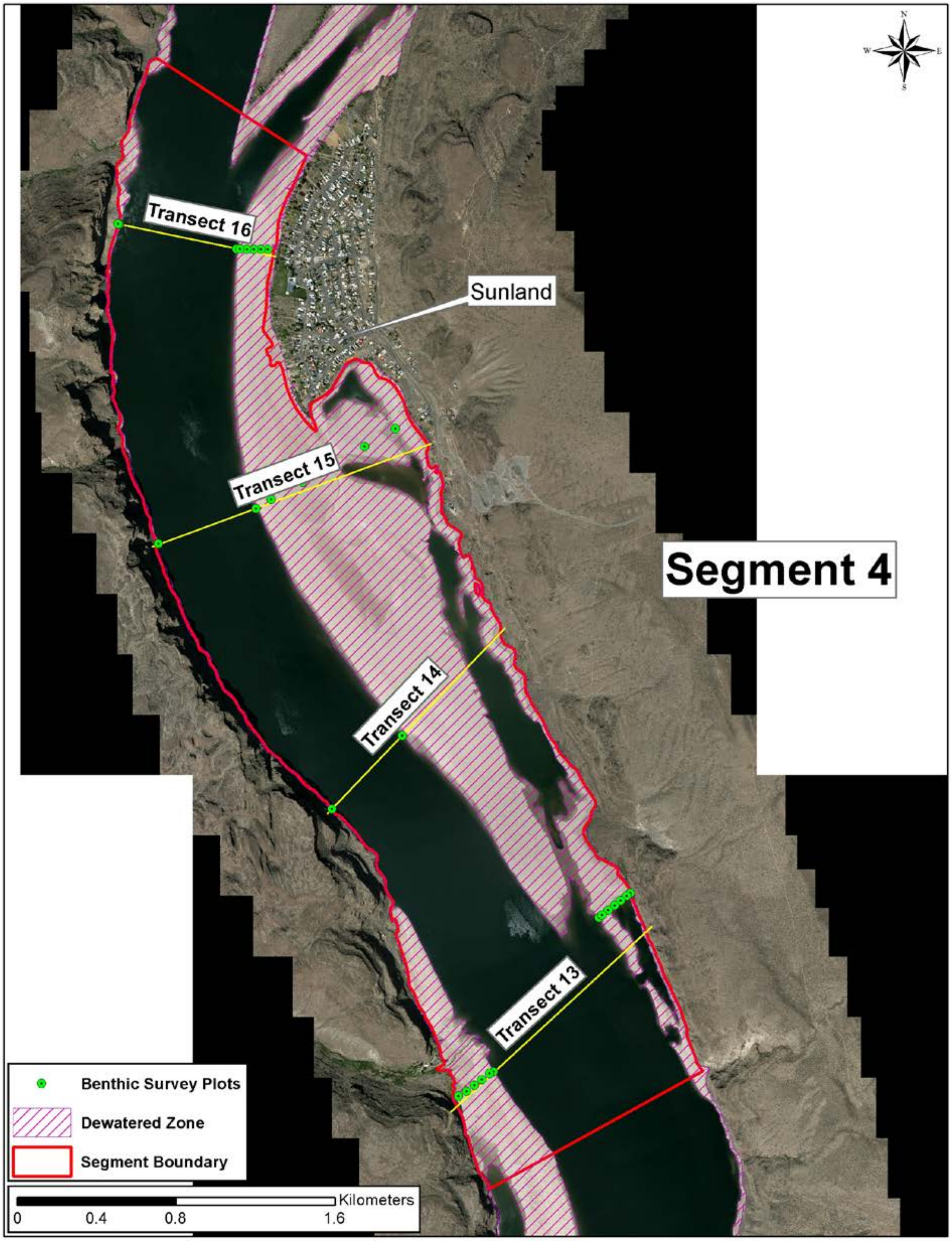
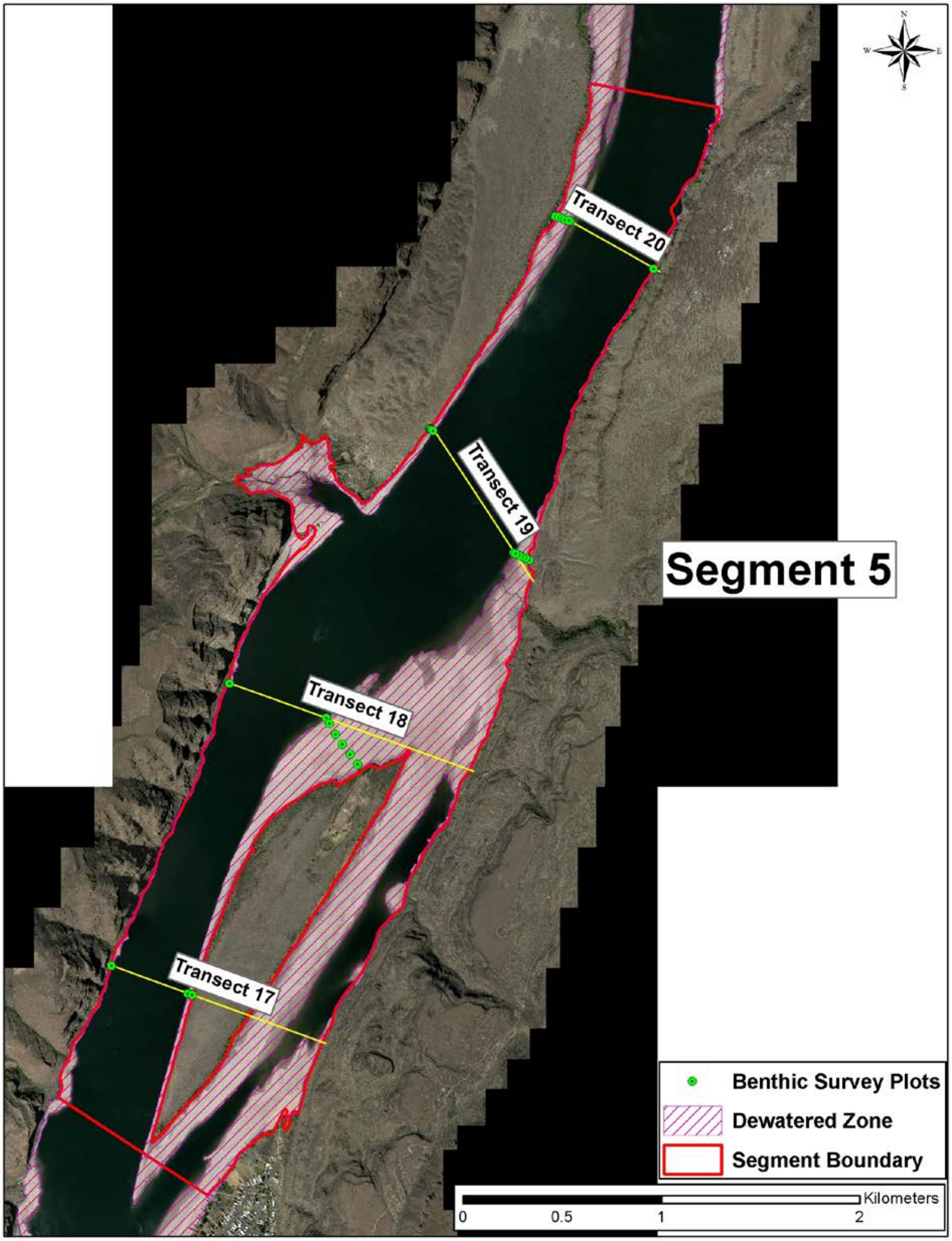
1
2



N
W
E
S
Transect 16
Sunland
Transect 15
Segment 4
Transect 14
Transect 13
Benthic Survey Plots
Dewatered Zone
Segment Boundary
Kilometers
0
0.4
0.8
1.6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S
E
W
Transect 20
Transect 19
Segment 5
Transect 18
Transect 17
Benthic Survey Plots
Dewatered Zone
Segment Boundary
Kilometers
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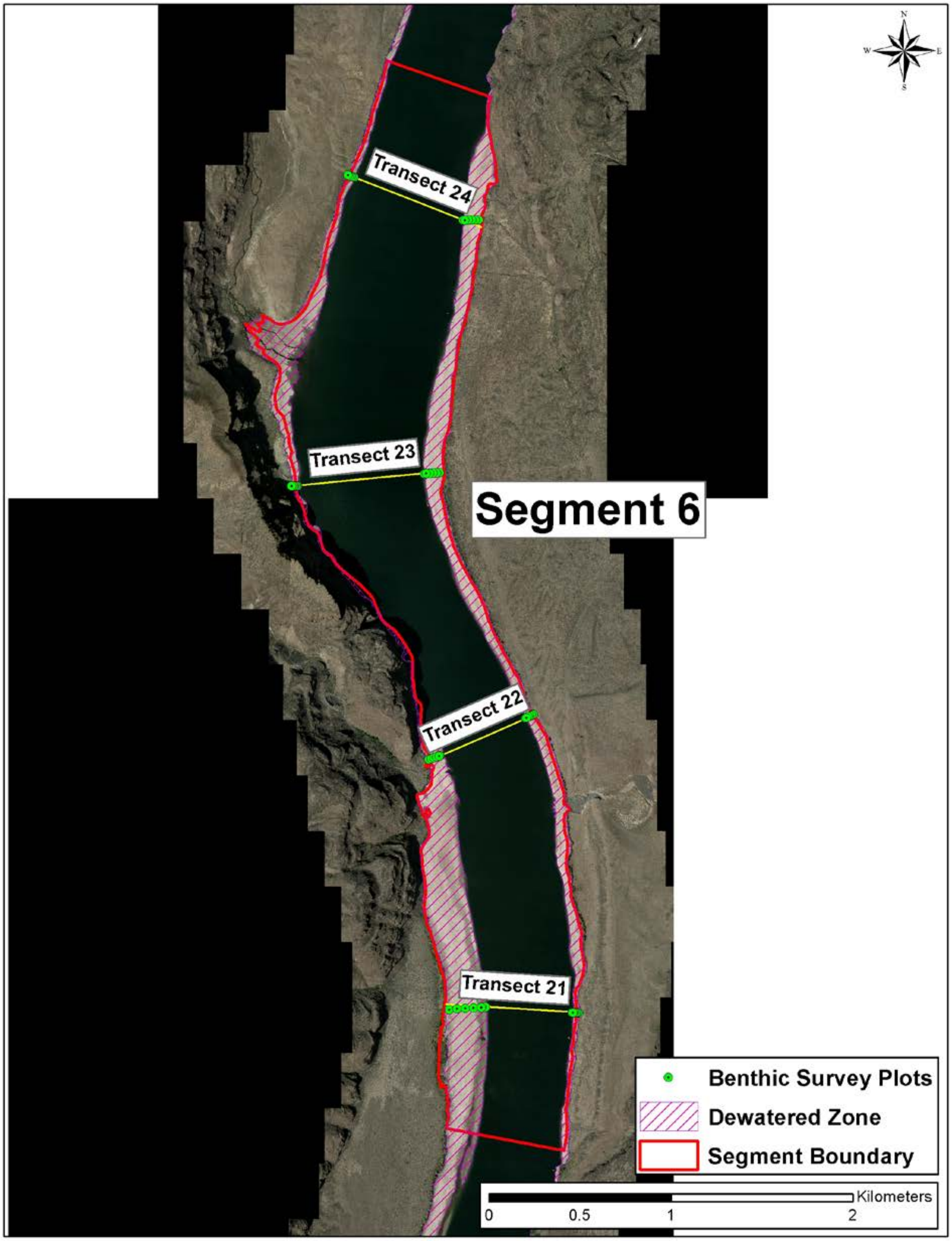
0.5
1
2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E
S
Transect 24
Transect 23
Segment 6
Transect 22
Transect 21
Benthic Survey Plots
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Segment Boundary
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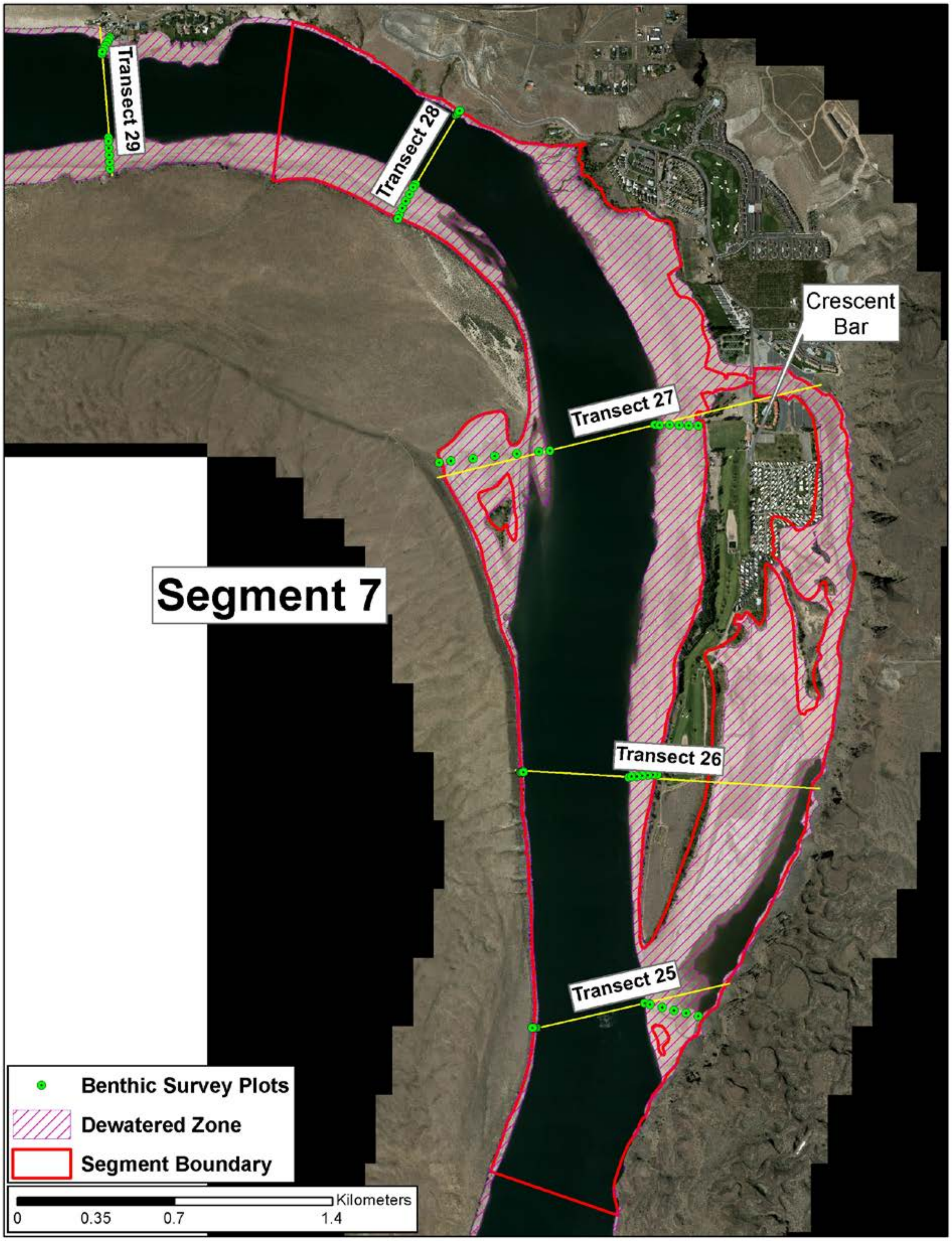
0.5
1
2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Transect 28
Crescent Bar
Transect 27
Segment 7
Transect 26
Transect 25
Benthic Survey Plots
Dewatered Zone
Segment Boundary
Kilometers
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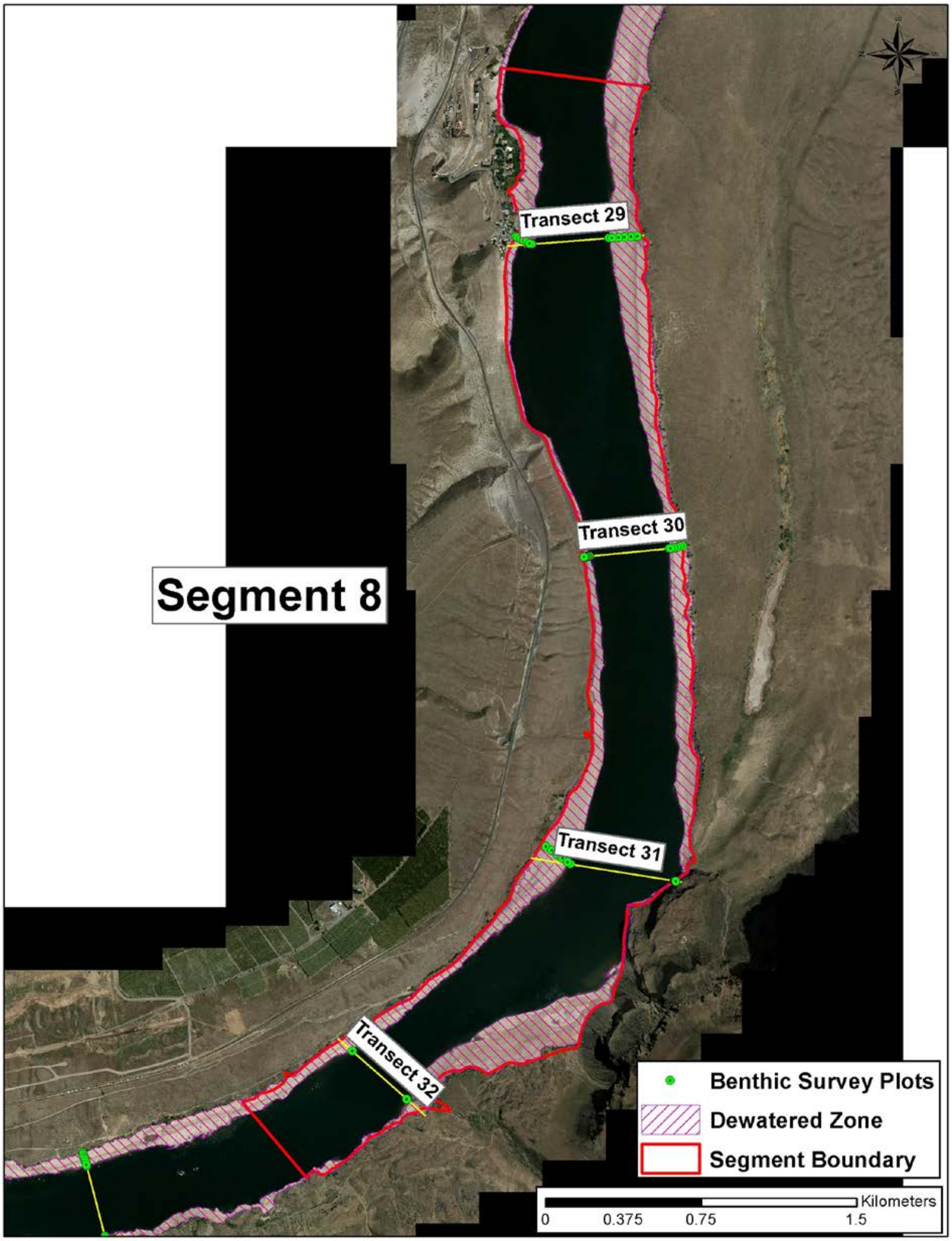
0.35
0.7
1.4


Segment 8
Transect 29
Transect 30
Transect 31
Transect 32
Benthic Survey Plots
Dewatered Zone
Segment Boundary
0
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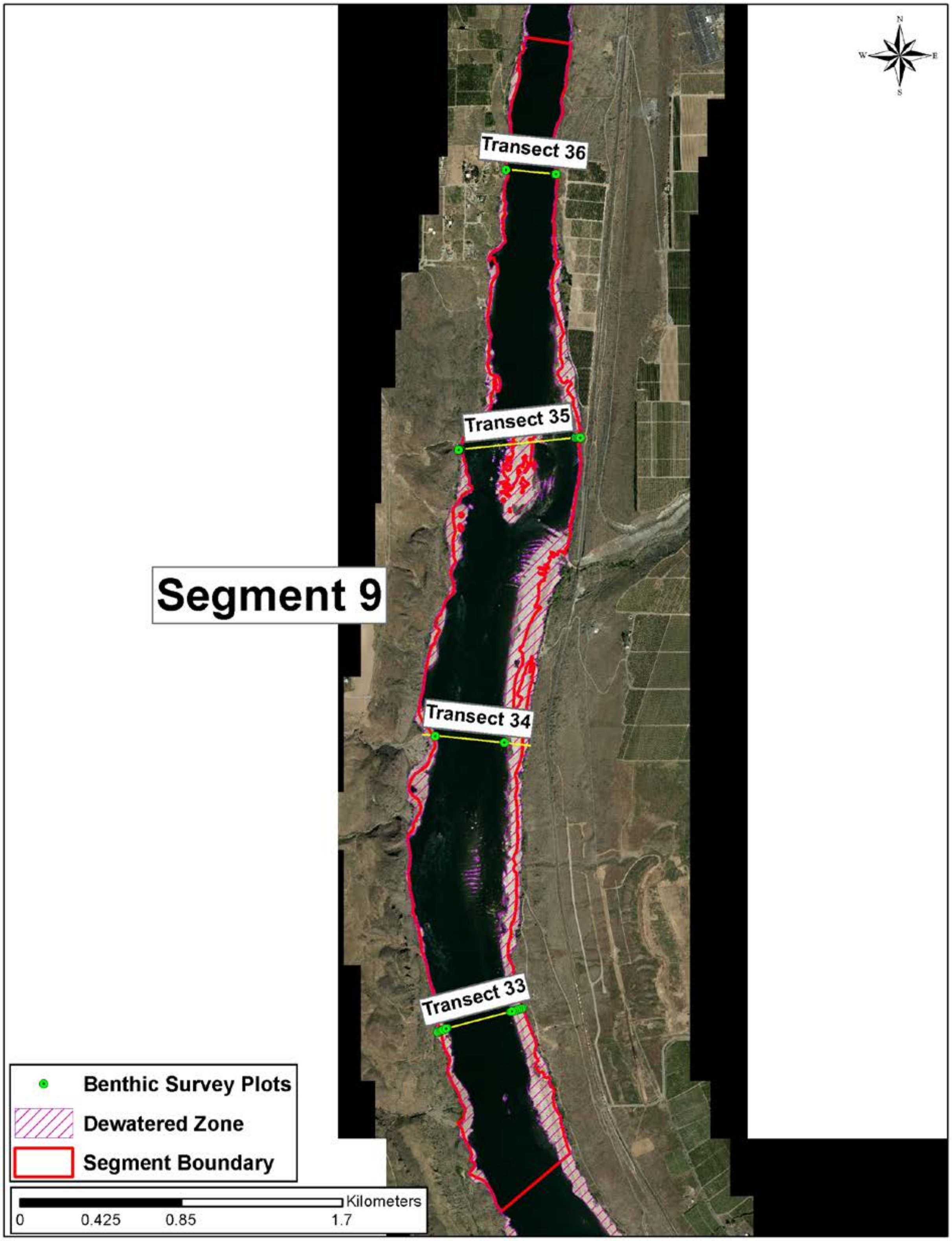
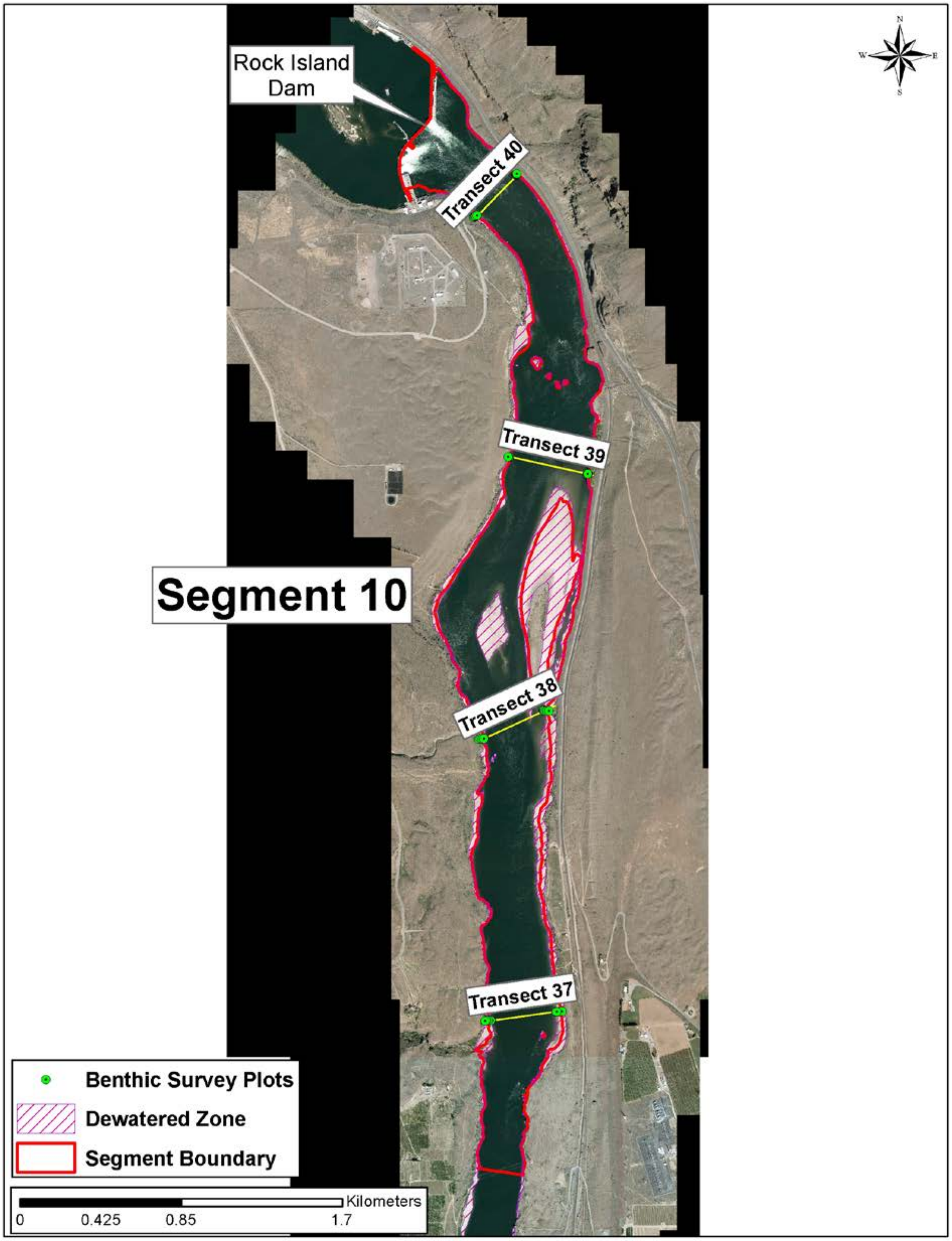
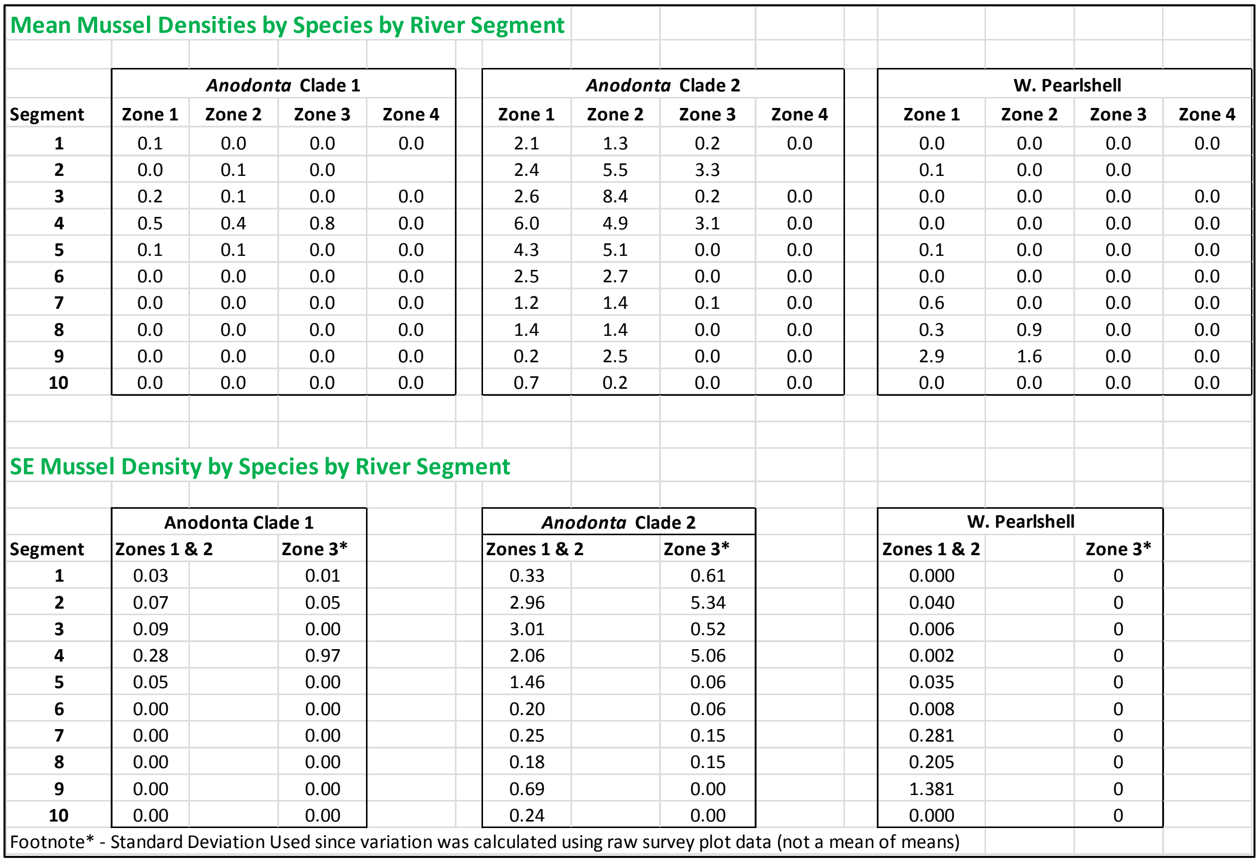
0.75
1.5
Kilometers


N
W
E
S
Transect 36
Transect 35
Segment 9
Transect 34
Transect 33
Benthic Survey Plots
Dewatered Zone
Segment Boundary
Kilometers
0
0.425
0.85
1.7


N
W
E
S
Rock Island Dam
Transect 40
Transect 39
Segment 10
Transect 38
Transect 37
Benthic Survey Plots
Dewatered Zone
Segment Boundary
0
0.425
0.85
1.7
Kilometers

4.2 APPENDIX Calculation Tables for Total Number of Mussels Dewatered, 2014



Mean Mussel Densities by Species by River Segment

	Anodonta Clade 1				*Anodonta* Clade 2				W. Pearlshell			
Segment	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
1	0.1	0.0	0.0	0.0	2.1	1.3	0.2	0.0	0.0	0.0	0.0	0.0
2	0.0	0.1	0.0		2.4	5.5	3.3		0.1	0.0	0.0	
3	0.2	0.1	0.0	0.0	2.6	8.4	0.2	0.0	0.0	0.0	0.0	0.0
4	0.5	0.4	0.8	0.0	6.0	4.9	3.1	0.0	0.0	0.0	0.0	0.0
5	0.1	0.1	0.0	0.0	4.3	5.1	0.0	0.0	0.1	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	2.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	1.2	1.4	0.1	0.0	0.6	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	1.4	1.4	0.0	0.0	0.3	0.9	0.0	0.0
9	0.0	0.0	0.0	0.0	0.2	2.5	0.0	0.0	2.9	1.6	0.0	0.0
10	0.0	0.0	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0

SE Mussel Density by Species by River Segment

	Anodonta Clade 1		***Anodonta* Clade 2**		**W. Pearlshell**	
Segment	**Zones 1 & 2**	**Zone 3***	**Zones 1 & 2**	**Zone 3***	**Zones 1 & 2**	**Zone 3***
1	0.03	0.01	0.33	0.61	0.000	0
2	0.07	0.05	2.96	5.34	0.040	0
3	0.09	0.00	3.01	0.52	0.006	0
4	0.28	0.97	2.06	5.06	0.002	0
5	0.05	0.00	1.46	0.06	0.035	0
6	0.00	0.00	0.20	0.06	0.008	0
7	0.00	0.00	0.25	0.15	0.281	0
8	0.00	0.00	0.18	0.15	0.205	0
9	0.00	0.00	0.69	0.00	1.381	0
10	0.00	0.00	0.24	0.00	0.000	0

Footnote* - Standard Deviation Used since variation was calculated using raw survey plot data (not a mean of means)

Mean # Mussels by Species by River Segment

River Segment	Anodonta Clade 1	Anodonta Clade 2	Western Pearlshell
	Zones 1 , 2, 3	**Zones 1 , 2, 3**	**Zones 1 , 2, 3**
1	205,208	4,163,201	0
2	54,803	3,411,643	24,133
3	85,110	2,976,149	2,500
4	1,432,987	11,826,844	3,376
5	101,271	5,223,311	38,893
6	7,971	1,846,210	7,336
7	9,155	1,972,662	484,827
8	1,526	848,579	381,555
9	1,1290	709,711	1,163,581
10	0	132,382	0
Totals	**1,899,320**	**33,110,694**	**2,106,203**

Upper 95% C.I. # Mussels by Species by River Segment

River Segment	Anodonta Clade 1	Anodonta Clade 2	Western Pearlshell
	Zones 1 , 2, 3	**Zones 1 , 2, 3**	**Zones 1 , 2, 3**
1	731,278	7,872,826	0
2	85,649	5,081,340	72,400
3	268,231	6,824,421	7,500
4	1,723,882	16,005,079	10,129
5	212,177	10,451,821	116,678
6	29,659	3,672,947	22,009
7	26,167	3,838,738	1,435,533
8	3,816	1,697,491	877,753
9	6,448	1,964,604	2,144,686
10	0	326,168	0
Totals	**3,087,308**	**57,735,437**	**4,996,622**

Lower 95% C.I. # Mussels by Species by River Segment

River Segment	Anodonta Clade 1		Anodonta Clade 2		Western Pearlshell
	Zones 1 , 2, 3		**Zones 1 , 2, 3**		**Zones 1 , 2, 3**
1	196,376		453,575		0
2	0		1,741,946		0
3	71,872		0		0
4	735,974		7,648,609		0
5	0		0		0
6	7,537		19,474		0
7	6,790		106,586		0
8	763		0		0
9	1,127		0		0
10	0		0		0
Totals	**1,020,439**		**9,970,191**		**0**

4.3 APPENDIX Comments on Taxa Found

Species summaries here are derived principally from Frest & Johannes (1995); Frest et al. (2008), and have been updated here using the current literature.

GASTROPODS

Family Valvatidae

Valvata humeralis (Say, 1817) glossy valvata

Despite a Mexico City, Mexico type locality, Columbia River basin populations are tentatively placed under this species until further study and or DNA analysis indicate if the western U.S. populations are a separate species.

This sporadically widespread western North American taxon is a cold water form restricted to perennial water bodies, including spring pools and slower-flowing spring-fed creeks, rivers and lakes. The species generally is found on oxygenated soft substrates with some macrophytes present (the calcareous alga *Chara* is especially characteristic), but can occur on rocks and cobbles. It is also quite successful in clean kettle lakes and larger spring pools. It appears unable to strongly grasp hard substrate particles, and hence cannot tolerate heavy currents. None of the valvatids are strongly pollution tolerant, and none are backwater, ditch, marsh, swamp, or stagnant water species. This species, like most valvatids, seems to be found almost exclusively in cold water habitats. *Valvata humeralis* has been extirpated from some of its range.

Pleistocene fossils of *V. humeralis* have been found in deposits in the nearby Grand and Lind coulees (Henderson 1929; Enbysk 1956; Landye, 1973). Found at 17 sites from lower to upper end of Wanapum Lake.

Valvata tricarinata (Say, 1817) threeridge valvata

This species occurs in a variety of permanent lacustrine or perennial lake-like habitats, including portions of larger rivers. Generally found in cool-cold clear waters, on soft substrate, in areas with macrophytes (*Chara*, *Myriophyllum*, *Ceratophyllum*, etc.). Very abundant on marl substrates in kettle lakes, often to a considerable depth. Distributed from "Quebec and New Brunswick west to Alberta and south to Wyoming, Arkansas, and Virginia" (Burch 1989).

As emphasized by Taylor & Bright (1987), western U. S. occurrences are strongly disjunct, as this species does not now occur in the Missouri headwaters. This is possibly one of a handful of snails that have crossed the continental divide from eastern North America during either late Miocene or early Pleistocene into northwestern Montana (Taylor & Bright 1987; Taylor 1985). In the western U. S., this species is quite rare, similar environments being occupied by *Valvata humeralis*. Through the efforts of R. B. Brunson in the 1950's to the 70's (University of Montana, Missoula), this basically Mississippi drainage and Atlantic species is now known from several lakes in the Clark Fork and Flathead drainages, Montana. T. Burke (pers. comm., 2012) has found this species in Lake Roosevelt, Washington as well. Taylor & Bright (1987) show this taxon from 3 Ferry County, Washington sites. Some known sites are on the Flathead Indian Reservation (Montana), Bureau of Reclamation reservoirs, Pend Oreille River at Boundary Dam, Washington and other public owned or regulated lands. Just above Wanapum Lake it has been found in the reservoirs of Wells and Rocky Reach dams (DE&S & RL&L 2000; BioAnalysts 2006). The species is certainly very rare in Washington; so far searches in Idaho turned up no sites.

Valvata tricarinata seems to be restricted to the mainstem Columbia River above the Hanford Reach and in the Pend Oreille River in Washington. Unlike northwestern Montana, only *Valvata humeralis* has been found in lakes in the Columbia River Basin in eastern Washington. No Pleistocene fossils of *V. tricarinata* have been found in deposits in the nearby Grand or Lind coulees (Henderson 1929; Enbysk 1956; Landye 1973) or reported elsewhere in the basin in Washington. It is possible this species spread recently from Montana through the Clark Fork River to the Columbia River as a result of the construction of impoundments in these rivers. Found at 17 sites from lower to upper end of Wanapum Lake.

Family Lymnaeidae

***Radix auricularia* (Linnaeus, 1758) big-ear radix**

This Euarasian aquarium species was first collected from the Great Lakes in 1901 (Mills *et al.*, 1993). This taxon is now widely introduced over the whole State and is similarly common elsewhere in the western U. S.

While most likely to be found in relatively quiet situations on soft substrates, often with common macrophytes, this taxon is effectively a poikilothermophile and has been noted from streams of all sizes, lakes, ponds, springs, spring runs, and spring pools. It appears most successful in warmer areas with little current and definite nutrient enrichment; and has even been seen occasionally in cattle troughs. While often an epiphyte scraper, then species is also believed to be able to survive on aquatic macrophytes.

Note that Taylor (1981) has sometimes considered the species, at least in Alaska, native. However, its rapid spread in much of the western U. S. in recent years suggests that it was not recently present historically. Has been noted by Frest & Johannes at a number of sites elsewhere in the State, especially in eastern Washington. Found at 12 Wanapum Lake sites.

Family Hydrobiidae

***Potamopyrgus antipodarum* (Gray, 1853) New Zealand mudsnail**

This species is fairly pollution tolerant and known to occupy a variety of habitats from freshwater (rivers, creeks, lakes and springs) to brackish and occupy various substrates from mud to bedrock (pers. obs.).

The New Zealand mudsnail was first noticed in the Columbia in 1995, at Youngs Bay near Astoria, Oregon (Litton, 2000; Bersine *et al.*, 2008). In the Columbia Basin the range is now known to extend from the mouth of the Columbia eastward to St. Helens (Frest & Johannes, 2004), mouth of the Deschutes River, Oregon, and from the long established Middle Snake River sites (Taylor, 1987). This taxon may have been found in Hells Canyon and Asotin Co, WA by

2006. It has been present in Crooked Creek in the Owyhee River drainage for some time (Deixis, unpub.). Finds must be preserved properly to establish identity and to avoid confusion with native hydrobiids, such as *Pyrgulopsis*. Recently found in a freeze core sample sent to Deixis collected by EAS in 2014 at Hanford Reach and samples collected in 2014 by Washington Department of Fish & Wildlife from a downstream site at Ringold Fish Hatchery. Not seen in any of the Wanapum Lake sites.

Pyrgulopsis robusta **(Walker, 1908) Jackson Lake springsnail**

Synonym: ***Pyrgulopsis*** **n. sp. 6 of Frest & Johannes, 1995**

This taxon has a short but complex history in the Columbia system. It was not noted by classic collectors such as Henderson or Hemphill, nor found in historic museum collections. However, it was noted in dredge samples collected by USFWS personnel in 1988 in deep pools near Bonneville Dam. Since then it has been found at 14 lower Columbia sites, roughly from the mouth to Rufus, Oregon (Frest and Johannes 1995; Frest and Johannes 2004). Very recently it has been found at the Hanford Reach by Frest *et al.* (2008) and now has been shown to be moderately widespread there. Numerous previous studies done in this stretch of the river found no evidence of this species being present (see references in Neitzel and Frest 1993; Newell 1998).

DNA results by Hershler and Liu (2004a, b) have shown the Columbia River population is closely related to *P. robusta* population in Polecat Creek, a tributary in the upper Snake River, and not to the geographically closer Middle Snake River populations. This and other evidence cited above suggests that *P. robusta* was introduced into the Columbia River sometime in the 1980's. So far this taxon has not reached Wanapum Lake stretch of the Columbia River.

Family Lithoglyphidae

Fluminicola fuscus **(Haldeman 1847) ashy pebblesnail**

This is a former federal listing candidate previously under the name *Flumnicola columbiana* (Hershler and Frest, 1996). It is currently rare in several streams in the eastern part of the state and in the lower-upper Columbia River; see Neitzel and Frest (1993) and Hershler and Frest (1996) for distribution summary. Recorded previously from both the Methow and the Okanogan rivers. This taxon is mostly found live in oligotrophic, hard-substrate, swift-flow habitats, mostly in larger streams.

Recent DNA evidence has confirmed *Fluminicola* is not monophyletic and *fuscus* has been placed into a Clade B by Hershler and Liu (2012). This clade consists of a few riverine dwelling species but is dominated by environmentally sensitive spring dwelling species.

Three dead specimens of this species have been found occurring in the upper Wanapum Lake where a remnant preimpoundment Columbia River mollusk fauna survives. *F. fuscus* has been reported previously from the mainstem river, including the Hanford Reach.

Fluminicola **n. sp. unnamed pebblesnails**

About 7 undescribed taxa known over the state; range from common to highly restricted; see Frest and Johannes (1995) for details. One taxon in this group was reported from Okanogan River by Frest and Johannes (1995); see also Neitzel & Frest (1993). *Fluminicola* is likely to be a large and complex genus when revision is completed (Hershler and Frest 1996; Hershler and Liu 2012). The genus as now defined is not monophyletic (Hershler and Liu 2012). Many taxa are spring snails; but WA undescribed taxa are mostly amniphiles. Ecology is much like that for *fuscus* but some taxa may occur in smaller streams than is typical for *fuscus*.

Material found in this study occurred in the in area in upper Wanapum Lake where a remnant preimpoundment Columbia River mollusk fauna survives. *Fluminicola* n. sp. has been reported previously from the mainstem river above Wanapum Lake and downriver in the Hanford Reach. Found at a total of 5 sites (only 2 live) in the most upper part of Wanapum Lake.

Family Lymnaeidae

***Bakerilymnaea bulimoides* (Lea, 1841) prairie fossaria**

Formerly under the genus *Fossaria*, now placed under *Bakerilymnaea*. This subspecies is a detritus and epiphyte feeder. While widely distributed across the northern US and Canada, locally it has been found so far more often in southern Idaho. Preferred habitat is shallow water, typically found in lakes, ponds and slow flowing streams. Mostly found dead at Wanupum Lake sites (8 out the 12 sites).

***Galba obrussa* (Say, 1825) golden fossaria**

Formerly under the genus *Fossaria*, now placed under *Galba*. The golden fossaria is widespread in the US and Canada and seems able to tolerate a range of water temperatures. In Idaho, it is found over the State, generally in seeps; smaller drainages, stream edges; or pond and lake edges. It is an aufwuchs grazer, also found on a variety of surfaces and substrates, although epiphytes are often prominent when this taxon is found abundantly. Occurs very uncommonly in the Columbia River. Found at one Wanapum Lake site.

***Fisherola nuttalli* (Haldeman 1841) shortface lanx**

Former federal listing candidate (USFWS 1991); rare in the Lower Columbia and several E. WA streams; see Neitzel and Frest (1993) for state and regional distribution. This large limpet is found mostly on boulders and cobbles in clear, cold, swift and large streams. This Columbia River system endemic was reported historically from the Methow and Okanogan, Columbia, and a few other WA streams (Neitzel and Frest 1993). Reported from the Hanford Reach as abundant previously but not common there currently and likely in decline (Neitzel and Frest 1993; Frest et al. 2008). Not found in the upper Wanapum Lake where a remnant Columbia River fauna still exists.

Family Physidae

***Physella (Physella) gyrina* (Say, 1821) tadpole physa**

Physids are among the common snails in the Western U. S., as they are in the East as well. Taxonomy is badly in need of revision; and here Taylor (1981, 2003) and Burch (1989) are followed, both recognizing a small number of taxa in the West. Forms of *gyrina* are widespread in a variety of habitats in Western North America. Specimens from the upper Columbia in Washington were earlier ascribed to *Physella (Physella) propinqua* but that taxon is considered a synonym of *gyrina* (Taylor, 2003). This taxon seems to prefer small stream, pond, and lake habitats locally. Found at 17 sites spread across the total reach of Wanapum Lake.

Family Planorbidae

***Gyraulus* (*Torquis*) *parvus* (Say, 1817) ash gyro**

One of the most common small freshwater taxa over most of North America; equally common over the State; often abundant when found. An epiphyte feeder, equally at home in warm to cold-water. This small snail usually occurs in areas with mud substrates, with or without emergent or aquatic vegetation, and can tolerate seasonal habitats as well as permanent. This seems to be one of the better examples of a eurythermic taxon. It is most often found in low to nil velocity situations, such as lakes, ponds, quieter stream portions, fens, marshes, and springs. Found at a total of 18 sites in Wanapum Lake.

***Menetus (Menetus) callioglyptus* Vanatta, 1894 button sprite**

Note that most sources regard this taxon as *Menetus opercularis* (Gould, 1847); but Taylor (1981) argues that that name applies mostly to snails from Mountain Lake, California that are now extinct. This is a widespread taxon in western Washington, northern Oregon, and northwestern California in a variety of habitats. It is usually uncommon in larger streams. Abundant in western and northern Washington and sporadic in southeast; usually termed *opercularis* but true *opercularis* rare in Washington. This taxon is found in a variety of habitats, mostly in shallow water, and including springs and lakes a well as streams. Substrate preference is similarly broad. Found at 5 sites in Wanapum Lake.

***Vorticifex effusus* (Lea, 1856) Artemesian rams-hom**

This rather limpet-like species has an unusual distribution, being formerly widespread in the Sacramento system, the Klamath system, and the periphery of the Great Basin, including the middle Snake River. In the Columbia basin, the species occurs only sporadically, in the lower Willamette, the Deschutes, and the lower Columbia. Taylor (1985; see distribution map therein also) thought that the species was a recent migrant to the Columbia basin, perhaps via the Deschutes River in Oregon. Its absence from the lower Snake River and Hells Canyon is notable, and hard to explain without reference to drainage capture. This species has a type locality in the Sacramento River. It is presumed extinct in the lower Sacramento. At undisturbed sites in the Upper Sacramento and the Pit and its tributaries, this is often the dominant mollusk, and it often comprises the great majority of invertebrate biomass. Distribution very limited in the upper

Columbia River. Wanapum Lake site is the furthest north known site for this species in the Columbia River system. Formerly only known to occur in the Hanford Reach (Neitzel and Frest 1993) and small relict site in the Grand Coulee as well as in Pleistocene deposits from there (Deixis unpub.; Henderson 1929; Landye 1973).

It is a perilithon and periphyton feeder, and not very tolerant of hypoxia or anoxia, unlike many other planorbids. This cold-water form has been much reduced in abundance and territory in much of its historic range, but is one of the more tolerant members of the cold water biota. Found only in the riverine portion at the upper end of Wanapum Lake with other preinpoundment mollusk species at 2 sites.

Family Ancylidae

***Ferrissia rivularis* (Say, 1817) creeping ancylid**

This from is found mostly in the central and eastern U. S. and adjacent parts of southern Canada. In the West, it appears to be present widely, but is rare and scattered. This is especially so in the Pacific Northwest. This species prefers cobble and boulder substrate and rather more oligotrophic settings than does *californica*; but it is not a cold-water taxon and avoids the most pristine oligotrophic habitats in the West. Mostly a lithophile aufwuchs feeder. Found in the upper most site collected for this project in a remnant riverine habitat above Wanapum Lake.

BIVALVES

Family Unionidae

Recent genetic work on unionid mussels has complicated the picture on western U.S. mussels (Chong et al. 2008, 2009; Mock et al. 2004, 2010). Until the taxonomy of these genetic entities is worked out, current western unionid taxonomy will be followed herein. Taylor (1981) is followed regarding *Anodonta nuttalliana* as a synonym of *A. californiensis*, contra (Nideau et al., 2005).

Family Margaratiferidae

***Margaritifera falcata* (Gould, 1850) (western pearlshell)**

Now sporadic over state; formerly ubiquitous west and common east. Many populations show little evidence of reproduction. This mussel generally uses salmon and trout as glochidial host species. As a result, now somewhat restricted, especially in interior Washington. Reported formerly from the Methow and Okanogan; but not recently found live in typical Okanogan habitats. Seldom seen in the mainstem Columbia currently and recent studies indicate it may be almost extinct in the Upper Columbia River (Helmstetler & Cowles, 2008). Recent surveys in the last free flowing stretch of the upper Columbia River (Hanford Reach) resulted in only the find of two long dead shells (Mueller *et al.*, 2011). *Margaritifera* found in upper Wanapum Lake may be the last population living in the upper Columbia River.

This taxon prefers fast water, cold and clean, and gravel, cobble, or boulder habitat and is seldom seen in lakes unlike *Anodonta*. Of all the mussels species *Margaritifera* seems to be more temperature sensitive, this sensitive especially indicated by a far more precipitous decline in the increasingly warmer Columbia River than seen for *Anodonta*. Occurrence in mud substrate in the upper Wanapum Lake is atypical. May occur in streams of almost all sizes except the smallest; never seen in lakes or reservoirs. This taxon is usually seen as *Margaritifera falcata*; but Smith (2001) cites cogent reasons for separating *falcata* from other U. S. margaritiferids under a new genus. However, here it will be kept under *Margaritifera*.

Family Unionidae

***Anodonta nuttalliana* Lea, 1838 (winged floater)**

Synonym: *Anodonta californiensis* Lea, 1852 (California floater)

***Anodonta* clade 1 in** Chong et al. 2008

This mussel is widely but sporadically distributed in eastern Washington but is much less common west of the Cascades in Washington. The species may well be composite (Taylor 1981; pers. obs.). It is currently rare in the southwestern states and southern California, which area includes the type locality, and is understudy for possible listing there. The species appears to be declining seriously in California (Howard 2010) and Washington, including in the Columbia River proper. Found in Pleistocene deposits in the nearby Grand and Lind coulees (Henderson 1929, Enbysk 1956). *Anodonta californiensis* was formerly considered as a candidate for listing by USFWS (1991).

***Anodonta oregonensis* Lea, 1838 (Oregon floater)**

Synonym: *Anodonta kennerlyi* Lea, 1860 (western floater)

***Anodonta* clade 2 in** Chong et al. 2008

The mussel termed the Oregon floater was first described from the lower Columbia River but appears currently uncommon to rare in it. Formerly rather widespread, it is found over much of Washington and Oregon, although seldom in large numbers. On the east side of the Cascades, it seems to be more often found in streams than lentic habitats.

Family Corbiculidae

***Corbicula fluminea* (Müller, 1774) (Asian clam)**

Corbiculids were native residents of North America for a considerable time before becoming extinct on the continent relatively recently (Taylor 1988). The first known introduction, in North America, occurred in the lower Columbia River and it has been known to be present there since perhaps 1937 (Burch 1944; Counts 1985). Since its introduction, it is now found in 38 states and the District of Columbia (Foster *et al.* 2014). It can be a major biofouler of intakes (Isom 1986; Isom *et al.* 1986). Its method of dispersal in North America is not well understood. Unlike all freshwater native North American species, *Corbicula* has a free larva that may drift for days in a current (Taylor 1987). This may help in the rapid spread of this species.

Corbicula is uncommon in more prisitine oligotrophic habitats and more common in somewhat disturbed settings, especially if waters are warm. The local example thrives best in flowing water, although slow flow situations can support dense populations.

Taxonomic status of *Corbicula* in North America is still somewhat cloudy, with claims for at least two taxa**.** More recently, morphological differences within the introduced populations have been ascribed to origin as separate clones of uncertain number, distribution, and status.

Despite the early introduction, *Corbicula* is only moderately successful as an invader in Washington and Oregon, especially as compared with, say, the Tennessee Valley. It is a pest species with considerable economic impact in the central and eastern states, not so much in the western U. S., though impacts to native mollusks have been observed in the Klamath and Pit rivers in northern California due to recent introductions of *Corbicula* (E. Johannes, pers. obs. 2013).

McMahon (1999, fig. 22.2; 2001, fig. 11) seems to restrict *Corbicula* to the Lower Columbia in Washington. However, the species also occurs commonly in the state to the Idaho border and in the Snake River in Idaho, as well as in Utah (Counts 1985, 1986). The Idaho records date to at least 1966 (Hanna 1966; Frest & Bowler 1993; Frest & Johannes 2001). McMahon (1999, p. 317) has it that *Corbicula* in North America likely derives from a single introduction in northeastern Washington. Presumably, he means southwestern Washington, i.e., the lower Columbia River, as Counts (1986) says. This now seems unlikely, given the widespread occurrences, sometimes in isolated drainages. One of two (*Pisidium variabile* the other) mollusks most commonly encountered at Wanapum Lake survey sites; total of 25.

Family Sphaeriidae

Pisidium (Cyclocalyx) casertanum **(Poli, 1791) ubiquitous peaclam**

As the common name implies, this is a very frequently encountered sphaeriid species, perhaps the most widespread native mollusk in the northern hemisphere. It is rapidly spreading currently south of the Equator as well. Very frequent in a wide variety of habitats in the West. For examples, see Frest and Johannes (2001). Note, however, that the species is quite rare in Wanapum Lake sites and rare or not seen elsewhere in the upper Columbia River basin (BioAnalysts 2006; DE&S and RL&L, 2000; Frest et al. 2008).

Pisidium (Cyclocalyx) compressum **Prime, 1852 ridgebeak peaclam**

This small taxon is found widely in both the western and eastern portions of the U. S. and southern Canada. It is perhaps less common in the West, particularly in the formerly ubiquitous cold oligotrophic habitats once prevalent but now much reduced in areal extent. It appears here to be much more common in slow or slack water habitats. This was the second most common sphaeriid species encountered at Wanapum Lake at 19 sites.

***Pisidium* (*Cyclocalyx*) *variabile* Prime, 1852 triangular peaclam**

Found over much of the U. S. and Canada. Mostly a filter feeder that is equally at home in cold or warm water and noted from a variety of habitats. This and *Corbicula* are the most encountered taxons at 25 Wanapum Lake survey sites.

4.4 APPENDIX Species and Number of Gastropods and Sphaeriacean Clams Found at Wanapum Lake Drawdown Survey Plot Sites

Table Explanation:

*=introduced species.

bold=Species Special of Concern (as defined in Frest & Johannes, 1993, 1995)

°=cold-water species (see criteria in Frest & Johannes, 1992)

†=preferring stream environments or an amniphile

1=formerly under the genus *Fossaria*.

2=identified as *Physella propinqua propinqua* in previous reports; synonym of *P. gyrina* (Taylor, 2003).

TABLE 1. Mollusks Found at Wanapum Lake Gastropod and Sphaeriacean Clam Survey Plot Sites.

TAXON NAME	LOCATION NUMBERS											
	T1-L1		T1-L3		T1-L5		T3-R1		T3-R3		T3-R5	
	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead
GASTROPODS												
°_Valvata humeralis_	-	5	4	4	-	-	3	3	-	5	-	-
°_Valvata tricarinata_	2	1	5	4	-	-	27	1	53	2	-	-
°†**_Fluminicola fuscus_**	-	-	-	-	-	-	-	-	-	-	-	-
°†**_Fluminicola_ n. sp.**	-	-	-	-	-	-	-	-	-	-	-	-
*****_Potamopyrgus antipodarum_	-	-	-	-	-	-	-	-	-	-	-	-
Bakerilymnaea bulimoides[1]	-	-	-	-	-	16	-	-	-	-	-	-
Galba obrussa[1]	-	-	-	-	-	-	-	-	-	-	-	-
Lymnaeidae	-	-	-	-	-	-	-	-	-	-	-	-
*****_Radix auricularia_	-	-	-	-	-	-	-	-	-	-	-	-
Physella (P.) gyrina[2]	-	-	-	-	5	6	2	-	1	-	-	-
Gyraulus (T.) parvus	-	2	-	-	-	3	-	-	20	20	-	-
Menetus (M.) callioglyptus	-	-	-	-	-	-	-	-	9	29	-	-
°†_Vorticifex effusus_	-	-	-	-	-	-	-	-	-	-	-	-
†_Ferrissia rivularis_	-	-	-	-	-	-	-	-	-	-	-	-
BIVALVES												
*_Corbicula fluminea_	-	-	-	-	3	5	6	3	75	1	-	1
Pisidium (C.) casertanum	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium (C.) compressum	-	3	-	1	-	-	4	-	6	4	-	-
Pisidium (C.) variabile	-	1	5	11	2	-	44	3	10	87	3	-
SPECIES OF CONCERN	0		0		0		0		0		0	
COLD-WATER SPECIES	2		2		0		2		2		0	
RIVERINE SPECIES	0		0		0		0		0		0	
INTRODUCED SPECIES	0		0		1		1		1		1	
TOTAL SITE DIVERSITY	5		4		5		6		8		2	

TABLE 1. Mollusks Found at Wanapum Lake Gastropod and Sphaeriacean Clam Survey Plot Sites. (cont.)

TAXON NAME	**LOCATION NUMBERS**											
	T9-L1		**T9-L5**		**T11-R3**		**T13-L3**		**T17-R1**		**T17-L3**	
	No. Live	**No. Dead**	**No. Live**	**No. Dead**	**No. Live**	**No. Dead**	**No. Live**	**No. Dead**	**No. Live**	**No. Dead**	**No. Live**	**No. Dead**
GASTROPODS												
°*Valvata humeralis*	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**
°*Valvata tricarinata*	**1**	**-**	**1**	**-**	**8**	**1**	**-**	**-**	**-**	**-**	**-**	**-**
°†***Fluminicola fuscus***	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
°†***Fluminicola*** **n. sp.**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
******Potamopyrgus antipodarum*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Bakerilymnaea bulimoides	**-**	**-**	**-**	**1**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**
Galba obrussa	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Lymnaeidae	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**
******Radix auricularia*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Physella (P.) gyrina	**-**	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Gyraulus (T.) parvus	**-**	**-**	**2**	**3**	**-**	**-**	**-**	**1**	**-**	**-**	**2**	**4**
Menetus (M.) callioglyptus	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
°†*Vorticifex effusus*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
†*Ferrissia rivularis*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
BIVALVES												
**Corbicula fluminea*	**1**	**2**	**17**	**1**	**-**	**1**	**2**	**-**	**-**	**8**	**-**	**-**
Pisidium (C.) casertanum	**8**	**8**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Pisidium (C.) compressum	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**
Pisidium (C.) variabile	**25**	**11**	**1**	**-**	**1**	**-**	**1**	**-**	**-**	**3**	**14**	**-**
SPECIES OF CONCERN	**0**		**0**		**0**		**0**		**0**		**0**	
COLD-WATER SPECIES	**2**		**1**		**1**		**0**		**0**		**0**	
RIVERINE SPECIES	**0**		**0**		**0**		**0**		**0**		**0**	
INTRODUCED SPECIES	**1**		**1**		**1**		**1**		**1**		**0**	
TOTAL SITE DIVERSITY	**7**		**4**		**5**		**3**		**2**		**4**	

TABLE 1. Mollusks Found at Wanapum Lake Gastropod and Sphaeriacean Clam Survey Plot Sites. (cont.)

TAXON NAME	LOCATION NUMBERS											
	T17-L5		T19-R3		T21-L3		T23-R5		T25-L1		T26-L5	
	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead
GASTROPODS												
°*Valvata humeralis*	-	-	24	-	2	-	1	3	8	-	13	8
°*Valvata tricarinata*	-	-	-	2	2	1	12	-	33	-	-	-
°†***Fluminicola fuscus***	-	-	-	-	-	-	-	-	-	-	-	-
°†***Fluminicola*** **n. sp.**	-	-	-	-	-	-	-	-	-	-	-	-
*Potamopyrgus antipodarum	-	-	-	-	-	-	-	-	-	-	-	-
Bakerilymnaea bulimoides	54	12	-	1	1	-	-	4	-	-	-	-
Galba obrussa	-	-	-	-	-	-	-	-	-	-	-	-
Lymnaeidae	-	-	-	-	-	-	-	-	-	-	-	-
*Radix auricularia	-	2	-	-	1	-	1	-	1	5	5	3
Physella (P.) gyrina	3	-	6	2	3	4	4	3	11	59	26	10
Gyraulus (T.) parvus	7	11	1	-	1	3	-	-	10	-	19	8
Menetus (M.) callioglyptus	-	-	-	-	-	-	-	-	2	-	-	-
°†*Vorticifex effusus*	-	-	-	-	-	-	-	-	-	-	-	-
†*Ferrissia rivularis*	-	-	-	-	-	-	-	-	-	-	-	-
BIVALVES												
*Corbicula fluminea	-	1	1	4	3	11	-	10	46	30	-	17
Pisidium (C.) casertanum	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium (C.) compressum	-	-	22	5	20	4	38	3	37	1	-	12
Pisidium (C.) variabile	-	-	57	37	23	5	108	29	67	7	36	7
SPECIES OF CONCERN	0		0		0		0		0		0	
COLD-WATER SPECIES	0		2		2		2		2		1	
RIVERINE SPECIES	0		0		0		0		0		0	
INTRODUCED SPECIES	2		1		2		2		2		2	
TOTAL SITE DIVERSITY	5		8		9		8		9		7	

TABLE 1. Mollusks Found at Wanapum Lake Gastropod and Sphaeriacean Clam Survey Plot Sites. (cont.)

TAXON NAME	LOCATION NUMBERS											
	T27-R3		T28-R5		T29-L3		T30-L3		T32-R3		T33-L3	
	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead
GASTROPODS												
°*Valvata humeralis*	39	28	11	1	-	-	2	2	-	-	18	2
°*Valvata tricarinata*	9	2	-	-	-	1	3	-	-	-	20	1
°†***Fluminicola fuscus***	-	-	-	-	-	-	-	-	-	-	-	-
°†***Fluminicola* n. sp.**	-	-	-	1	-	-	-	-	-	-	-	-
*****Potamopyrgus antipodarum*	-	-	-	-	-	-	-	-	-	-	-	-
Bakerilymnaea bulimoides	-	-	-	1	-	-	-	-	-	1	-	-
Galba obrussa	-	-	-	-	-	-	-	-	-	-	-	1
Lymnaeidae	-	-	-	-	-	1	-	-	-	-	-	-
*****Radix auricularia*	-	8	4	13	-	-	2	1	-	-	1	58
Physella (P.) gyrina	10	41	8	4	-	-	1	3	-	-	3	123
Gyraulus (T.) parvus	4	21	18	50	-	-	3	3	-	-	24	-
Menetus (M.) callioglyptus	1	6	-	-	-	-	-	1	-	-	-	39
°†*Vorticifex effusus*	-	-	-	-	-	-	-	-	-	-	-	-
†*Ferrissia rivularis*	-	-	-	-	-	-	-	-	-	-	-	-
BIVALVES												
**Corbicula fluminea*	5	8	8	40	2	31	-	6	-	1	21	9
Pisidium (C.) casertanum	-	-	-	-	-	-	-	-	-	-	-	-
Pisidium (C.) compressum	31	3	5	-	-	6	16	1	-	-	56	1
Pisidium (C.) variabile	27	2	46	8	1	6	24	1	-	-	120	16
SPECIES OF CONCERN	0		1		0		0		0		0	
COLD-WATER SPECIES	2		2		1		2		0		2	
RIVERINE SPECIES	0		1		0		0		0		0	
INTRODUCED SPECIES	2		2		1		2		1		2	
TOTAL SITE DIVERSITY	9		9		5		9		2		10	

TABLE 1. Mollusks Found at Wanapum Lake Gastropod and Sphaeriacean Clam Survey Plot Sites. (cont.)

TAXON NAME	LOCATION NUMBERS								TOTAL SITE OCCURRENCES
	T34-L3		T35-R3		T37-L3		T39-R1		
	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	No. Live	No. Dead	
GASTROPODS									
°*Valvata humeralis*	**6**	**1**	**-**	**-**	**58**	**46**	**-**	**-**	**17**
°*Valvata tricarinata*	**8**	**2**	**-**	**-**	**15**	**2**	**-**	**-**	**17**
°†***Fluminicola fuscus***	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3**	**1**
°†***Fluminicola* n. sp.**	**-**	**12**	**4**	**-**	**-**	**3**	**5**	**79**	**5**
*****_Potamopyrgus antipodarum_	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**
Bakerilymnaea bulimoides	**-**	**-**	**-**	**3**	**-**	**1**	**1**	**4**	**12**
Galba obrussa	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**
Lymnaeidae	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2**
*****_Radix auricularia_	**-**	**2**	**2**	**2**	**11**	**15**	**-**	**-**	**12**
Physella (P.) gyrina	**-**	**5**	**-**	**1**	**2**	**16**	**-**	**-**	**17**
Gyraulus (T.) parvus	**1**	**2**	**-**	**-**	**2**	**11**	**6**	**7**	**18**
Menetus (M.) callioglyptus	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**5**
°†*Vorticifex effusus*	**-**	**-**	**-**	**-**	**-**	**1**	**11**	**10**	**2**
†*Ferrissia rivularis*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**14**	**1**
BIVALVES									
**Corbicula fluminea*	**128**	**9**	**12**	**8**	**-**	**2**	**42**	**3**	**25**
Pisidium (C.) casertanum	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**
Pisidium (C.) compressum	**7**	**2**	**-**	**-**	**57**	**11**	**-**	**2**	**19**
Pisidium (C.) variabile	**58**	**5**	**15**	**1**	**71**	**8**	**-**	**-**	**25**
SPECIES OF CONCERN	**1**		**1**		**1**		**2**		**5**
COLD-WATER SPECIES	**3**		**1**		**4**		**3**		**21**
RIVERINE SPECIES	**1**		**1**		**2**		**4**		**5**
INTRODUCED SPECIES	**2**		**2**		**2**		**1**		**25**
TOTAL SITE DIVERSITY	**9**		**6**		**11**		**8**		**28**

RELATIONSHIPS BETWEEN ANADROMOUS LAMPREYS AND THEIR HOST FISHES IN THE EASTERN BERING SEA

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RELATIONSHIPS BETWEEN ANADROMOUS LAMPREYS AND THEIR HOST FISHES IN THE EASTERN BERING SEA

A

THESIS

Presented to the Faculty

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By

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Abstract

Arctic Lamprey *Lethenteron camtschaticum* and Pacific Lamprey *Entosphenus tridentatus* are ecologically and culturally important anadromous, parasitic species experiencing recent population declines in the North Pacific Ocean. However, a paucity of basic information on lampreys feeding in the ocean precludes an incorporation of the adult trophic phase into our understanding of lamprey population dynamics. The goal of this research was to provide insight into the marine life-history stage of Arctic and Pacific lampreys through lamprey-host interactions in the eastern Bering Sea. An analysis of two fishery-independent surveys conducted between 2002 and 2012 in the eastern Bering Sea revealed that Arctic Lampreys were captured in epipelagic waters of the inner and middle continental shelf and were associated with Pacific Herring *Clupea pallasii* and juvenile salmonids *Oncorhynchus* spp. In contrast, Pacific Lampreys were captured in benthic waters along the continental slope associated with bottom-oriented groundfish. Consistent with this analysis of fish assemblages, morphology of recently inflicted lamprey wounds observed on Pacific Cod *Gadus macrocephalus* was similar to morphology of Pacific Lamprey oral discs, but not that of Arctic Lamprey oral discs. Examination of 8,746 Pacific Cod, of which 4.9% had lamprey wounds, showed recent wounding rates positively increased with fish length up to 78 cm, and penetrating lamprey wounds were less likely to heal compared with superficial lamprey wounds, suggesting lamprey-related mortality. This study elucidates differences in the oceanic ecology between Arctic and Pacific lampreys and suggests a native lamprey can negatively impact hosts, which increases our understanding of lamprey ecology beyond traditional freshwater studies.

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General Introduction

Lampreys (Petromyzontiformes) are a resilient group of organisms that have persisted through extreme and cataclysmic mass extinction events. Along with hagfishes, lampreys comprise the only extant groups of jawless fishes, collectively referred to as agnathans, which are representatives of groups basal to all vertebrates (Hardisty and Potter 1971a). Modern adult lampreys are remarkably similar to the oldest fossilized lamprey dated at 360 million years before present, including the presence of an oral disc with circumoral teeth (Gess et al. 2006). This exceptional evolutionary longevity can be attributed to the unique and highly specialized life cycle exhibited by lampreys.

A simplified lamprey life cycle includes a larval phase, transitional period, and adult phase. All lampreys begin as microphagous filter-feeding larvae, living in riverine sediments for 3 to 7 years and recycling nutrients therein (Hardisty and Potter 1971b). Larval lampreys then undergo a metamorphosis that includes the development of functional eyes, a toothed oral disc, a toothed tongue, and externally exposed gill pores (Hardisty and Potter 1971a). Following metamorphosis, adult lampreys are classified as either nonparasitic or parasitic (Hardisty and Potter 1971a). Nonparasitic lampreys, also known as brook lampreys, forgo feeding as adults and remain relatively small, spawning and dying shortly after metamorphosis. In contrast, parasitic lampreys, collectively referring to lampreys that feed as adults on aquatic vertebrates via consumption of blood, flesh, or both, spend between a few months and several years feeding in freshwater or the ocean before traveling to headwater streams to spawn and die (Hardisty and Potter 1971a; Potter and Hilliard 1987). Paired species and stem-satellite species concepts are used to describe nonparasitic lamprey species that likely derived from parasitic varieties, such that the larvae are indistinguishable, but the adult feeding habit and body size differ between life-history variants (Zanandrea 1959; Vladykov and Kott 1979). Because lamprey taxonomy continues to be a source of debate (Docker 2009), I will accept the taxonomy presented in Renaud (2011) for the purposes of this thesis.

Lampreys are commonly misperceived as a nuisance, which can mostly be attributed to the damaging impact of the invasive Sea Lamprey *Petromyzon marinus* on fish stocks in the Laurentian Great Lakes (Close et al. 2002). However, native lampreys are an integral component of the ecological systems in which they are found (Vladykov 1973; Renaud 1997). In contrast to the invasive Sea Lamprey, native lampreys play a valuable ecological role as prey at all stages of their lives: fishes consume eggs in redds, piscivorous birds and fishes feed on larvae from riverine sediments, marine mammals target concentrations of anadromous adults, and invertebrates eat the remains of post-spawning adults (Cochran 2009). Abundant anadromous lampreys may even buffer predation on other organisms such as salmonids (Close et al. 2002). Additionally, larval lampreys increase oxygen levels, maintain softness of the streambed and increase fine particulate organic matter found on the streambed of the freshwater ecosystems in which they are present (Shirakawa et al. 2013). Although there is still a paucity of research on the ecological services provided by lampreys, the known and potential benefits of intact native lamprey populations should not be overlooked.

As modern human societies continue to expand, lamprey habitats are at risk, and new challenges arise that lampreys must overcome (Renaud 1997). Chemical treatments used to remove the invasive Sea Lamprey in the Great Lakes have additional adverse effects on native lamprey populations in the region (Schuldt and Goold 1980), and misguided poisoning of native lampreys has been carried out to rid ecosystems of these perceived pests (Close et al. 2004). Furthermore, poor water quality can negatively impact filter-feeding larvae (Myllynen et al. 1997), and in regions where water is diverted for agricultural irrigation, larval lampreys can become stranded in dewatered streambeds (Close et al. 2002). Additionally, exotic species can introduce a potential source of mortality to native lampreys that is often overlooked (Cochran 2009). One great challenge for lampreys is presented by the erection of waterway impediments; recently transformed lampreys that travel with water currents can become impinged on screens across water intakes of dams (Moursund et al. 2003) and adults can be impeded by these same barriers when traveling upstream to spawn (Beamish and Northcote 1989). Even when fish ladders are present, they are usually designed for strong swimming charismatic species and are inadequate for allowing unencumbered passage by comparatively weak swimming lampreys (Mesa et al. 2003; Keefer et al. 2013).

Cultures that exploit lampreys as a resource regard these species with esteem. Parasitic, anadromous lampreys grow much larger than brook lampreys, are energetically dense, and have predictable spawning runs, thus making them ideal targets for fisheries. Anadromous lampreys have a rich history as a regal food, enjoyed by Roman and English nobility, and although European River Lamprey *Lampetra fluviatilis* and Sea Lamprey continue to be targeted in fisheries across Europe today (Renaud 2011), their distributions are markedly reduced from historical accounts (Mateus et al. 2012). Indigenous cultures often harvest lampreys for food and ceremonial uses, as is the case for the Maori of New Zealand who target the Pouched Lamprey *Geotria australis* (McDowall 1990) and native tribes in the U.S. Pacific Northwest who target the Pacific Lamprey *Entosphenus tridentatus* (Close et al. 2002). The Arctic Lamprey *Lethenteron camtschaticum* is similarly utilized as a subsistence resource in western Alaska, and this species is additionally targeted for commercial use in a centuries-old fishery in Japan and a developing fishery in Alaska (Renaud 2011).

The Arctic Lamprey and Pacific Lamprey inhabit the highly productive waters of the North Pacific Ocean during their adult trophic phase, and together are the only known species of lampreys found in the Bering Sea (Mecklenburg et al. 2002). Arctic Lampreys have a nearly circumpolar distribution in the northern hemisphere, inhabiting shallow nearshore waters from the Sea of Japan to the Bering Sea in the Pacific Ocean and the Beaufort Sea to the Barents Sea in the Arctic Ocean (Mecklenburg et al. 2002; Renaud 2011). Occurring at lower latitudes in the northern hemisphere, Pacific Lampreys occupy deeper waters and have a geographic distribution that extends from the Sea of Japan to the Bering Sea to the eastern North Pacific Ocean as far south as Mexico (Mecklenburg et al. 2002; Renaud 2011).

Arctic Lampreys are traditionally harvested by Alaska Natives from villages along the Yukon and Kuskokwim rivers using rakes and nets dipped through holes cut into river ice (Brown et al. 2005). Desired for human consumption and dog food because of their high lipid content, Arctic Lampreys remain an important resource in western Alaska (Brown et al. 2005; Andersen and Scott 2010). In 2003, a commercial fishery began near Grayling, Alaska, and commercial harvest is limited to 20 metric tons because population information on this Arctic Lamprey stock is unknown (Bue et al. 2011). Additionally, traditional fishers for Arctic Lamprey in Japan use nets and baskets placed on the streambed that create breaks in the current to capture adults swimming upstream, later being sold as food and medicine (Honma 1960; Renaud 2011).

Population trends for Arctic Lamprey are poorly understood because of a lack of information, but harvest records may provide an indication of regional abundance trends. The International Union for Conservation of Nature Red List reports the status of Arctic Lamprey as "least concern," but it is acknowledged that population trends are unknown (Freyhof and Kottelat 2008). In Alaska, stake-holders recognize that Arctic Lamprey abundance and distribution remain poorly understood (ADFG 2006), but harvest records have been kept since 2003, when a commercial fishery began for this species. However, effort in this fishery is highly variable from year to year, so there is no reliable index of abundance in the region. Japanese harvest records are believed to track Arctic Lamprey abundance in that region, and catches of Arctic Lamprey declined nearly 90% from 1990 to 1997 in the Ishikari River which was largely attributed to overfishing (Yazawa 1998). Additional causes for this decline are likely acting in concert with overfishing, including stream channelization (Nagayama et al. 2008) and the construction of dams (Fukushima et al. 2007).

Although Pacific Lampreys are also found in rivers of Alaska and Japan (Renaud 2011), fisheries for Pacific Lampreys are primarily in the U.S. Pacific Northwest (Close et al. 2002). Native tribes of the Pacific Northwest catch Pacific Lampreys for food and medicinal and ceremonial use, with traditional fishing grounds for numerous tribes on the main stem and tributaries of the Columbia and Klamath rivers (Close et al. 2002; Petersen 2009). Fishing for Pacific Lamprey is conducted using hooks, nets, and traps, and this tradition is deeply intertwined with many Pacific Northwest cultures, such that reductions in or extirpations of Pacific Lamprey populations can result in a loss of culture to these people (Close et al. 2002; Petersen 2009).

Pacific Lamprey populations in the U.S. Pacific Northwest have declined in recent decades, prompting local, state, and federal intervention (Luzier et al. 2011). For example, the average count of adult Pacific Lampreys passing Bonneville Dam on the Columbia River from 1997 to present was one-third that from 1939 to 1969 (Murauskas et al. 2013). A failed attempt to list the Pacific Lamprey under the Endangered Species Act in 2004, attributed to a lack of information on population trends, ultimately resulted in a bolstered effort to conserve and restore this species, including a multi-agency and multi-tribal conservation initiative drafted by the U.S. Fish and Wildlife Service (Luzier et al. 2011). Conservation actions to date include the translocation of adult Pacific Lamprey into headwater streams beyond dams (Ward et al. 2012) and the retrofitting of fish ladders to be more easily passable by lampreys (Moser et al. 2011). The complete successes of these projects remain to be seen, but the efforts themselves highlight improvements in the way resource managers view native lampreys in the USA.

Although the freshwater phases of Arctic and Pacific lampreys are being investigated for potential threats to these species, the adult trophic phase remains relatively unexplored, ignoring potentially important lamprey-host interactions. Because

Arctic Lampreys, Pacific Lampreys, and fishes bearing lamprey wounds are captured during fishery surveys conducted in the eastern Bering Sea, it is possible to investigate the adult trophic phase of lampreys in this region. The eastern Bering Sea is a highly productive ecosystem that is economically valuable because of the commercial fish resources present. These fish resources are ecologically valuable for the endemic Arctic and Pacific lampreys that feed therein. Thus, the eastern Bering Sea provides an ideal system for initiating studies on anadromous Arctic and Pacific lampreys and their hosts in the ocean, as well as elucidating important differences between lamprey species and their relationships with marine hosts.

The goal of this thesis is to investigate ecological interactions between anadromous lampreys and their marine hosts. My intention is to provide insight into the adult trophic phase of native lampreys, and inform future lamprey conservation and management programs. The studies in this thesis focus on Arctic and Pacific lampreys captured in the eastern Bering Sea and have been separated into two chapters with the following goals and objectives.

Chapter 1—Explore associations between the distributions of lampreys and potential hosts in the eastern Bering Sea:

- Compile vertical and horizontal distributions for anadromous lampreys in the eastern Bering Sea.
- Examine whether fish assemblages in regions with and without lampreys differ from one another.

- Explore associations between catches of potential host fishes and lampreys in fishery-independent surveys.

Chapter 2—Examine parasitic interactions between anadromous lampreys and Pacific Cod in the eastern Bering Sea:

- Discern which lamprey species inflicted wounds observed on Pacific Cod.
- Investigate the potential relationship between lamprey wounding rates and Pacific Cod length.
- Infer Pacific Cod survival via examination of lamprey wound severity and location on Pacific Cod across sequential stages of wound healing.

References

ADFG (Alaska Department of Fish and Game). 2006. Our wealth maintained: a strategy for conserving Alaska’s diverse wildlife and fish resources. ADFG, Juneau, Alaska.

Andersen, D. B., and C. L. Scott. 2010. An update on the subsistence-caught fish to feed sled dogs in the Yukon River drainage, Alaska. U.S. Fish and Wildlife Service, Final Report 08-250, Anchorage, Alaska.

Beamish, R. J., and T. G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey, *Lampetra tridentata*, upstream of an impassable dam. Canadian Journal of Fisheries and Aquatic Sciences 46:420–425.

Brown, C. L., J. Burr, K. Elkin, and R. J. Walker. 2005. Contemporary subsistence uses and population distribution of non-salmon fish in Grayling, Anvik, Shageluk, and Holy Cross. U.S. Fish and Wildlife Service, Final Report 02-037-2, Anchorage, Alaska.

Bue, F., S. J. Hayes, E. Newland, D. F. Evenson, K. Clark, B. M. Borba, W. H. Harbor, and M. Horne-Brine. 2011. Annual management report for the Yukon and Northern Area, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 11-29, Anchorage, Alaska.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19–25.

Close, D. A., A. D. Jackson, B. P. Conner, and H. W. Li. 2004. Traditional ecological knowledge of Pacific Lamprey (*Entosphenus tridentatus*) in northeastern Oregon and southeastern Washington from indigenous peoples of the Confederated Tribes of the Umatilla Indian Reservation. Journal of Northwest Anthropology 38:141–162.

Cochran, P. A. 2009. Predation on lampreys. Pages 139–151 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Docker, M. F. 2009. A review of the evolution of nonparasitism in lampreys and an update of the paired species concept. Pages 71–114 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Freyhof, J., and M. Kottelat. 2008. *Lethenteron camtschaticum*. IUCN (International Union for Conservation of Nature) Red List of Threatened Species. Version 2013.2. Available: www.iucnredlist.org. (January 2014).

Fukushima, M., S. Kameyama, M. Kaneko, K. Nakao, and E. A. Steel. 2007. Modelling the effects of dams on freshwater fish distributions in Hokkaido, Japan. Freshwater Biology 52:1511–1524.

Gess, R. W., M. I. Coates, and B. S. Rubidge. 2006. A lamprey from the Devonian period of South Africa. Nature 443:981–984.

Hardisty, M. W., and I. C. Potter. 1971a. The general biology of adult lampreys. Pages 127–206 *in* M. W. Hardisty and I. C. Potter, editors. The biology of lampreys, volume 1. Academic Press, London.

Hardisty, M. W., and I. C. Potter. 1971b. The behavior, ecology and growth of larval lampreys. Pages 85–125 *in* M. W. Hardisty and I. C. Potter, editors. The biology of lampreys, volume 1. Academic Press, London.

Honma, Y. 1960. A story of the fisheries of hagfish and sea lamprey in the waters of Sado and Awashima islands, the Sea of Japan. Collecting and Breeding 22:34–36. Translated from Japanese by Canada Institute for Scientific and Technical Information, Department of Fisheries and Oceans, Ottawa.

Keefer, M. L., C. T. Boggs, C. A. Peery, and C. C. Caudill. 2013. Factors affecting dam passage and upstream distribution of adult Pacific Lamprey in the interior Columbia River basin. Ecology of Freshwater Fish 22:1–10.

Luzier, C. W., H. A. Schaller, J. K. Brostrom, C. Cook-Tabor, D. H. Goodman, R. D. Nelle, K. Ostrand, and B. Streif. 2011. Pacific Lamprey (*Entosphenus tridentatus*) assessment and template for conservation measures. U.S. Fish and Wildlife Service, Portland, Oregon.

Mateus, C. S., R. Rodríguez-Muñoz, B. R. Quintella, M. J. Alves, and P. R. Almeida. 2012. Lampreys of the Iberian Peninsula: distribution, population status and conservation. Endangered Species Research 16:183–198.

McDowall, R. M. 1990. New Zealand freshwater fishes: a natural history and guide. Heinemann Reed, Wellington, New Zealand.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Mesa, M. G., J. M. Bayer, and J. G. Seelye. 2003. Swimming performance and physiological responses to exhaustive exercise in radio-tagged and untagged Pacific Lampreys. Transactions of the American Fisheries Society 132:483–492.

Moser, M. L., M. L. Keefer, H. T. Pennington, D. A. Ogden, and J. E. Simonson. 2011. Development of Pacific Lamprey fishways at a hydropower dam. Fisheries Management and Ecology 18:190–200.

Moursund, R. A., D. D. Dauble, and M. Langeslay. 2003. Turbine intake diversion screens: investigating effects on Pacific Lamprey. Hydro Review 22:40–46.

Murauskas, J. G., A. M. Orlov, and K. A. Siwicke. 2013. Relationships between the abundance of Pacific Lamprey in the Columbia River and their common hosts in the marine environment. Transactions of the American Fisheries Society 142:143–155.

Myllynen, K., E. Ojutkangas, and M. Nikinmaa. 1997. River water with high iron concentration and low pH causes mortality of lamprey roe and newly hatched larvae. Ecotoxicology and Environmental Safety 36:43–48.

Nagayama, S., Y. Kawaguchi, D. Nakano, and F. Nakamura. 2008. Methods for and fish responses to channel remeandering and large wood structure placement in the Shibetsu River Restoration Project in northern Japan. Landscape and Ecological Engineering 4:69–74.

Petersen, R. S. 2009. Yurok and Karuk traditional ecological knowledge: insights into Pacific Lamprey populations of the lower Klamath Basin. Pages 1–39 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Potter, I. C., and R. W. Hilliard. 1987. A proposal for the functional and phylogenetic significance of differences in the dentition of lampreys (Agnatha: Petromyzontiformes). Journal of Zoology 212:713–737.

Renaud, C. B. 1997. Conservation status of Northern Hemisphere lampreys (Petromyzontidae). Journal of Applied Ichthyology 13:143–148.

Renaud, C. B. 2011. Lampreys of the world: an annotated and illustrated catalogue of lamprey species known to date. Food and Agriculture Organization, Rome.

Schuldt, R. J., and R. Goold. 1980. Changes in the distribution of native lampreys in Lake Superior tributaries in response to Sea Lamprey (*Petromyzon marinus*) control, 1953–77. Canadian Journal of Fisheries and Aquatic Sciences 37:1872–1885.

Shirakawa, H., S. Yanai, and A. Goto. 2013. Lamprey larvae as ecosystem engineers: physical and geochemical impact on the streambed by their burrowing behavior. Hydrobiologia 701:313–322.

Vladykov, V. D. 1973. North American nonparasitic lampreys of the family Petromyzontidae must be protected. The Canadian Field-Naturalist 87:235–239.

Vladykov, V.D., and E. Kott. 1979. Satellite species among the holarctic lampreys (Petromyzonidae). Canadian Journal of Zoology 57:860–867.

Ward, D. L., B. J. Clemens, D. Clugston, A. D. Jackson, M. L. Moser, C. Peery, and D. P. Statler. 2012. Translocating adult Pacific Lamprey within the Columbia River basin: state of the science. Fisheries 37:351–361.

Yazawa, Y. 1998. Annual change of lamprey catch at the lower stream of Ishikari River near Ebetsu City. Reports of the Taisetsuzan Institute of Science 32:61–66. (In Japanese with English summary.)

Zanandrea, G. 1959. Speciation among lampreys. Nature 184:380.

Chapter 1:

Associations between anadromous lamprey distributions and potential host fishes in the eastern Bering Sea[1]

1.1 Abstract

Arctic Lamprey *Lethenteron camtschaticum* and Pacific Lamprey *Entosphenus tridentatus* are ecologically and culturally valuable native species that co-occur in the eastern Bering Sea. There is a paucity of information on anadromous lampreys feeding in the ocean; however, fish assemblages associated with lamprey distributions can be used to provide insight into potential lamprey-host interactions and foraging behavior of lamprey in the ocean. To examine lamprey distributions and potential hosts affecting those distributions, I utilized data from two fishery-independent surveys conducted between 2002 and 2012 in the eastern Bering Sea. I found that Arctic Lampreys predominantly inhabited waters of less than 100-m depth in northern regions on the inner and middle continental shelf in which Pacific Herring *Clupea pallasii* and juvenile salmonids *Oncorhynchus* spp. were common. Pacific Lampreys predominantly inhabited benthic waters deeper than 150 m along the continental slope and co-occurred with bottom-oriented fishes, including Greenland Halibut *Reinhardtius hippoglossoides* and Pacific Cod *Gadus macrocephalus*. Arctic and Pacific lampreys do not appear to have overlapping distributional ranges in the eastern Bering Sea, and as a result, these species likely interact with different fish assemblages. These results could be explained by differences in feeding strategies or host preferences by Arctic and Pacific lampreys.

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Alternatively, Arctic and Pacific lampreys may distribute differently, placing them in regions with different fish assemblages. Regardless, in the eastern Bering Sea, Arctic Lampreys are likely to impact Pacific Herring and juvenile salmonids, whereas Pacific Lampreys are likely to impact groundfish. This study provides an initial baseline of the oceanic ecology of lampreys, which increases our understanding of species-specific differences beyond traditional freshwater studies.

1.2 Introduction

Anadromous lampreys (Petromyzontiformes) are jawless fishes that play important ecological roles in freshwater and marine environments and are valuable to the cultures that harvest them (Renaud 2011). They are prey for a variety of fishes, birds, terrestrial and marine mammals, and invertebrates during their life cycle (Cochran 2009), and adults feed on aquatic vertebrates via consumption of blood, flesh, or both during their trophic phase (Potter and Hilliard 1987). Species of lamprey that feed as adults are referred to as parasites, whereas those that forgo feeding as adults are nonparasitic and generically referred to as brook lampreys (Hardisty and Potter 1971). Although lamprey fisheries occur in freshwater rivers, the parasitic species that feed in the ocean are the varieties targeted because of their large size, high caloric content, and predictable spawning runs. Anadromous lampreys are historically a regal food enjoyed by Roman and English nobility, and fisheries for European River Lamprey *Lampetra fluviatilis* and Sea Lamprey *Petromyzon marinus* continue across Europe today (Renaud 2011). In the USA, Alaska Natives living on the lower Yukon and Kuskokwim rivers target Arctic Lamprey *Lethenteron camtschaticum* in late November to early December using dip nets swept through holes cut in the frozen surface of the river (Brown et al. 2005), and native tribes in the U.S. Pacific Northwest fish for Pacific Lamprey *Entosphenus tridentatus* in the summer using nets, poles with hooks, and bare hands (Close et al. 2002).

Adult lamprey trophic ecology can be gleaned from evidence of lamprey-host interactions, including lampreys still attached to hosts and wounds left as a result of these encounters. Although lampreys are occasionally observed attached to large bodied vertebrates such as whales (Pike 1951; Nichols and Tscherter 2011; Samarra et al. 2012) and sharks (Gallant et al. 2006), teleosts more frequently exhibit evidence of parasitic lamprey interactions, specifically wounds in their skin and muscle. These wounds have been observed on the following groups of teleosts in the North Pacific Ocean: Gadidae, Clupeidae, Salmonidae, Sebastidae, and Pleuronectidae (Sviridov et al. 2007; Orlov et al. 2009; Shevlyakov and Parensky 2010). Conversely, lamprey wounds are apparently absent on teleosts that possess protective body structures, slender body forms, slimy skin, or watery flesh such as members of Cottidae, Psychrolutidae, Hemitripteridae, Agonidae, Zoarcidae, Stichaeidae, Liparidae, and Macrouridae (Orlov et al. 2009).

Additional information about the trophic ecology of adult anadromous lampreys can be inferred from specimens opportunistically captured in the ocean. Lamprey captures in the Atlantic Ocean provide evidence that first-year Sea Lampreys feed on small fish in benthic waters of the continental shelf, whereas older Sea Lampreys feed on large pelagic species near the continental slope (Halliday 1991). Long-term data on Arctic Lamprey captures in the North Pacific Ocean (total-length range, 15–79 cm) suggests the greatest abundance occurs in the western Bering Sea in the upper 100 m of the water column (Orlov et al. 2014). Similarly, Pacific Lamprey captures in the North Pacific Ocean (total-length range, 12–85 cm) are most abundant in the Bering Sea, but are located in deeper waters and throughout the water column (Orlov et al. 2008).

Understanding the trophic ecology of adult lampreys in the ocean is important because hosts may experience adverse impacts from parasitic interactions with lampreys. For example, in the Fraser River plume, British Columbia, the flesh-feeding Western

River Lamprey *Lampetra ayersii* was estimated to consume hundreds of millions juvenile salmonids *Oncorhynchus* spp. and Pacific Herring *Clupea pallasii* (Beamish and Neville 1995). In the Amur River Estuary, Russia, the greatest source of early stage mortality for Chum Salmon *Oncorhyncus keta* and Pink Salmon *O. gorbuscha* smolts was attributed to feeding by Arctic Lamprey (Novomodnyy and Belyaev 2002). For the invasive Sea Lamprey in the Laurentian Great Lakes, lamprey parasitism reduced populations of native species such as Burbot *Lota lota* and Lake Trout *Salvelinus namaycush* and negatively impacted the rehabilitation of the imperiled Lake Sturgeon *Acipenser fulvescens* (Sutton et al. 2004; Stapanian et al. 2006). The potential severe consequences of lamprey-host interactions for host populations cannot be overstated.

An increased understanding of lamprey-host interactions has been identified as a research need for native lamprey species in the North Pacific Ocean (Mesa and Copeland 2009). However, the vast geographic area over which anadromous lampreys feed and the difficulty in capturing them makes this an arduous task. Although general distributions have been established for Arctic and Pacific lampreys by combining multiple years and data sources in the North Pacific Ocean (Orlov et al. 2008, 2014), details pertaining to interannual variation or mechanistic drivers are precluded in this approach. As a result, we still do not know if specific habitats are consistently being utilized by lampreys or why certain areas may be more important for one species or another. Furthermore, single-species distributions of Arctic and Pacific lampreys in the North Pacific Ocean show an apparent segregation of habitat use in the eastern Bering Sea, but to date, this phenomenon has not been explored, obviating underlying differences in how these species distribute. Because we know that the adult phase of anadromous lampreys is characterized by feeding, one potential driver of the distributions of Arctic and Pacific lampreys in the eastern Bering Sea is the availability of hosts.

The goal of this study was to explore associations between the distributions of lampreys and potential hosts in the eastern Bering Sea. To accomplish this, I first compiled information on the vertical and horizontal distributions of Arctic and Pacific lampreys captured in the eastern Bering Sea. Once I established where Arctic and Pacific lampreys were found in this region, I examined whether fish assemblages in regions with and without lampreys differed from one another. Finally, I explored associations between catches of potential host fishes and lampreys in fishery-independent surveys. Addressing these objectives provides an initial step towards understanding the ecology of adult trophic-phase anadromous lampreys in the eastern Bering Sea.

1.3 Methods

I analyzed lamprey and fish catch data from two fishery-independent surveys occurring in the eastern Bering Sea. One survey was conducted in epipelagic waters and the other in benthic waters, and when combined, these surveys provided vertical and horizontal coverage of the region. To analyze the distributions of Arctic and Pacific lampreys in the eastern Bering Sea, I first summarized annual lamprey distributions by geographic region (horizontal) and survey (vertical). I then examined differences in fish assemblages in regions with and without lampreys using nonparametric analyses. Finally, I explored which potential hosts were most likely important to lampreys by examining correlations between lamprey CPUE and potential host CPUE.

1.3.1 Data sources, compilation, and processing

Catch rates of lampreys and surface-oriented teleosts were acquired from an epipelagic rope trawl survey conducted by the National Marine Fisheries Service (NMFS) as part of the Bering Aleutian Salmon International Survey (BASIS). This survey in eastern Bering Sea occurred annually from mid-August to early October of 2002 through 2012, but in 2008, effort was reduced because of a transition in survey programs, so this year was excluded from the analysis (Farley et al. 2009). Prior to 2008, the entire survey was conducted on one vessel, but following 2008, this survey was carried out concurrently in the northern and southern (south of 60° N) portions of the eastern Bering Sea using two vessels. Epipelagic survey gear consisted of a 198-m midwater rope trawl, modified for use in the epipelagic zone, with a 1.2-cm cod end mesh liner, and tows were 30 min in duration (Farley et al. 2009). Twenty-six stations sampled during one leg of the 2002 BASIS survey did not identify the species of captured lampreys. Because all other years of this survey only documented Arctic Lamprey in these regions, I assumed unidentified lampreys were the same species rather than remove these stations from the analysis.

Catch rates of lampreys and bottom-oriented teleosts were obtained from a benthic rope trawl survey conducted by the NMFS Resource Assessment and Conservation Engineering Groundfish Assessment Program. This survey occurred annually between June and August on the Bering Shelf from 1982 to 2013 and biennially along the Bering Slope from 2002 to 2012; however, the Bering Slope survey was not conducted in 2006 due to a lack of funding (Hoff 2013; Lauth and Nichol 2013). Because lamprey captures were predominantly along the continental slope, analyses were limited to years with both a Bering Shelf and Bering Slope survey (2002, 2004, 2008, 2010, and 2012). Survey gear consisted of an 83-112 eastern otter trawl with a 25.3-m headrope, 34.1-m footrope, 8.9- to 10.2-cm mesh net, and 3.2-cm cod end mesh liner (Hoff 2013; Lauth and Nichol 2013). One leg during the 2010 Bering Slope survey did not identify the species of captured lampreys; however, based on the fact that all other lampreys captured by this survey were identified as Pacific Lamprey, I assumed that those unidentified lamprey were the same species rather than removing those stations from the analysis.

Catch data of teleosts and lampreys from each survey were summarized by Bering Sea Integrated Ecosystem Research Program (BSIERP) regions. There were 16 BSIERP regions (Figure 1.1), which divided the eastern Bering Sea along known oceanographic, bathymetric, and ecological boundaries (Ortiz et al. 2012). For example, the eastern Bering Sea was separated into three depth domains of 0–50, 51–100, and 101–150 m (Coachman 1986), and the boundaries of BSIERP regions often coincided with these domains. Any stations located outside of the BSIERP region boundaries were not examined further in this study. All survey-year-region combinations were included for compiling lamprey distributions, but a minimum of three stations sampled per year-region-combination was required for subsequent analyses to avoid inadequate characterization of fish assemblages in under-sampled regions (Tables 1.1 and 1.2).

For stations included in the analysis, CPUE by species was standardized to mass per unit of area swept by the trawl (kg/ha), and rare species were removed. Mass data (kg) from the epipelagic trawl was converted to CPUE through division by the average area swept per unit time of 25 hectares per 30 min tow (Murphy et al. 2009). Rare species, defined as those occurring at less than 5% of stations within the study area for all years of a survey, were removed prior to analysis because they were unlikely to influence lamprey distribution, but would tend to distort clustering patterns that might exist in their absence. For the epipelagic trawl survey, the five species of Pacific salmon were further divided into a juvenile group, individuals in their first summer in the ocean and that generally do not exceed 300 mm in length, and an immature/mature group, which consisted of individuals that had already overwintered once in the ocean. I summarized the remaining teleost CPUE data for each survey-year-region combination by calculating the mean CPUE by teleost fish group. A total of 1,345 epipelagic stations and 2,946 benthic stations were examined for this analysis.

Because the primary interest of this study was the relationship between the presence of lampreys and their potential hosts, each survey-year-region combination was categorized as “High” or “Low” lamprey catch, defined below, and this factor was used for statistically testing whether fish assemblages differed in areas with and without lampreys. Because Pacific Lampreys were infrequently captured in the epipelagic survey (< 0.1% of stations), I limited my analysis of epipelagic teleost CPUE data to Arctic Lamprey. Arctic Lampreys were never captured at a benthic station, so I limited my analysis of benthic teleost CPUE data to Pacific Lamprey. The criterion for establishing High and Low lamprey catch categories varied slightly between surveys because the larger mesh size of the benthic trawl was believed to be less efficient at sampling lamprey compared to the smaller mesh of the epipelagic trawl; in the epipelagic survey, the High lamprey catch category was defined as two or more Arctic Lampreys per year-region combination, whereas in the benthic survey, the High lamprey catch category was defined as one or more Pacific Lamprey per year-region combination.

1.3.2 Ordination analysis

To investigate whether fish assemblages in regions with High and Low lamprey catch differed from one another, I employed nonparametric multivariate analyses in the program PRIMER version 6.1.15 (Clarke & Gorley 2006). Summarized teleost CPUE data was compared to identify fish assemblages, such that year-region combinations with similar teleost groups occurring at similar proportions had similar fish assemblages. Because lamprey species were segregated by survey, data from the epipelagic survey and benthic survey were treated separately in the analysis. The resulting epipelagic survey matrix was 121 year-region combinations by 25 teleost groups, and the benthic survey matrix was 68 year-region combinations by 64 teleost groups. A two-part analysis was conducted for each survey to visualize and test for differences in fish assemblages between regions with High and Low lamprey catch.

First, I visualized patterns in fish assemblages among year-region combinations using nonmetric multidimensional scaling (NMDS), a nonparametric method that reduces similarities to rank order. To do this, I applied a square-root transformation to the summarized teleost CPUE data, deemphasizing high CPUE values, but not over-emphasizing low CPUE values. A similarity matrix was then constructed from the square-root-transformed data for each survey using a Bray-Curtis dissimilarity measure

(Clarke and Gorley 2006). An NMDS plot was then created for each survey based on rank orders from the similarity matrix, and multidimensional data was reduced to two or three dimensions. The Kruskal's stress value was used to estimate how well the NMDS scaling represented the multivariate data, such that values closer to zero provide a better representation of the data (Kruskal 1964). For this study, I only considered the three-dimensional solution if the Kruskal's stress value for the resulting NMDS in two dimensions was greater than 0.2, indicating a poor fit (Kruskal 1964).

Second, I used an analysis of similarity (ANOSIM) routine to test for significant differences in fish assemblages by lamprey catch group (High or Low). The ANOSIM test is a rank-based analog to an analysis of variance (ANOVA) test, establishing a permutation-based null distribution from the similarity matrix by which a test statistic R is compared (Clarke and Gorely 2006). I ran 9,999 permutations of the data for each survey to create a null distribution, and used R values to aid in interpreting group similarities, where an R value of zero indicated similarities between and within groups were equivalent and an R value of one indicated all year-region combinations within a group were more similar to each other than year-region combinations from the other group (Clarke and Gorely 2006). Additionally, an index of multivariate dispersion (MVDISP) was used to assess differences in variability between groups (Clarke and Gorely 2006). Significant differences between High and Low lamprey catch groups from an ANOSIM test ($\alpha = 0.05$) were interpreted using a similarity percentage (SIMPER) routine, which partitioned the contributions of individual teleost groups to the dissimilarity between year-region combinations with High and Low lamprey catch.

1.3.3 Lamprey and host correlation analysis

To identify potentially important teleost hosts for Arctic and Pacific lampreys, I investigated positive associations between lamprey CPUE and potential host CPUE, a relationship expected for hosts that are important to lampreys, using nonparametric Spearman’s rank-order correlation (Hollander and Wolfe 1973). For this portion of the analysis, only regions with three or more stations sampled during each year were included. Additionally, regions in which lampreys were rarely captured, less than 5% of stations, were excluded to avoid including excessive zeros in the data.

The potential hosts investigated were selected using the results of the previously described SIMPER routine and prior knowledge of lamprey feeding in the eastern Bering Sea. Included teleost groups had a greater average CPUE for the High lamprey catch group compared to the Low lamprey catch group in the SIMPER analysis, contributed more than two percent to the dissimilarity between these groups, and consistently contributed to the dissimilarity, defined here as having a dissimilarity divided by standard deviation that is greater than one. Substantial evidence indicates that Pacific Cod are frequently found with Pacific Lamprey wounds (see Chapter 2); therefore, this species was included in the benthic survey analysis regardless of the SIMPER results.

Summarized lamprey and teleost catch data were analyzed differently by survey to account for differences in the number of years sampled. To examine general trends between teleosts and lampreys, I paired lamprey CPUE and potential host CPUE for all included year-region combinations and tested for a positive relationship. Because the epipelagic survey sampled ten years, compared to five years for the benthic survey, I was able to further analyze correlations between lamprey CPUE and suspected host CPUE for each included region separately. Significance was determined at an alpha equal to 0.05 divided by the number of simultaneous tests occurring, reducing the chance of making a Type I error associated with multiple comparisons.

1.4 Results

Distributions of Arctic and Pacific lampreys in the eastern Bering Sea differed vertically within the water column and geographically. In the study area, Arctic Lampreys were captured at 19.0% of epipelagic stations and 0.0% of benthic stations, whereas Pacific Lampreys were captured at < 0.1% of epipelagic stations and 8.3% of benthic stations. Arctic Lampreys were predominantly captured in regions on the inner and middle continental shelf and in northern region of the study area (Figure 1.2), whereas Pacific Lampreys were predominantly captured in regions along the continental slope (Figure 1.3). Arctic and Pacific lampreys were never captured at the same station, but both species were captured in the north middle shelf region during the 2002 epipelagic survey. Among sampled years in the study region, 2002 exhibited the highest annual mean lamprey CPUE and proportion of stations with lampreys present for both Arctic and Pacific lampreys, and lamprey catches were relatively depressed in subsequent years (Tables 1.1 and 1.2).

1.4.1 Ordination analysis

Ordination of teleost CPUE data for year-region combinations allowed for the detection of differences in fish assemblages in regions with and without lampreys present. Teleost CPUE data from the epipelagic survey clustered by High and Low Arctic

Lamprey catch groups. These clusters were evident in a two-dimensional NMDS plot (Kruskal's stress value = 0.22), but due to the high stress value I further examined a three-dimensional NMDS plot (Kruskal's stress value = 0.14; Figure 1.4). Latitudinal and longitudinal gradients were evident in epipelagic fish assemblages occurring in the eastern Bering Sea, suggesting regional consistency in fish assemblages over time. Fish assemblages were significantly different between High and Low Arctic Lamprey catch groups (ANOSIM: $R = 0.158$; $P < 0.001$), though the Low group did exhibit more within-group variability of fish assemblages compared to the High group (MVDISP: 1.15 and 0.64, respectively). The NMDS plot further illustrated that the Low Arctic Lamprey group included a few year-region combinations that had relatively great Pacific Herring CPUE and were similar to the High group, but the majority of the Low group that was distinct from the High group had little or no Pacific Herring CPUE. A SIMPER routine identified that Pacific Herring was the most distinguishing teleost group between High and Low Arctic Lamprey catch groups. The High group had a relatively greater average abundance of Pacific Herring, juvenile Chum Salmon, juvenile Chinook Salmon *Oncorhynchus tshawytscha*, juvenile Coho Salmon *O. kisutch*, and juvenile Pink Salmon, and the Low group had a relatively higher abundance of Walleye Pollock *Gadus chalcogrammus*, immature/mature Chum Salmon, and immature/mature Chinook Salmon (Table 1.3).

Teleost CPUE data from the benthic survey clustered by High and Low Pacific Lamprey catch groups. Overall, benthic fish assemblages in the eastern Bering Sea exhibited both latitudinal and depth gradients, evident from a two-dimensional NMDS plot (Kruskal's stress value = 0.08), and reflecting regional consistency of fish assemblages (Figure 1.5). Fish assemblages were significantly different between High and Low Pacific Lamprey catch groups (ANOSIM: R = 0.48; P < 0.001), although the Low group exhibited more within-group variability of fish assemblages than the High group (MVDISP: 1.01 and 0.90, respectively). A SIMPER routine identified the High Pacific Lamprey catch group to have a relatively higher abundance of Pacific Ocean Perch *Sebastes alutus*, Arrowtooth Flounder *Atheresthes stomias*, Flathead Sole *Hippoglossoides elassodon*, Greenland Halibut *Reinhardtius hippoglossoides*, Kamchatka Flounder *Atheresthes evermanni*, and Rex Sole *Glyptocephalus zachirus* compared to the Low group. Additionally, Giant Grenadier *Albatrossia pectoralis*, Popeye Grenadier *Coryphaenoides cinereus*, and Shortspine Thornyhead *Sebastolobus alascanus* were abundant in the High group and completely absent from the Low group. The Low Pacific Lamprey catch group had a relatively higher abundance of Walleye Pollock, Yellowfin Sole *Limanda aspera*, Northern Rock Sole *Lepidopsetta polyxystra*, Alaska Plaice *Pleuronectes quadrituberculatus*, and Pacific Cod *Gadus macrocephallus* compared to the High group (Table 1.4).

1.4.2 Lamprey and host correlation analysis

The regions in which three or more epipelagic stations were sampled for each year included in this study and, at which Arctic Lampreys were present at a minimum of 5% of the stations, were the following: south Bering Strait, north inner, midnorth inner, south inner, St. Matthews, and south middle (Figure 1.1). Of the five potential hosts suggested by the epipelagic SIMPER analysis results, Arctic Lamprey CPUE was positively and significantly correlated with the CPUE of Pacific Herring and juvenile Chinook Salmon ($P < 0.01$), and although not significant at $\alpha = 0.01$ (adjusted for the occurrence of five simultaneous tests), Arctic Lamprey CPUE was positively correlated with the CPUE of juvenile Chum, Coho, and Pink Salmon ($P < 0.02$; Table 1.3). Region-specific analysis indicated that no suspected hosts had a significantly positive relationship with Arctic Lamprey CPUE for the south Bering Strait, north inner, St. Matthews, or south middle regions (Table 1.5). However, Arctic Lamprey CPUE was significantly and positively correlated with juvenile Chinook Salmon ($\rho = 0.93$, $P < 0.001$) and juvenile Pink Salmon ($\rho = 0.92$, $P < 0.001$) for the south inner region (Figure 1.6).

The regions in which three or more benthic stations were sampled for each year included in this study and, at which Pacific Lampreys were present at a minimum of 5% of the stations, were the off-shelf north and off-shelf southeast regions (Figure 1.1). The only identified potential hosts that were positively correlated with Pacific Lamprey CPUE were Pacific Cod, Greenland Halibut, Kamchatka Flounder, and Shortspine Thornyhead, although the CPUE of all potential hosts were not significantly correlated with Pacific Lamprey CPUE at $\alpha = 0.005$ (Table 1.4).

1.5 Discussion

Non-overlapping distributions of Arctic and Pacific lampreys in the eastern Bering Sea emphasize the unique life-history patterns of these two species. Arctic Lampreys were consistently found in epipelagic waters of northerly regions on the inner and middle continental shelf, and Pacific Lampreys were very rarely captured in epipelagic stations further west. Pacific Lampreys were consistently captured in benthic waters along the continental slope, and Arctic Lampreys were never captured in the benthic trawl survey. In this study, Arctic and Pacific lampreys were never captured at the same station, further confirming the habitat separation of these species in the eastern Bering Sea. Additionally, the only time both species were captured in the same region (North Middle, epipelagic survey in 2002 that includes stations with one hour tows not included in this analysis), the location of the single station with Pacific Lamprey was located westward of the eleven stations with Arctic Lamprey present. These findings are consistent with previous compilations of single species distributions of anadromous lampreys in this region, placing Arctic lamprey distribution nearshore and Pacific Lamprey distribution near the continental slope (Orlov et al. 2008, 2014).

Juvenile salmonids and Pacific Herring were distributed in the same regions of the eastern Bering Sea as Arctic Lamprey. In general, Arctic Lampreys were not present in regions that lacked Pacific Herring, and the average Pacific Herring CPUE was more than double for year-region combinations in which Arctic Lamprey were present, suggesting an association between Arctic Lamprey distribution and Pacific Herring presence. In addition, four species of juvenile salmon (Chinook, Chum, Coho, and Pink salmon) had an average CPUE more than double in year-region combinations with Arctic Lamprey present, suggesting a similar association between Arctic Lamprey distributions and juvenile salmonid presence. This relationship is believed to be related to feeding because juvenile salmon and Pacific Herring have been observed with small lamprey wounds, thought to be inflicted by Arctic Lamprey, during BASIS surveys (J. Murphy, Alaska Fisheries Science Center, personal communication). Thus, Arctic Lamprey may be distributing where Pacific Herring and juvenile salmon are more abundant. Alternatively, Arctic Lamprey, Pacific Herring, and juvenile salmon may all simply prefer shallow nearshore areas, resulting in the observed coincidental overlap of their distributions. Regardless, Pacific Herring and juvenile salmon are likely to be impacted by Arctic Lamprey in the eastern Bering Sea because overlapping distributions make them available hosts. This hypothesis is supported by the positive rank-order correlation between the CPUE of Arctic Lamprey and the CPUE of all five potential teleost hosts. I infer that Arctic Lamprey distribution in the eastern Bering Sea is largely a function of the presence of one or more of the five potential hosts identified, while the density of Arctic Lamprey is related to the abundance of those hosts.

In the south inner region, Arctic Lamprey CPUE was significantly and positively correlated with both juvenile Chinook Salmon ($P < 0.001$) and juvenile Pink Salmon CPUE ($P < 0.001$), suggesting that Arctic lampreys are only found in the south inner region when potential hosts are there and are more abundant when their hosts are more abundant (Figure 1.6). This overall trend was evident in the south inner region for the CPUE of Arctic Lamprey and the remaining three potential hosts identified (Pacific Herring and juvenile Chum and Coho salmon), although these relationships were not found to be significantly correlated. Little or no potential hosts were present in the south inner region during 2010, 2011, and 2012, likely reflecting the change in timing of the southern Bering Sea BASIS survey beginning in 2009 rather than declines in the abundance of potential hosts. However, there was a small catch of potential hosts and Arctic Lamprey in 2009, following the change in survey timing, and a lack of hosts and

Arctic Lamprey in 2006 prior to the change in survey timing, suggesting that Arctic Lamprey vary in concordance with Pacific Herring and juvenile salmonids. The overall lack of region-specific correlation found for northerly regions analyzed could be from the fact that Arctic Lamprey and the potential hosts identified are ubiquitous in these regions during the sampled periods.

The results of this study indicate that the continental slope is an important habitat for Pacific Lamprey, but there were no significant positive correlations between the CPUE of any of the ten potential hosts and Pacific Lamprey. The diversity of fish present on the continental slope (68 teleost groups were present at > 5% of stations) may reflect a great diversity of hosts available to Pacific Lamprey, such that no specific species drive lamprey density. Teleosts that utilize the continental slope, but are not likely to drive Pacific Lamprey density, as suggested by negative or near-zero correlation coefficients, include Arrowtooth Flounder, Flathead Sole, Rex Sole, Giant Grenadier, Popeye Grenadier, Pacific Ocean Perch, Kamchatka Flounder, and Shortspine Thornyhead (Table 1.4). Pacific Cod and Greenland Halibut did have the greatest positive correlation coefficients (Table 1.4), though not significant, making these species the most likely hosts associated with Pacific Lamprey in the eastern Bering Sea. In the western Bering Sea, Pacific Cod and Greenland Halibut are suspected of being important hosts for Pacific Lamprey (Orlov et al. 2009), further supporting the hypothesis that they are important to Pacific Lamprey in the eastern Bering Sea. Interestingly, Pacific Cod typically had a higher CPUE in continental shelf regions that lacked Pacific Lampreys in this study, despite evidence that Pacific Lamprey parasitize this species along the continental slope in the eastern Bering Sea (see Chapter 2). However, this species is known to spawn on the outer continental shelf in waters between 100 and 200 m from March to April (Neidetcher et al. 2014), and lamprey parasitism may be occurring during these episodic spawning events not captured during the time frame of this study.

Feeding behavior can differ among parasitic lamprey species, and this could play a role in host selection and lamprey distribution. Lampreys that feed on blood are expected to select larger hosts that can sustain longer feeding events, whereas lampreys that feed on flesh target smaller hosts that are easily killed and more abundant (Beamish 1980; Renaud et al. 2009). Pacific Lampreys are known to consume both flesh and blood of their hosts (Renaud et al. 2009), and the association of this species with large groundfish (Greenland Halibut and Pacific Cod) along the continental slope of the eastern Bering Sea is consistent with a lamprey that feeds on blood. In contrast, Arctic Lampreys are inferred to be flesh feeders (Renaud et al. 2009), and the observed association between Arctic Lamprey distribution and small pelagic fish (Pacific Herring and juvenile salmonids) is consistent with the expected feeding behavior of a flesh-feeding lamprey. Differing feeding behaviors could be a possible basis for differences in lamprey-host interactions, and thus separated marine distributions observed in this study, but it is also possible that restricted migratory ranges of lampreys in the eastern Bering Sea has limited the types of hosts available for feeding, giving rise to these species-specific feeding behaviors in the region.

Another possible mechanism contributing to the longitudinal separation of Arctic and Pacific lamprey distributions is the eastern Bering Sea cold pool, which annually forms on the middle continental shelf. The cold pool does restrict the dispersion of a variety of fish that lampreys may parasitize such as Pacific Herring, Walleye Pollock, Pacific Cod, and Capelin *Mallotus villosus* (Hollowed et al. 2012; Stabeno et al. 2012). In this study, Arctic and Pacific lampreys both had relatively broad distributions during the warm year of 2002, which was associated with a small cold pool extent. In contrast, during the cold year of 2010, lamprey distributions were relatively restricted, which was associated with a vast cold pool extent (Stabeno et al. 2012). One possible reason for the observed separation of the distributions of Arctic and Pacific lampreys is that the cold pool is not directly limiting lamprey movements, but rather, the hosts on which lampreys are feeding are restricted by this cold water mass, and lampreys remain where there are abundant hosts. Alternatively, Arctic Lamprey movements may be limited to nearshore environments while Pacific Lamprey movements allow for offshore excursions, and the cold pool could be one mechanism limiting which hosts are available in these different habitats.

A glimpse of a finer-scale understanding of the distributions of Arctic and Pacific lampreys and associations with potential host fishes can be provided through examination of the north middle shelf region from the 2002 epipelagic survey, in which Arctic and Pacific lampreys were both captured (note that the duration of some of the tows was one hour and not included in the main analysis). Of the 13 stations sampled, Arctic Lampreys were captured at 11 sites and Pacific Lampreys were captured at one site. The single station with Pacific Lamprey also produced the maximum Walleye Pollock CPUE in the region. However, a quantitative understanding of the relationship between Pacific

Lamprey and Walleye Pollock in pelagic habitats is not possible from this analysis because Pacific Lamprey were excluded from the epipelagic analysis. Of the 11 stations at which Arctic Lamprey were captured, the one site with the maximum Arctic Lamprey CPUE co-occurred with the maximum Capelin CPUE. This suggests that Capelin abundance may be associated with Arctic Lamprey distribution at finer scales, whereas the broader scale regional analysis did not indicate this possibility. One possible reason for this discrepancy is the high annual variability in Capelin abundance observed in epipelagic surveys, making this species an available host when abundant, but not when rare. Because Arctic and Pacific lampreys likely feed on a variety of hosts, localized or annual abundance of some fishes may actually be related to lamprey distributions at finer scales yet go unnoticed at broader scales, precluding those potential lamprey-host interactions from being inferred by the approach utilized in this study.

One potential limitation to the interpretation of the results is that epipelagic and benthic surveys utilized in this study employed different sampling gear. The smaller mesh used in the epipelagic survey (1.2 cm) is certainly more effective at capturing both Arctic and Pacific lampreys compared to the larger mesh used in the benthic survey (3.2 cm). The absence of Pacific Lamprey in inner and middle continental shelf epipelagic trawls indicates that this species is not actively using this environment. However, Pacific Lampreys were captured in five epipelagic trawls conducted over the outer continental shelf and continental slope despite the low sampling effort, suggesting that Pacific Lampreys are occasionally utilizing epipelagic waters in these regions, as well as the benthic environment. The benthic trawl survey does occasionally capture small fishes such as Pacific Herring, Capelin, and myctophids (Myctophidae), and if Arctic Lamprey were frequently utilizing the benthos, I would expect at least sporadic catches of this species. Because no Arctic Lampreys were captured in benthic trawl surveys, even in regions where Arctic Lamprey were known to be in pelagic waters, I believe that this species rarely inhabits benthic habitats. As such, I do not believe that the differences between trawls used in these surveys contributed to the results described herein, rather the presence and absence of lampreys accurately reflects habitat utilization by species.

An additional limitation of this study is that surveys were limited spatially and temporally, potentially missing important seasonal or episodic shifts in distributions. Survey data used in this analysis did not include nearshore estuarine habitats and would not capture lampreys utilizing these habitats, but lampreys are often found feeding in estuaries in other regions. For example, Arctic Lampreys in the western Bering Sea were estimated to consume 75% of Pink and Chum salmon smolts in the Amur river estuary (Novomodnyy and Belyaev 2002), and the Western River Lamprey fed on Pacific Herring and Pacific salmon smolts in the nearshore Fraser River plume (Beamish and Neville 1995). It is expected that similar predation events on juvenile salmon occur in the western Alaska river deltas due to the close proximity of Arctic Lampreys to the estuaries of the Yukon and Kuskokwim Rivers, and sampling of these habitats could find concentrations of lampreys not identified by this study. Additionally, no sampling occurred in any year from November through May, and distributions and associations of lampreys and potential hosts reported herein may not hold true during these colder months.

In the future, several improvements can be incorporated into research of adult trophic-phase lampreys. Analysis into the relative importance of different hosts should be pursued in more detail, with lamprey digestive tract analysis as one possible method for investigating contributions of different species to lamprey diets. This study found correlation between lampreys and potential hosts, but a diet analysis would be able to test the proposed hypothesis that feeding is the cause for this correlation, bolstering the argument that association is related to feeding. Furthermore, lamprey sampling components should be included in estuarine and nearshore research occurring in Alaska, as this is believed to be an important habitat for these species. To determine the rivers of origin of adult lampreys captured in the Bering Sea which may aid in explaining the nearshore distributions of Arctic Lamprey and the magnitude of Pacific Lamprey movements, genetic and tagging studies should be pursued. Finally, the NMFS Observer program provides a platform which already captures and records lampreys in the eastern Bering Sea (AFSC 2013), and efforts should be made to confirm species identification using dentition, an easily distinguishable characteristic for separating Arctic and Pacific lampreys (see Chapter 2).

With the continuation of lamprey exploitation and evident declines in many lamprey populations, it is important to understand all life history stages of parasitic, anadromous lampreys, and not just those occurring in freshwater. The role of the adult trophic phase in shaping lamprey populations has not been well studied, but host availability has been suggested as potentially limiting the number of spawning adults returning to rivers (Luzier et al. 2011, Murauskas et al. 2013). Further inference of lamprey-host interactions through the study of distributions can aid in understanding which regions and host species are likely important to anadromous lampreys while in the ocean. If the adult trophic phase is important to lamprey survival and health, conservation and restoration programs will need to consider factors occurring during the adult trophic phase in their plans. For example, restoration efforts are underway for the Pacific Lamprey in the U.S. Pacific Northwest (Luzier et al. 2011), but we do not currently know where or on which hosts these animals are feeding while in the ocean. This study is an initial step towards understanding the adult trophic phase of Arctic and Pacific lampreys in the eastern Bering Sea, showing that Pacific Lamprey and Arctic Lamprey inhabit different regions, occur with different fish assemblages, and are thus likely to parasitize different fishes. As such, these two species will be impacted differently by stressors such as commercial fisheries, climatic shifts, or a warming ocean. Going forward, resource managers will need to consider and reconcile these differences to establish effective measures which support the conservation of Arctic and Pacific lampreys when needed, sustaining harvests of these species for generations to come.

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1.7 References

AFSC (Alaska Fisheries Science Center). 2013. AFSC/FMA: web map observer groundfish data, Alaska, 1993–2012. Available: www.afsc.noaa.gov/maps/FMA/datamap/obsmap.html. (December 2013).

Beamish, R. J. 1980. Adult biology of the River Lamprey (*Lampetra ayresi*) and the Pacific Lamprey (*Lampetra tridentata*) from the Pacific coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 37:1906–1923.

Beamish, R. J., and C. E. M. Neville. 1995. Pacific salmon and Pacific Herring mortalities in the Fraser River plume caused by River Lamprey (*Lampetra ayresi*). Canadian Journal of Fisheries and Aquatic Sciences 52:644–650.

Brown, C. L., J. Burr, K. Elkin, and R. J. Walker. 2005. Contemporary subsistence uses and population distribution of non-salmon fish in Grayling, Anvik, Shageluk, and Holy Cross. U.S. Fish and Wildlife Service, Final Report 02-037-2, Anchorage, Alaska.

Clarke, K. R., and R. N. Gorley. 2006. User manual/tutorial. PRIMER-E Ltd., Plymouth, UK.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19–25.

Coachman, L. K. 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. Continental Shelf Research 5:23–108.

Cochran, P. A. 2009. Predation on lampreys. Pages 139–151 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Farley, E. V., Jr., J. Murphy, J. Moss, A. Feldmann, and L. Eisner. 2009. Marine ecology of western Alaska juvenile salmon. Pages 307–330 *in* C. C. Krueger and C. E. Zimmerman, editors. Pacific salmon: ecology and management of Western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.

Gallant, J., C. Harvey-Clark, R. A. Myers, and M. J. Stokesbury. 2006. Sea Lamprey attached to a Greenland Shark in the St. Lawrence Estuary, Canada. Northeastern Naturalist 13:35–38.

Halliday, R. C. 1991. Marine distribution of the Sea Lamprey (*Petromyzon marinus*) in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 48:832–842.

Hardisty, M. W., and I. C. Potter. 1971. The general biology of adult lampreys. Pages 127–206 *in* M. W. Hardisty and I. C. Potter, editors. The biology of lampreys, volume 1. Academic Press, London.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-258, Seattle.

Hollander, M., and D. A. Wolfe. 1973. Nonparametric statistical methods. John Wiley & Sons, New York.

Hollowed, A. B., S. J. Barbeaux, E. D. Cokelet, E. Farley, S. Kotwicki, P.H. Ressler, C. Spital, and C. D. Wilson. 2012. Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography 65:230–250.

Kruskal, J. B. 1964. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29:1–27.

Lauth, R. R., and D. G. Nichol. 2013. Results of the 2012 Eastern and Northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-256, Seattle.

Luzier, C. W., H. A. Schaller, J. K. Brostrom, C. Cook-Tabor, D. H. Goodman, R. D. Nelle, K. Ostrand, and B. Streif. 2011. Pacific Lamprey (*Entosphenus tridentatus*) assessment and template for conservation measures. U.S. Fish and Wildlife Service, Portland, Oregon.

Mesa, M. G., and E. S. Copeland. 2009. Critical uncertainties and research needs for restoration and conservation of native lampreys in North America. Pages 311–321 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Murauskas, J. G., A. M. Orlov, and K. A. Siwicke. 2013. Relationships between the abundance of Pacific Lamprey in the Columbia River and their common hosts in the marine environment. Transactions of the American Fisheries Society 142:143–155.

Murphy, J. M., W. D. Templin, E. V. Farley Jr., and J. E. Seeb. 2009. Stock-structured distribution of western Alaska and Yukon juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) from United States BASIS surveys, 2002–2007. North Pacific Anadromous Fish Commission Bulletin, 5:51–59.

Neidetcher, S. K., T. P. Hurst, L. Ciannelli, and E. A. Logerwell. 2014. Spawning phenology and geography of Aleutian Islands and eastern Bering Sea Pacific Cod (*Gadus macrocephalus*). Deep Sea Research Part II.DOI: 10.1016/j.dsr2.2013.12.006.

Nichols, O. C., and U. T. Tscherter. 2011. Feeding of sea lampreys *Petromyzon marinus* on minke whales *Balaenoptera acutorostrata* in the St. Lawrence Estuary, Canada. Journal of Fish Biology 78:338–343.

Novomodnyy, G. V., and V. A. Belyaev. 2002. Predation by lamprey smolts *Lampetra japonica* as a main cause of Amur chum salmon and pink salmon mortality in the early sea period of life. North Pacific Anadromous Fish Commission, Technical Report No. 4. Vancouver, British Columbia.

Orlov, A. M., A. A. Baytalyuk, and D. V. Pelenev. 2014. Distribution and size composition of Arctic Lamprey *Lethenteron camtschaticum* in the North Pacific. Oceanology 54:180–194.

Orlov, A. M., R. J. Beamish, A. V. Vinnikov, and D. Pelenev. 2009. Feeding and prey of Pacific lamprey in coastal waters of the western North Pacific. Pages 875–877 in A. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment, American Fisheries Society, Symposium 69, Bethesda, Maryland.

Orlov, A. M., V. F. Savinyh, and D. V. Pelenev. 2008. Features of the spatial distribution and size structure of the Pacific Lamprey *Lampetra tridentata* in the North Pacific. Russian Journal of Marine Biology 34: 276–287.

Ortiz, I., F. K. Wiese, and A. Grieg. 2012. Marine Regions Boundary Data for the Bering Sea Shelf and Slope. UCAR/NCAR-Earth Observing Laboratory/Computing, Data, and Software Facility. Available: http://dx.doi.org/10.5065/D6DF6P6C. (November 2013).

Pike, G. C. 1951. Lamprey marks on whales. Journal of the Fisheries Board of Canada 8:275–280.

Potter, I. C., and R. W. Hilliard. 1987. A proposal for the functional and phylogenetic significance of differences in the dentition of lampreys (Agnatha: Petromyzontiformes). Journal of Zoology 212:713–737.

Renaud, C. B. 2011. Lampreys of the world: an annotated and illustrated catalogue of lamprey species known to date. Food and Agriculture Organization, Rome.

Renaud, C. B., H. S. Gill, and I. C. Potter. 2009. Relationships between the diets and characteristics of the dentition, buccal glands and velar tentacles of the adults of the parasitic species of lamprey. Journal of Zoology 278:231–242.

Samarra, F. I., A. Fennell, K. Aoki, V. B. Deecke, and P. J. Miller. 2012. Persistence of skin marks on killer whales (*Orcinus orca*) caused by the parasitic Sea Lamprey (*Petromyzon marinus*) in Iceland. Marine Mammal Science 28:395–401.

Shevlyakov, V. A., and V. A. Parensky. 2010. Traumatization of Kamchatka River Pacific salmon by lampreys. Russian Journal of Marine Biology 36:396–400.

Stabeno, P. J., N. B. Kachel, S. E. Moore, J. M. Napp, M. Sigler, A. Yamaguchi, and A. N. Zerbini. 2012. Comparison of warm and cold years on the southeastern Bering Sea shelf and some implications for the ecosystem. Deep Sea Research Part II: Topical Studies in Oceanography 65:31–45.

Stapanian, M. A., C. P. Madenjian, and L. D. Witzel. 2006. Evidence that Sea Lamprey control led to recovery of the burbot population in Lake Erie. Transactions of the American Fisheries Society 135:1033–1043.

Sutton, T. M., B. L. Johnson, T. D. Bills, and C. S. Kolar. 2004. Effects of mortality sources on population viability of Lake Sturgeon: a stage-structured model approach. Great Lakes Fishery Commission Technical Report, Ann Arbor, Michigan.

Sviridov, V. V., I. I. Glebov, A. N. Starovoytov, A. V. Sviridova, M. A. Zuev, V. V. Kulik, and M. A. Ocheretyanny. 2007. Wounding of Pacific salmon in relation to the spatio-temporal variation in distribution patterns of important predatory fishes in the Russian economic zone. North Pacific Anadromous Fish Commission Bulletin 4:133–144.

1.8 Figures

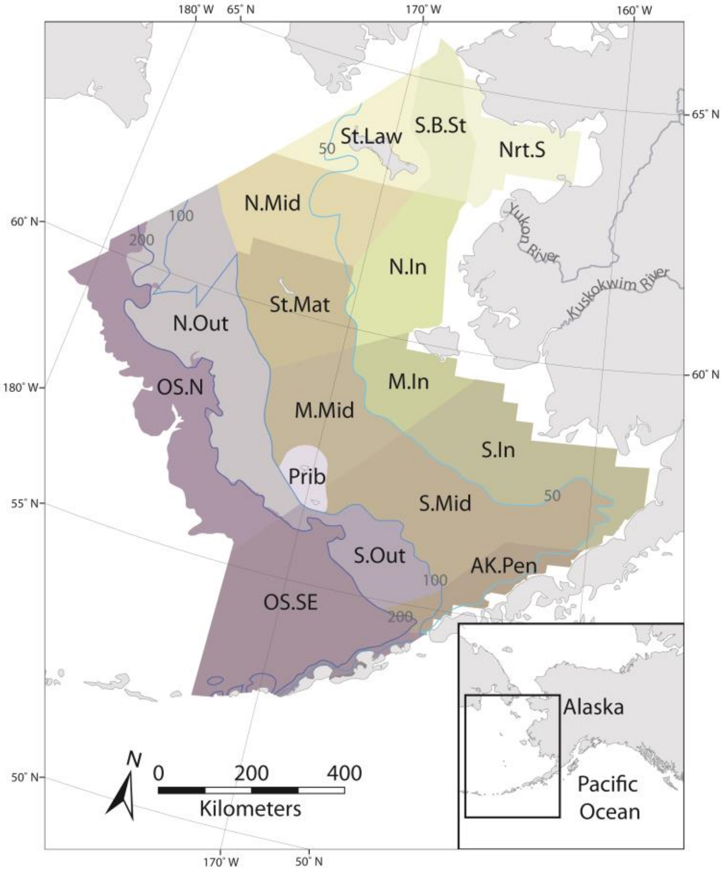

Figure 1.1. Map of Bering Sea Integrated Ecosystem Research Program regions used for summarizing lamprey and teleost CPUE data with map extent shown as a rectangle in lower right inset (Source: Ortiz et al. 2012). Isobaths are shown for 50-, 100-, and 200-m depths. Abbreviated region names for the inner continental shelf are S.B.St = south Bering Strait, Nrt.S = Norton Sound, N.In = north, M.In = midnorth, and S.In = south; middle continental shelf are St.Law = St. Lawrence, N.Mid = north, St.Mat = St. Matthews, M.Mid = midnorth, S.Mid = south, and AK.Pen = Alaska Peninsula; outer continental shelf are N.Out = north, Prib = Pribilofs, and S.Out = south; and off-shelf are OS.N = north and OS.SE = southeast.

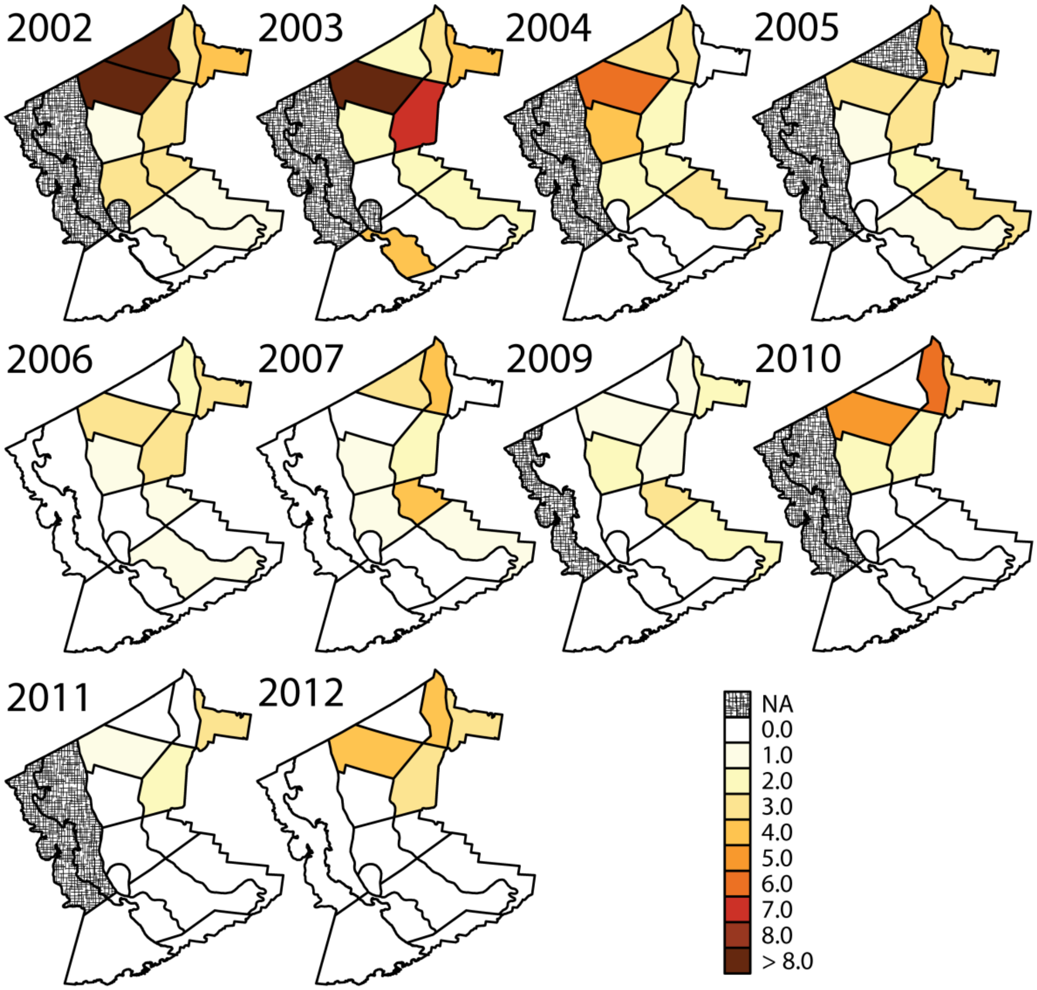

Figure 1.2. Annual maps of Arctic Lamprey epipelagic distribution (except 2008) depicting the average CPUE (kg/ha ×10^{-4}). The extent of annual maps is the BSIERP regions described in Figure 1.1. Note that prior to 2009, this survey was conducted by one vessel, and beginning in 2009, two vessels sampled concurrently changing the timing of sampling in some regions.

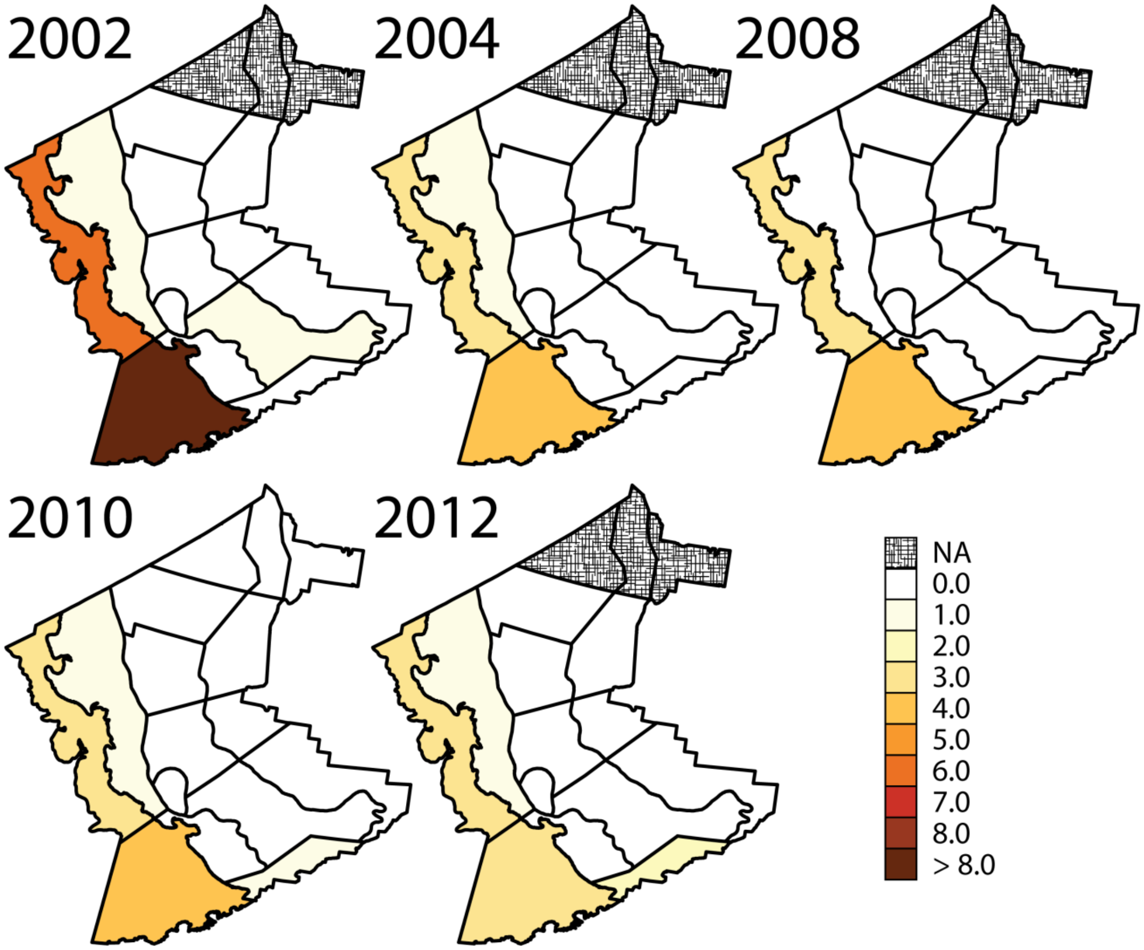

Figure 1.3. Biennial maps of Pacific Lamprey benthic distribution (except 2006) depicting the average CPUE (kg/ha ×10^{-2}). The extent of biennial maps is the BSIERP regions described in Figure 1.1.

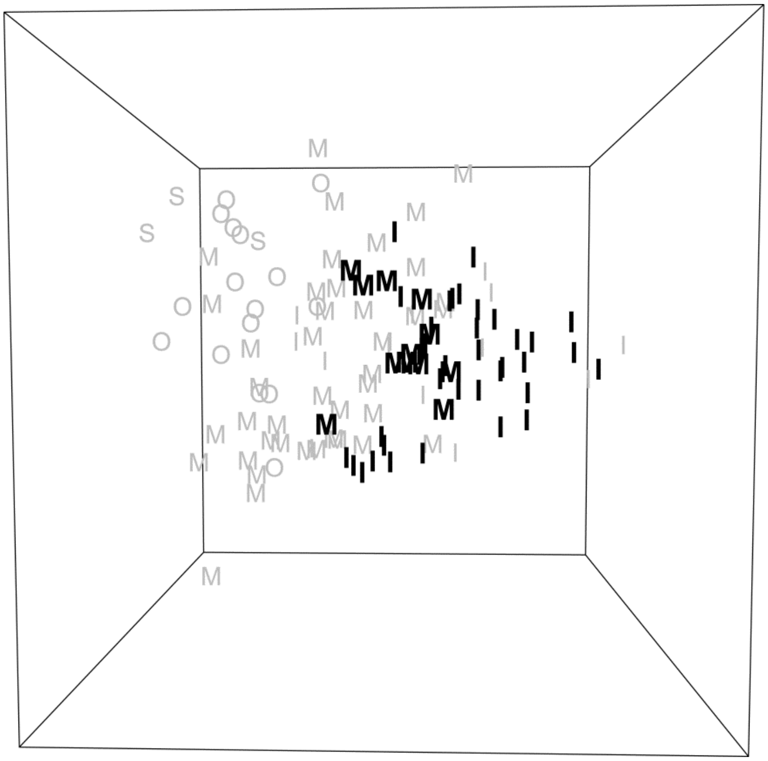

Figure 1.4. Nonmetric multidimensional scaling (NMDS) ordination of epipelagic fish reduced to three dimensions (Kruskal’s stress = 0.14) and based on a Bray-Curtis similarity matrix of square-root-transformed teleost CPUE data. Year-region combinations with two or more Arctic Lampreys present are shown in black and those with fewer than two Arctic Lampreys present are shown in gray. Letters refer to the location of each region on the continental shelf as described in Figure 1.1: inner (I), middle (M), outer (O), and off-shelf (S).

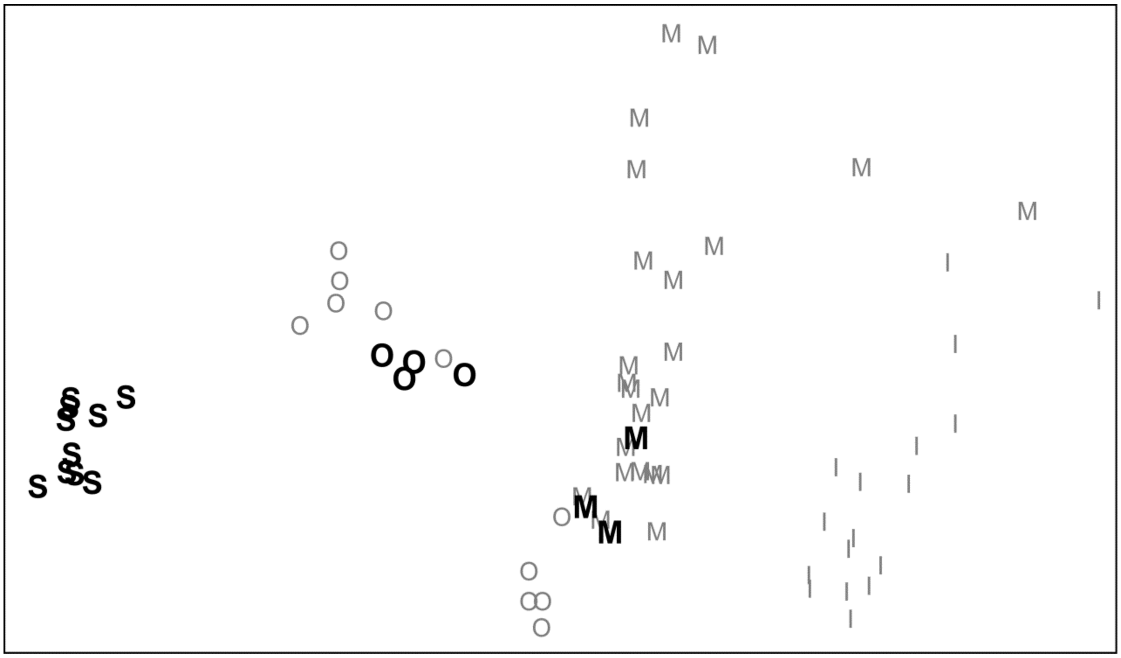

Figure 1.5. Nonmetric multidimensional scaling (NMDS) ordination of benthic fish reduced to two dimensions (Kruskal's stress = 0.08) and based on a Bray-Curtis similarity matrix of square-root-transformed teleost CPUE data. Year-region combinations with at least one Pacific Lamprey present are shown in black and those with no Pacific Lamprey present are shown in gray. Letters refer to regions location on the continental shelf described in Figure 1.1: inner (I), middle (M), outer (O), and off-shelf (S).

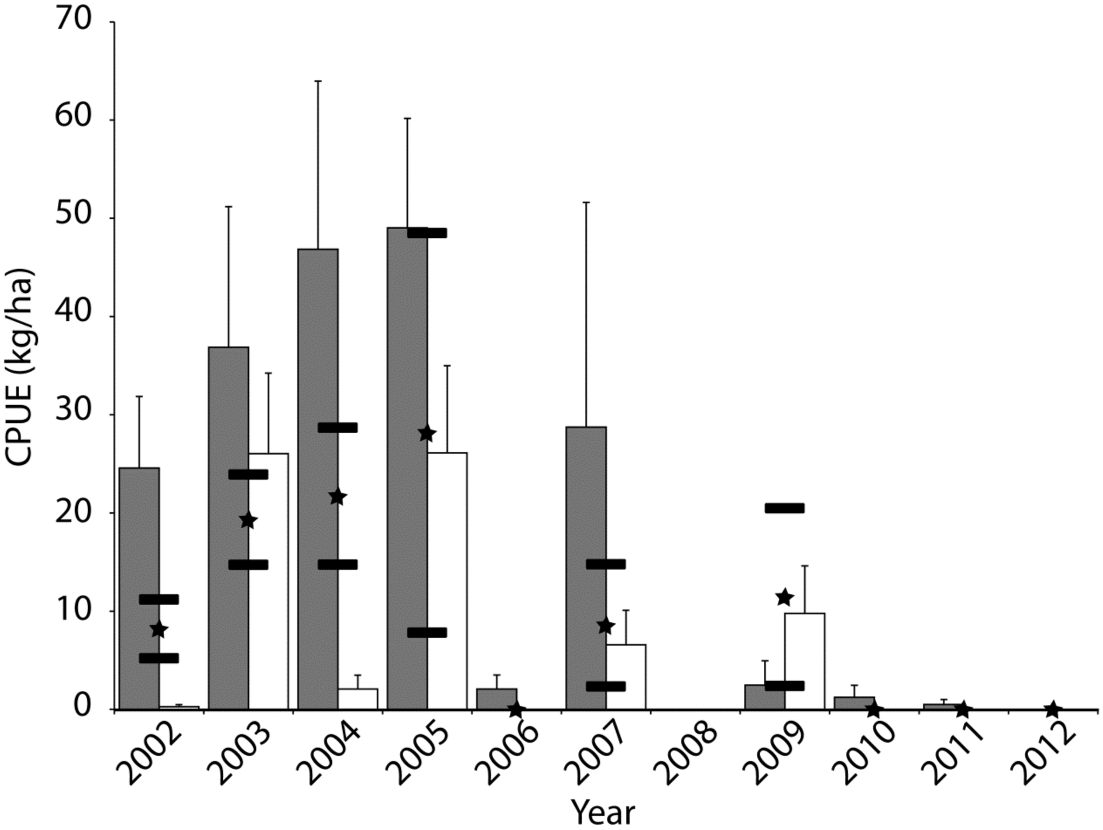

Figure 1.6. Mean CPUE of Arctic Lamprey and hosts in epipelagic south inner region of the eastern Bering Sea where black stars and horizontal bars indicate Arctic Lamprey ± SE (×10^{-4}), gray vertical bars indicate juvenile Chinook Salmon + SE (×10^{-3}), and white vertical bars indicate juvenile Pink Salmon + SE (×10^{-3}).

1.9 Tables

Table 1.1. Frequency of epipelagic trawl stations sampled by year and region (region locations and abbreviations described in Figure 1.1). Values in light gray indicate a year-region combination that was removed prior to teleost CPUE analysis because of insufficient sampling. The final two rows and columns list the percent of stations with Arctic Lamprey present (%AL) and the average Arctic Lamprey CPUE in kg/ha ($\times 10^{-5}$).

Region	02	03	04	05	06	07	09	10	11	12	%AL	CPUE
S.B.St[c]	15	13	7	4	7	12	8	12	11	12	38.6	25.5
Nrt.S	5	3	5	2[a]	6	4	7	12	11	8	38.1	22.2
N.In[c]	15	15	16	16	17	13	15	15	17	14	35.3	23.1
M.In[c]	14	7	10	10	9	10	3	8	4	9	28.6	14.6
S.In[c]	30	29	19	18	14	16	7	15	10	11	24.9	11.5
St.Law	12	4	9	-	4	8	2	2	3	2	32.6	30.9
N.Mid	7	1[a]	15	9	9	8	8	10	7	1[a]	45.3	41.9
St.Mat[c]	5	9	10	15	9	10	7	8	5	4	18.3	12.2
M.Mid	2[a]	10	10	6	15	15	8	12	12	16	3.8	1.8
S.Mid	30	27	25	24	30	27	14	22	21	25	1.2	0.7
AK.Pen	12	11	5	7	5	5	3	8	5	7	0.0	0.0
N.Out	-	-	-	-	5	2	6	-	-	3	0.0	0.0
Prib	-	-	2	2	4	4	1	1	4	4	0.0	0.0
S.Out	1	4	8	10	12[b]	10	4	17	10	10	1.2	1.5
OS.N	-	-	-	-	3	1	-	-	-	1	0.0	0.0
OS.SE	1	1	1	1	7	6	2	2	1	2	0.0	0.0
%AL	33.6	27.6	30.3	14.5	12.8	14.6	13.7	14.6	13.2	11.6		
CPUE	25.5	18.3	18.9	11.6	6.9	9.0	6.6	11.3	4.8	8.4		

[a] Indicates at least one station contained Arctic Lamprey, but was not included in further analysis.

[b] Indicates at least one station contained Pacific Lamprey, but was not further examined for this species.

[c] Indicates regions included in Spearman’s rank-order correlation analysis between the CPUE of Arctic Lamprey and that of potential hosts.

Table 1.2. Frequency of benthic trawl stations sampled by year and region (region locations and abbreviations described in Figure 1.1). Dashes in light gray indicate a year-region combination that was removed prior to teleost CPUE analysis because of no sampling effort. The final two rows and columns list the percent of stations with Pacific Lamprey present (%PL) and the average Pacific Lamprey CPUE in kg/ha (×10^{-3}).

Region	02	04	08	10	12	%PL	CPUE
S.B.St	-	-	-	23	-	0.0	0.0
Nrt.S	-	-	-	22	-	0.0	0.0
N.In	7	7	7	40	7	0.0	0.0
M.In	24	24	24	24	24	0.0	0.0
S.In	55	55	54	55	55	0.0	0.0
St.Law	-	-	-	25	-	0.0	0.0
N.Mid	13	13	13	46	13	0.0	0.0
St.Mat	43	43	43	45	42	0.0	0.0
M.Mid	41	41	41	41	41	0.0	0.0
S.Mid	64	64	62	64	63	0.3	0.4
AK.Pen	19	19	8	19	20	3.5	4.9
N.Out	76	75	75	75	79	1.3	1.2
Prib	14	15	14	14	14	0.0	0.0
S.Out	22	23	11	24	25	0.0	0.0
OS.N[a]	72	101	101	97	95	23.4	27.6
OS.SE[a]	66	126	97	100	82	27.0	41.1
%PL	11.4	7.8	8.7	7.3	6.8		
CPUE	18.4	12.6	8.6	8.6	9.3		

[a] Indicates regions included in Spearman's rank-order correlation analysis between the CPUE of Pacific Lamprey and that of potential hosts.

Table 1.3. Epipelagic similarity percentage (SIMPER) and correlation results, enumerating relative dissimilarity in epipelagic fish assemblages between year-region combinations with and without Arctic Lamprey present. Average transformed CPUE in the Low Arctic Lamprey catch group (Low), average transformed CPUE in the High Arctic Lamprey catch group (High), and average dissimilarity between these groups (Av. Diss) are listed for each species with a dissimilarity divided by standard deviation (Diss/SD) greater than 1.0 and contribution to the overall dissimilarity (%) greater than 2%. Bolded species were suspected hosts of Arctic Lamprey, and values of Spearman's correlation coefficient rho (ρ) are listed for comparisons between Arctic Lamprey CPUE and the CPUE of the listed species. Asterisks denote significant positive correlation between CPUE of Arctic Lamprey and the CPUE of suspected host fishes (P < 0.01).

Species	Low	High	Av. Diss	Diss/SD	%	ρ
Pacific Herring	0.36	0.83	12.61	1.29	19.24	0.49*
Chum Salmon	0.54	0.25	7.68	1.02	11.72	
Walleye Pollock	0.40	0.29	7.48	1.01	11.41	
Juvenile Chum Salmon	0.10	0.24	4.03	1.24	6.16	0.32
Juvenile Pink Salmon	0.08	0.16	2.63	1.17	4.01	0.32
Chinook Salmon	0.14	0.12	2.62	1.07	4.00	
Juvenile Coho Salmon	0.05	0.11	2.10	1.03	3.21	0.31*
Juvenile Chinook Salmon	0.03	0.12	2.08	1.44	3.17	0.48

Table 1.4. Benthic similarity percentage (SIMPER) and correlation results, enumerating the relative dissimilarity in benthic fish assemblages between year-region combinations with and without Pacific Lamprey present. Average transformed CPUE in the Low Pacific Lamprey catch group (Low), average transformed CPUE in the High Pacific Lamprey catch group (High), and average dissimilarity (Av. Diss) are listed for each species with a dissimilarity divided by standard deviation (Diss/SD) greater than 1.0 and contribution to the overall dissimilarity (%) greater than 2%. Bolded species were suspected hosts of Pacific Lamprey, and values of Spearman's correlation coefficient rho (ρ) are listed for comparisons between Pacific Lamprey CPUE and the CPUE of the listed species; no significant relationships were detected (P < 0.005 level).

Species	Low	High	Av. Diss	Diss/SD	%	ρ
Giant Grenadier	0.00	7.37	7.73	1.10	11.66	-0.53
Walleye Pollock	6.62	6.21	5.49	1.30	8.28	
Yellowfin Sole	5.12	1.49	5.43	1.35	8.20	
Northern Rock Sole	5.56	1.61	5.13	1.27	7.75	
Pacific Ocean Perch	0.33	4.30	4.53	1.36	6.84	-0.64
Arrowtooth Flounder	1.64	4.34	3.56	1.74	5.37	-0.14
Alaska Plaice	2.97	0.65	2.86	1.58	4.32	
Popeye Grenadier	0.00	2.31	2.44	1.16	3.68	-0.36
Flathead Sole	2.23	3.09	2.27	1.48	3.43	-0.30
Greenland Halibut	0.20	1.94	1.97	1.68	2.98	0.54
Pacific Cod	3.26	2.25	1.88	1.39	2.84	0.36
Kamchatka Flounder	0.46	2.09	1.88	1.60	2.83	0.18
Shortspine Thornyhead	0.00	1.67	1.79	1.12	2.71	0.21
Rex Sole	0.30	1.51	1.43	2.04	2.16	-0.08

Table 1.5. Spearman's correlation coefficients (ρ) of suspected host fishes by region (region locations and abbreviations described in Figure 1.1), where comparisons are between the CPUE of Arctic Lamprey and the CPUE of suspected host fishes. Asterisks denote significant positive correlation between CPUE of Arctic Lamprey and the CPUE of suspected host fishes ($P \leq 0.002$).

Region	Pacific Herring	Juvenile Chinook Salmon	Juvenile Chum Salmon	Juvenile Coho Salmon	Juvenile Pink Salmon
M.In	0.56	0.62	0.46	0.74	0.56
N.In	0.54	-0.42	0.44	0.12	-0.15
S.B.S	-0.20	0.12	-0.41	-0.30	-0.33
S.In	0.64	0.93^{*}	0.56	0.72	0.92^{*}
St.Mat	0.56	0.62	0.46	0.74	0.56

CHAPTER 2:

Interactions between lampreys and Pacific Cod in the eastern Bering Sea[1]

2.1 Abstract

Interactions between adult anadromous lampreys and their hosts are not well understood, even though lampreys pose a potential threat to species targeted by large-scale commercial fisheries. Arctic Lamprey *Lethenteron camtschaticum* and Pacific Lamprey *Entosphenus tridentatus* are anadromous species found in the eastern Bering Sea, and lamprey parasitism is evident on Pacific Cod *Gadus macrocephalus* near the continental slope. To examine this parasitic interaction, I explored similarities between the morphology of lamprey oral discs and lamprey wounds on Pacific Cod, examined relationships between lamprey wounding rates and Pacific Cod length, and explored healing patterns in the severity and location of lamprey wounds. In total, 8,746 Pacific Cod were scanned for lamprey wounds, of which 4.9% had at least one. The circular shape of lamprey wounds on Pacific Cod was similar to that of Pacific Lamprey oral discs, both differing from the oblong shape of Arctic Lamprey oral discs, which suggests that Pacific Lamprey were inflicting the wounds observed on Pacific Cod. Additionally, recent lamprey wounding was consistently more prevalent as Pacific Cod length increased, from 2% on fish < 65 cm to 3.5% on fish > 78 cm, possibly the result of size-dependent mortality experienced by Pacific Cod. Recently inflicted lamprey wounds that penetrated Pacific Cod muscle tissue were observed four times as often as superficial wounds that did not penetrate muscle tissue, but superficial wounds were twice as likely to be observed reaching a completely healed state, suggesting that Pacific Cod possibly

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[1] Siwicke, K. A. 2014. Interactions between lampreys and Pacific Cod in the eastern Bering Sea. Prepared for submission to Transactions of the American Fisheries Society.

experience lamprey-related mortality when muscle tissue is penetrated during parasitism. However, the ratio of penetrating lamprey wounds observed in five different Pacific Cod body regions was consistent across four sequential healing stages, suggesting no difference in the likelihood of a lamprey wound to reach a completely healed state between vital and non-vital body regions. I believe that Pacific Lamprey parasitizing Pacific Cod may result in increased host mortality, which is likely resulting from indirect effects of parasitism such as increased vulnerability to predators and disease. This effect may be exacerbated for smaller hosts, which would explain why fewer small hosts are observed with wounds in samples compared to larger conspecifics. Parasitic interactions between native lampreys and their host fishes should not be overlooked as there is potential for this interaction to negatively affect host fish.

2.2 Introduction

Eighteen species of lamprey (Petromyzontiformes) undergo an adult trophic phase and are commonly referred to as parasitic, a term encompassing lampreys that feed on the blood, flesh, or blood and flesh of aquatic vertebrates (Potter and Hilliard 1987; Renaud et al. 2009; Renaud 2011). This parasitism is accomplished by a toothed oral disc used for securely attaching to hosts and a piston-like tongue used to bore into host tissue when feeding (Hardisty and Potter 1971). After a parasitic lamprey has detached from a host, an imprint of the oral disc remains as evidence of the interaction (Lennon 1954; King 1980), which can provide inference about the resulting consequences.

Frequently, parasitic interactions between lampreys and their hosts negatively impact individual hosts and entire fish stocks (Bence et al. 2003). The most severe consequence of lamprey parasitism is the mortality of the host. For example, Lake Sturgeon *Acipenser fulvescens* parasitized by Sea Lamprey *Petromyzon marinus* in a laboratory experienced 15% mortality attributed directly to the lamprey feeding (Patrick et al. 2009). In situ sampling of the Fraser River plume in British Columbia indicated Western River Lamprey *Lampetra ayresii* killed and consumed Pacific Herring *Clupea pallasii* and Pacific salmon *Oncorhynchus* spp. smolts (Beamish and Neville 1995). Similarly, Arctic Lamprey *Lethenteron camtschaticum* killed and consumed Chum Salmon *Oncorhynchus keta* and Pink Salmon *O. gorbuscha* smolts in the Amur River estuary, Russia (Novomodnyy and Belyaev 2002).

In addition to direct mortality, lamprey parasitism can cause deleterious sub-lethal impacts to hosts or result in the indirect mortality of hosts. For example, a lamprey feeding event can cause anemia, leading to reduced growth and poor health of a host fish (Edsall and Swink 2001). While a lamprey is feeding, foraging ability and locomotion may be compromised, impacting the energy use of a host fish (Lennon 1954; Patrick et al. 2009). Additional impacts suffered by hosts include elevated stress levels and depressed blood chemistry parameters (e.g., hematocrit, hemoglobin, and plasma proteins; Sepulveda et al. 2012). In the northwestern Pacific Ocean, Sockeye Salmon *Oncorhynchus nerka*, Chinook Salmon *O. tshawytscha*, Pink Salmon, and Pacific Cod *Gadus macrocephalus* that were believed to be parasitized by a Pacific Lamprey *Entosphenus tridentatus* had lower gonado-somatic index values compared to healthy conspecifics (Pelenev et al. 2008; Pelenev et al. 2010). Indirect mortality can also follow the detachment of a feeding lamprey, as was the case for Lake Sturgeon that became more prone to secondary infections from fungus *Saprolegnia* spp. following lamprey parasitism (Patrick et al. 2009). Therefore, fishes that survive a parasitic lamprey feeding event may have compromised health, which can lead to a reduction in life span.

Beyond individual-level effects on host fishes, lampreys can have population-level effects. In the Laurentian Great Lakes, the invasive Sea Lamprey drastically reduced populations of native fish species such as Burbot *Lota lota* and Lake Trout *Salvelinus namaycush* (Stapanian et al. 2006) and had additional negative impacts on the rehabilitation of imperiled Lake Sturgeon stocks (Sutton et al. 2004). In the Fraser River plume, British Columbia, the estimated mortality induced by Western River Lamprey over two years was 359 million Pacific Herring and 90 million salmon smolts (Beamish and Neville 1995). Similarly, Arctic Lamprey feeding was the single greatest cause of early stage mortality for Chum Salmon and Pink Salmon smolts in the Amur River estuary, Russia (Novomodnyy and Belyaev 2002). Therefore, lampreys pose a potentially great source of mortality to populations of the aquatic vertebrates they parasitize.

Lamprey parasitism does not impact all hosts equally, and a common factor that influences host selection and survival in lamprey-host dynamics is host size. In laboratory studies, the frequency of Sea Lamprey feeding events on individual hosts increased with host size (Farmer and Beamish 1973), and the number of lamprey feeding attempts significantly increased with host surface area (Cochran 1985). A theoretical comparison of Rainbow Trout *Oncorhynchus mykiss* and Lake Trout weight to lamprey weight showed that a 40:1 ratio is needed to survive, suggesting that host and lamprey size will influence survivorship (Farmer et al. 1975). In the western Bering Sea, Pacific Cod less than 50 cm did not exhibit any lamprey wounds, while lamprey wounds were common on larger conspecifics (Pelenev et al. 2010). This could imply that Pacific Cod less than 50 cm in length are not selected as lamprey hosts as often as larger individuals (Pelenev et al. 2010), or that this 50-cm length may be a threshold below which a Pacific Cod is not likely to survive a lamprey feeding event.

In addition to host size, the location of a lamprey feeding event on the body of a host fish appears to be an important factor for host survival. Lampreys typically select feeding locations to minimize being dislodged by the host fish, such as behind the pectoral fins where water velocity is reduced or anterior locations where there is less lateral movement (Farmer 1980; Cochran 1986; Bergstedt et al. 2001; Patrick et al. 2009). Additional factors thought to influence feeding location selection include closeness of blood vessels to skin surface, presence of larger blood vessels, and areas where scales are reduced, thin, or absent (Farmer 1980; Cochran and Lyons 2010; Nichols and Tscherter 2011). On Pacific salmon, Pacific Lamprey wounds were observed more often in anterior and ventral body regions, proximal to vital organs, whereas Arctic Lamprey wounds were observed more often above the lateral line (Shevlyakov and Parensky 2010). In Pacific Cod examined for lamprey wounds in the western Bering Sea, over half of the fish were observed with wounds on the dorsal side (Pelenev et al. 2010). When feeding location coincides with vital regions of high blood supply, like the head and abdomen, the result can be higher mortality for the hosts, which may explain the lower prevalence of ventral wounds versus dorsal wounds often observed in situ (Beamish 1980; Cochran 1986; Pelenev et al. 2010).

Outside of the Laurentian Great Lakes, there is a paucity of information on lamprey-host interactions (Mesa and Copeland 2009). Native lampreys are believed to be in equilibrium with their hosts (Renaud 1997), but some native species do reduce host populations (Beamish and Neville 1995; Novomodnyy and Belyaev 2002), making the effects of native lamprey parasitism on fish stocks a potentially overlooked source of mortality. Arctic and Pacific lampreys are anadromous parasites that spend an adult trophic phase in the North Pacific Ocean and co-occur in the eastern Bering Sea with large-scale commercial fisheries including those targeting Walleye Pollock *Gadus chalcogrammus,* Pacific Cod, and Pacific Halibut *Hippoglossus stenolepis*. Both Arctic and Pacific lampreys are native species that evolved with the marine fishes they parasitize, but it is unknown which lamprey species interact with which commercially valuable fishes and whether these interactions pose any impact to these fishes in the eastern Bering Sea (Shevlyakov and Parensky 2010). The paucity of information on adult trophic-phase Arctic and Pacific lampreys in the North Pacific Ocean warrants investigation for informing future hypotheses regarding native lamprey parasitism in this highly productive and economically valuable ecosystem.

My goal was to utilize lamprey wounds observed on a marine host to infer ecological interactions between native anadromous lampreys and host fishes in the North Pacific Ocean. I restricted my analyses to the eastern Bering Sea, where large-scale commercial fisheries occur and Arctic and Pacific lampreys are the only known species of parasitic lampreys present (Mecklenburg et al. 2002). I chose to examine Pacific Cod because this species is commonly captured in fishery surveys across a broad geographic expanse, often exhibit lamprey wounds, and are targeted in lucrative large-scale commercial fisheries. Before inferring ecological interactions, I needed to discern which lamprey species was inflicting wounds on Pacific Cod, so I examined similarities in the morphological shape of lamprey wounds and oral discs of Arctic and Pacific lampreys. To then see if wounding varied with host size, I explored relationships between lamprey wounding rates and Pacific Cod length. Finally, because I was interested in which characteristics of lamprey wounds were likely to reach a completely healed state as a means for inferring impacts to Pacific Cod survival, I explored lamprey wound severity and location on Pacific Cod across sequential stages of healing. Combined, this information provides an initial step towards describing and understanding the interactions of native lampreys and hosts in the eastern Bering Sea.

2.3 Methods

2.3.1 Data sources, processing, and classification

Pacific Cod were scanned for lamprey wounds during the International Pacific Halibut Commission (IPHC) annual longline surveys conducted from June through August in 2011 and 2012. This survey collected fishery-independent data on Pacific Halibut, with coverage from northern California to the eastern Bering Sea (Henry et al. 2013). The target sampling effort at a station was six skates with 100 baited hooks each, and for this study, a total of 250 stations in the eastern Bering Sea were sampled over two years. At each station, IPHC sea-samplers measured the total length of the first 15 Pacific Cod landed per skate and scanned them for potential lamprey wounds, such that the maximum number of Pacific Cod scanned per station was 90 fish. When lamprey wounds were suspected, IPHC sea-samplers took photographs orthogonal to the wounds using a Panasonic DMC-TS3, including information on the roughness of scales surrounding the wound, wound depression, and a length scale utilized in post-survey processing and analysis.

To describe the oral disc morphology of lampreys in the eastern Bering Sea, I opportunistically utilized lamprey specimens captured by the 2012 National Marine Fisheries Service (NMFS) benthic rope trawl survey. This survey was designed to collect biological and oceanographic data for assessing groundfish stocks and has occurred annually between June and August on the Bering Shelf since 1982 and biennially along on the Bering Slope and Aleutian Islands since 2002. Survey gear consisted of an 83-112 eastern otter trawl, with a 25.3-m headrope, 34.1-m footrope, 8.9- to 10.2-cm mesh net, and 3.2-cm end mesh liner (Hoff 2013; Lauth and Nichol 2013). All specimens captured during this survey were identified as Pacific Lamprey based on their dentition, the most distinguishing character being three large supraoral lamina teeth (Mecklenburg et al. 2002). Counts of endolateral (2-3-3-2) and infraoral (5) teeth were also checked as slight variations in the number of these teeth can occur. These Pacific Lamprey specimens were predominantly captured near the continental slope (Figure 2.1).

Additional anadromous lampreys were opportunistically obtained from epipelagic trawls conducted during the 2012 Bering Aleutian Salmon International Survey (BASIS), which was designed to collect biological and oceanographic data to study the epipelagic ecosystem and has been conducted annually from August to early October in the eastern Bering Sea and Chukchi Sea since 2002. The survey gear consisted of a 198-m midwater rope trawl, with a 1.2-cm cod end mesh liner towed in the upper 50 m of the water column for approximately 30 minutes per station at speeds of 6.9–9.3 km/h (Farley et al. 2009). All specimens captured on this survey were identified as Arctic Lamprey based on their dentition, the most distinguishing character being two large supraoral lamina teeth (Mecklenburg et al. 2002). Counts of endolateral (2-2-2) and infraoral (6–10) teeth were also checked as slight variations to these teeth can occur. These Arctic Lamprey specimens were predominantly captured in the northeastern Bering Sea (Figure 2.1).

I digitally photographed oral discs of Arctic and Pacific lampreys, and measured disc dimensions using the image processing software ImageJ (Abràmoff et al. 2004). To photograph lamprey oral discs, I pressed them tooth-side down against a flat piece of glass so that the entire disc was visible, and images were taken facing upwards with a

Panasonic DMC-TS3. In ImageJ, I placed an elliptical perimeter around the exterior edge of the marginal teeth and inside of the oral fimbriae, recording the length of the major and minor axes making up the ellipse around the oral disc (Figure 2.2). An analysis of the correlation between lamprey size (total-length) and oral disc size (perimeter) was carried out for each species. I then used the aspect ratio, calculated by dividing the major axis by the minor axis, as a metric for comparing the morphological shape of oral discs. An oral disc would be a perfect circle at an aspect ratio of 1:1, and would become more oblong as the aspect ratio increased. An analysis of the correlation between lamprey size (total-length) and aspect ratio was used to test the assumption that oral disc aspect ratio did not vary by lamprey length.

I examined all photographs of suspected lamprey wounds taken by IPHC sea-samplers, and only further processed wounds that were assessed to be caused by a lamprey. Evidence that a wound was the result of a lamprey interaction included visible dentition patterns, circular or oval shape, evidence of a sliding oral disc, and scale loss on the surrounding skin (Lennon 1954; King 1980). In ImageJ, I placed an elliptical perimeter around the exterior edge of each lamprey wound and recorded the length of the major and minor axes of the ellipse (Figure 2.2). I then calculated the aspect ratio of each lamprey wound for comparison with the same measurements made on oral discs of Arctic and Pacific lampreys as described above. The margins of some lamprey wounds were not clearly discernible because of sloughing of the surrounding skin, so I categorized lamprey wounds with discernible margins as High Confidence and those without discernable margins as Low Confidence.

To examine interactions between anadromous lampreys and Pacific Cod, I classified lamprey wounds on Pacific Cod using methods adapted from lamprey studies in the Laurentian Great Lakes (King 1980). Similar methods have been utilized to research Pacific Lamprey interactions with various host species in the North Pacific Ocean (e.g., Orlov et al. 2009). In addition to morphological dimensions, I considered the following characteristics of lamprey wounds: degree of severity, degree of healing, and location on the Pacific Cod body. For individual Pacific Cod with multiple wounds from the same lamprey feeding event (as evidenced by sliding connections) only the most recent wound was counted to avoid inflating the perceived number of feeding lampreys (Ebener et al. 2006). When there was no connection, each wound was examined separately.

Each lamprey wound was first classified by severity. Wounds that penetrated into host muscle tissue and were associated with a depression were categorized as type A, whereas superficial wounds that did not penetrate into host muscle tissue or leave a depression were categorized as type B (Figure 2.3). Type-A wounds were inferred to result from a successful feeding event where blood and flesh were consumed. In contrast, type-B wounds were more likely the result of a failed attempt by a lamprey to feed or a successful blood feeding event only.

Four healing stages were used to classify lamprey wounds by the relative amount of time since a lamprey detachment (King 1980). Healing stages were characterized as follows: (1) rough skin surrounds the wound, no healing, and no re-pigmentation; (2) smooth skin surrounds the wound, limited healing evident, and no re-pigmentation; (3)

smooth skin surrounds the wound, considerable healing, and some re-pigmentation; and (4) complete healing of wound, complete re-pigmentation, and regeneration of scales (Figure 2.3). For this analysis, I defined “recent” wounds as those classified (type-stage) as A-1, A-2, and A-3 (Figure 2.3), following a convention set in lamprey research on the Laurentian Great Lakes (e.g., Prichard and Bence 2013). On the IPHC longline survey, lampreys were occasionally observed detaching during haulback, so I assumed that some stage-1 wounds were the result of premature lamprey detachment due to a fish being captured and brought to the surface. For wounds that had healed beyond stage 1, I assumed that lamprey detachment was most likely the result of lamprey satiation prior to the Pacific Cod being captured.

To examine patterns in locations of parasitism on Pacific Cod, lamprey wounds were assigned to body regions. I defined Pacific Cod body regions following Orlov et al. (2009): (I) anterior-dorsal, (II) posterior-dorsal, (III) anterior-ventral, (IV) posterior-ventral, (V) head, and (VI) caudal (Figure 2.4). For wounds that were connected via slide marks, I assigned the body region using the location of the wound with the most recent detachment, such that an A-1 wound in region II connected to a B-3 wound in region III would only be counted as a single A-1 wound in region II.

2.3.2 Comparison of oral discs and lamprey wounds

I compared differences in the aspect ratio among Arctic Lamprey oral discs, Pacific Lamprey oral discs, and recent lamprey wounds on Pacific Cod using an ANOVA test followed by a Tukey-Kramer test for multiple pairwise comparisons. Because samples were opportunistically collected, the sampling design was unbalanced, and detection of possible heterogeneity among the variances necessitated the inclusion of a Welch's correction for the ANOVA test (Welch 1951) and use of the Dunnett modified Tukey-Kramer test (Dunnett 1980). I assumed that the oral disc aspect ratios calculated for each lamprey species were constant for individuals beyond the sampled length ranges. I further assumed that the aspect ratio of an oral disc was retained in lamprey wounds on Pacific Cod. To minimize unknown distortion effects in the shape of a wound that has completely healed, I limited this analysis to recent lamprey wounds. To minimize bias from measurement error, I only included lamprey wounds classified as High Confidence. Finally, I assumed independence of samples because the lamprey specimens were captured in different surveys than the Pacific Cod, and thus sampled lamprey were not likely to be responsible for wounds observed on sampled Pacific Cod.

2.3.3 Pacific Cod length and lamprey wounds

I investigated relationships between lamprey wounding rates and Pacific Cod length in two ways. First, I compared the number of Pacific Cod exhibiting at least one recent lamprey wound to the number of Pacific Cod exhibiting no lamprey wounds using length-based size-classes and a chi-square contingency table. I selected size classes using midpoints between mean length-at-age estimates for age-5, age-6, age-7, and age-8 Pacific Cod captured in the Bering Sea in 2011 resulting in four groups: <65 cm, 65–70 cm, 71–78 cm, and >78 cm (Thompson and Lauth 2012). In these comparisons, a single Pacific Cod could have multiple separate recent lamprey wounds, but was only counted once.

Second, I utilized a generalized additive modeling (GAM) framework to explore how the number of recent lamprey wounds related to Pacific Cod length (Hastie and Tibshirani 1990). Pacific Cod total length was only measured to the nearest centimeter, so counts of Pacific Cod scanned and recent lamprey wounds were organized by 1 length bins. The model was as follows:

$$Y \sim \beta_0 + s(n) + s(L) + \varepsilon,$$

where Y is the number of recent lamprey wounds, s(n) is the smooth function of the number of fish scanned for lamprey wounds, s(L) is the smooth function of the length of Pacific Cod, β_0 is the intercept, and ε is the error term. Because the response variable was counts of recent wounds, I initially investigated fitting the model with a Poisson distribution. However, the variance was greater than the mean, suggesting the Poisson distribution was over-dispersed. To remedy this, I assumed a negative binomial distribution allowing the variance to be a quadratic function of the mean with the addition of a scale parameter theta (Venables and Ripley 2002). Smooth functions for the number of fish scanned and the length were selected using performance iteration, selecting functions by generalized cross-validation and ensuring that the estimate of theta was as close to one as possible (Wood 2011). In this analysis, a single Pacific Cod exhibiting multiple recent lamprey wounds would contribute more than one count to the assigned length bin.

2.3.4 Classified lamprey wounds on Pacific Cod

To explore associations between lamprey wound severity (type A or B) and healing (stage 1–4), I used a chi-square contingency table. I assumed that type-B lamprey wounds had little or no impact on Pacific Cod survival, so type B acts as a control group to which type A wounds can be compared. If type-A lamprey wounds had no effect on Pacific Cod survival beyond that of type-B wounds, I would expect the null hypothesis of no association between healing stage and wound type to be supported (i.e., the ratio of type-A: type-B lamprey wounds would be maintained across all healing stages).

To investigate associations between lamprey wound location on a Pacific Cod (regions I–VI) and healing (stages 1–4), I conducted a chi-square contingency test. I included only type-A lamprey wounds to remove any confounding effects introduced by differences between type-A and type-B wounds. If the location on a Pacific Cod where lamprey feeding occurred had no effect on the survival of the Pacific Cod, I would expect the null hypothesis of no association between healing stage and wound location to be supported (i.e., the proportion of lamprey wounds in each body region would remain constant across all healing stages). Because the expected values for some healing stage-body region combinations (1-I, 1-II, 3-I, 3-II, 4-I, 4-II, 4-IV, and 4-V) were low (<5), I approximated the P-value using a Monte Carlo simulation with 5,000 replicates (Hope 1968). Additionally, no type-A lamprey wounds were observed in region VI, so only regions I–V were included.

All statistical analyses were conducted using R version 2.12.2 (R Development Core Team 2011). The “mgcv” package was used for conducting generalized additive modeling (Wood 2011), and the “DTK” package was used to conduct multiple pairwise comparisons (Dunnett 1980). Statistical tests were evaluated at a significance level of $\alpha = 0.05$.

2.4 Results

2.4.1 Comparison of oral discs and lamprey wounds

I calculated the aspect ratio for 28 Arctic Lamprey oral discs, 46 Pacific Lamprey oral discs, and 148 recent lamprey wounds on Pacific Cod captured in the eastern Bering Sea (Figure 2.1). Arctic Lamprey specimens had total lengths of 27.2–43.9 cm with oral disc perimeters of 42.7–64.1 mm, and oral disc perimeter positively and significantly increased with lamprey length ($R^2 = 0.83$, $P < 0.001$, Figure 2.5). Pacific Lamprey specimens had total lengths of 47.2–71.3 cm with oral disc perimeters of 75.3–102.6 mm, and oral disc perimeter positively and significantly increased with lamprey length ($R^2 = 0.62$, $P < 0.001$, Figure 2.5). Recent lamprey wounds on Pacific Cod had perimeters ranging from 25.3–120.0 mm. Oral disc aspect ratio did not exhibit a significant trend with total length for Arctic Lamprey ($R^2 = 0.02$, $P = 0.40$) or Pacific Lamprey ($R^2 = 0.00$, $P = 0.81$), supporting the assumption that aspect ratio remains constant with length by lamprey species (Figure 2.5). Aspect ratio differed among Arctic Lamprey oral discs, Pacific Lamprey oral discs, and recent lamprey wounds on Pacific Cod ($F = 36.8$, df = 2, 66, $P < 0.001$). A Dunnett modified Tukey-Kramer pairwise comparison of aspect ratios indicated Arctic Lamprey oral discs were significantly more oblong than Pacific Lamprey oral discs ($P < 0.001$) and recent lamprey wounds found on Pacific Cod ($P < 0.001$), whereas the aspect ratio of Pacific Lamprey oral discs and recent lamprey wounds found on Pacific Cod were not significantly different in morphological shape ($P = 0.35$; Figure 2.6).

2.4.2 Pacific Cod length and lamprey wounds

In total, 8,746 Pacific Cod were scanned for lamprey wounds and 331 recent lamprey wounds were observed on 260 Pacific Cod. Of the four size classes of Pacific Cod, the lamprey wounding rate was lowest (2.0%) for Pacific Cod in the smallest size class (<65 cm) and greatest (3.5%) for Pacific Cod in the largest size class (>78 cm). The difference in wounding rate was greatest between the smallest two size classes, becoming progressively less between larger size classes. A rate of 2.97% recently wounded Pacific Cod was expected if there was no difference among size classes, but the lamprey wounding rate varied significantly among Pacific Cod size class ($\chi^2 = 14.7$, df = 3, $P = 0.002$), increasing with each consecutively larger size class of Pacific Cod (Figure 2.7). Although Pacific Cod with multiple lamprey wounds were not as common as those with a single wound, the proportion of wounded fish exhibiting multiple wounds also consistently increased with consecutively larger size classes, from 0.37% to 0.61%.

A GAM analysis revealed an increase in the number of recent lamprey wounds with an increase in Pacific Cod length and in the number of fish scanned per length bin. The scale parameter theta was 2.443, accommodating an increase in variance with the mean. The number of lamprey wounds significantly increased with the number of Pacific Cod scanned ($P < 0.001$), but a nonlinear relationship suggests that the most abundant size classes may reach wounding saturation (Figure 2.8). Specifically, Pacific Cod of intermediate lengths were scanned at much higher frequency than smaller and larger lengths, but after including an explanatory term to account for the varying number of fish scanned per length bin, the wounding rate increased from small- to intermediate-sized fish, reaching an apparent asymptote at a length of approximately 78 cm ($P < 0.001$; Figure 2.8).

2.4.3 Classified lamprey wounds on Pacific Cod

Of the 8,746 Pacific Cod scanned for lamprey wounds, 365 were observed with one, 46 with two, 12 with three, and nine with more than three. For freshly inflicted stages 1 and 2, penetrating type-A wounds, A-1 (9.7%) and A-2 (43.2%), were more prevalent than superficial type-B wounds, B-1 (2.4%) and B-2 (13.4%), but for more healed stages 3 and 4, type-B wounds, B-3 (14.3%), and B-4 (5.9%), were more prevalent than type-A wounds, A-3 (8.7%) and A-4 (2.4%). The ratio of type-A:type-B wounds significantly varied with healing stage ($\chi^2 = 88.3$, df = 3, $P < 0.001$), shifting from type A being nearly four times as frequent in observed stage-1 lamprey wounds to type B being approximately twice as frequent in observed stage-4 lamprey wounds (Figure 2.9).

Of the 345 penetrating type-A lamprey wounds identified on Pacific Cod, the majority were observed in region III (54%), the anterior ventral portion of the fish, compared to regions I (9.6%), II (9.3%), IV (11.9%), and V (15.4%), and 15.1% were stage 1, 67.5% were stage 2, 13.6% were stage 3, and 3.8% were stage 4. The proportion of type-A lamprey wounds by location on the Pacific Cod body did not vary significantly among healing stages ($\chi^2 = 15.8$, df = NA, $P = 0.19$), remaining relatively constant across all four (Figure 2.10).

2.5 Discussion

The results from this study indicate that lamprey wounds observed on Pacific Cod in the eastern Bering Sea are most likely inflicted by Pacific Lamprey, and penetrating lamprey wounds may have a negative impact on these hosts. Host size is an important factor to consider when investigating interactions with lampreys, and for Pacific Cod, larger individuals were significantly more likely to exhibit a recent lamprey wound compared to smaller conspecifics. Furthermore, lamprey parasitism that results in the penetration of muscle tissue is observed four times more frequently than superficial wounding, but the latter is twice as likely to be observed in a completely healed state as the former. Although type-A lamprey wounds were observed most frequently in the ventral and pectoral region of the Pacific Cod, no significant trends between wound location and healing stage were found.

The approach of using lamprey wound shape indicates that lamprey wounds on Pacific Cod were a similar circular shape to Pacific Lamprey oral discs, suggesting that parasitism on Pacific Cod is executed by Pacific Lampreys. Although Pacific Lampreys used in this study were all larger than collected Arctic Lampreys, both species can overlap in size (Orlov et al. 2008, 2014). As a result, wound size alone cannot be used for differentiating the inflicting species. Additional support for positing that wounds can be attributed to Pacific Lampreys comes from the observation of four lampreys that were landed attached to Pacific halibut during the IPHC longline survey in 2012 and, all four individuals were positively identified as Pacific Lampreys. Because aspect ratio results corroborate geographic distributions of lampreys (see Chapter 1), I believe that the majority, if not all, of lamprey wounds observed on Pacific Cod in the eastern Bering Sea can be confidently attributed to Pacific Lamprey. Therefore, further inferences of parasitic lamprey interactions with fish herein will be limited to this lamprey species.

The relationship between lamprey wounding rate and Pacific Cod length exhibited a logistic shape, which has been observed in other lamprey-host interactions. For example, Sea Lamprey wounding rates have been described as increasing with Lake Trout length before reaching an asymptote (Rutter and Bence 2003; Prichard and Bence 2013). Two alternative hypotheses may explain the logistic relationship between lamprey wounding rate and host length. The first hypothesis is size-selective parasitism of hosts by lampreys, which predicts that the largest available hosts would be selected for feeding (Farmer and Beamish 1973; Cochran 1985). This hypothesis aligns with optimal foraging theory (Emlen 1966; MacArthur and Pianka 1966), because large hosts would sustain longer feeding periods than smaller hosts and minimize additional energy expenditure associated with finding a new host. Evidence to support the size-selective hypothesis has been observed in laboratory investigations of Sea Lamprey (Swink 2003). In the Bering Sea, Pacific Cod shoal, thereby providing lampreys with the opportunity to select hosts based on size. Assuming that all the Pacific Cod captured from each station were equally available to a lamprey, the size-selective parasitism hypothesis would predict that at each station, the mean length of fish with a lamprey wound would exceed the mean length of unharmed fish. Although the mean length of a Pacific Cod exhibiting a lamprey wound was larger than the mean length of unharmed fish at two thirds of the stations, the opposite was true at the remaining one third, suggesting that smaller Pacific Cod are still parasitized when larger conspecifics are available.

An alternative hypothesis is size-dependent survival of hosts, which predicts that all sizes of hosts are parasitized but smaller hosts are less likely to survive compared to larger conspecifics. This phenomenon has been observed in the parasitic relationship between Sea Lamprey and Lake Trout, Lake Sturgeon, Burbot, and Rainbow Trout (Farmer et al. 1975; Swink 2003; Patrick et al. 2009). The results in this study support the size-dependent survival hypothesis because all sizes of Pacific Cod were being parasitized, not just the larger individuals, yet there was a preponderance of wounds on larger Pacific Cod in the observed data, suggesting a larger fish was more likely to survive a lamprey feeding event and be observed in sampling than a smaller fish. A potential explanation for the asymptote observed at approximately 78 cm in length is that Pacific Cod larger than this length have attained a size beyond which size-dependence survival no longer occurs. It is also possible that a combination of size-selective parasitism and size-dependent survival of hosts is responsible for the relationship between lamprey wounding and Pacific Cod length observed.

Examination of lamprey wounds suggests that Pacific Cod experience lamprey-related mortality when muscle tissue is penetrated during parasitism. This assertion is supported by the fact that as wounds progressively healed, transitioning from stage 1 to 4, the number of penetrating type-A wounds consistently declined relative to superficial type-B wounds. If I conservatively estimate mortality of Pacific Cod related to type-B wounds to be zero, I can infer any departure from this baseline as an additional effect related to penetrating type-A wounds. Type-A wounds were observed four times as often as type-B wounds at a recently inflicted stage 1, but half as often at a completely healed stage 4. From this observation, I infer that Pacific Cod with a type-A wound are approximately four times less likely to reach a completely healed state compared to those with a type-B wound. Although lamprey parasitism could directly cause a decrease in Pacific Cod survival, other possible reasons include increased susceptibility to predation or infection, or increased energy expenditure related to an open type-A wound. Although quantifiable estimates of lamprey-induced mortality cannot be made from this study because individual Pacific Cod were not resampled, the results herein do suggest that at the least, Pacific Lamprey parasitism may be related to a nominal portion of Pacific Cod mortality in the eastern Bering Sea.

The proportions of type-A wounds occurring in the five body regions examined for Pacific cod remained relatively constant for all four healing stages, providing no evidence that the location of a lamprey wound on a Pacific Cod impacted the survival of Pacific Cod. If lamprey parasitism directly had a negative impact on the survival of a host, this effect should be exacerbated when wounds are in vital regions III and IV, compared to non-vital regions I, II, and IV (Figure 2.4). However, because lamprey wounds in all vital and non-vital Pacific Cod body regions appeared equally likely to reach a completely healed state, I believe that direct mortality from lamprey feeding is unlikely in the examined lamprey-host interaction.

A preponderance of lamprey wounds observed on Pacific Cod occurred in body region III, the anterior ventral portion of the fish, which is consistent with a previous study of Pacific Lamprey wounds on Pink and Chum salmon in the western Bering Sea (Shevlyakov and Parensky 2010). The reason for lampreys attaching to the anterior ventral portion of a host is not investigated herein, but one possible hypothesis is the relatively high blood flow at this vital region. This phenomenon has been widely reported for Sea Lamprey parasitism on a variety of hosts, and is generally attributed to low water flows, thin muscle layers, and fewer scales in this region (Farmer 1980; Cochran 1986; Cochran and Lyons 2010; Nichols and Tscherter 2011). These factors are likely to influence where Pacific Lampreys attach to Pacific Cod.

Although this study did not investigate differences between direct and indirect mortality resulting from lamprey parasitism, inferences can be made by combining severity and body-region results. I hypothesize that the majority of lamprey-related mortality of Pacific Cod is caused by indirect effects of lamprey parasitism because if direct effects from a lamprey feeding event were the main cause, I would expect wounds in vital body regions (e.g., the head) to result in increased mortality relative to wounds in non-vital body regions (e.g., dorsal muscle tissue). Inferring that reduced survival of Pacific Cod is associated with type-A wounds, but feeding in vital regions is not, I believe that Pacific Cod are more susceptible to indirect causes of mortality related to lamprey parasitism such as secondary infections or predation than they are to direct mortality resulting from lamprey parasitism itself.

The opportunistic sampling utilized in this study introduced some challenges that should be mentioned. First, Pacific Cod examined in this study were limited to the continental slope region, which is a region where Pacific Lampreys are found but Arctic Lampreys are not (Orlov et al. 2008, 2014). As a result, lamprey wounding on Pacific Cod was not formally quantified herein for regions where Arctic Lampreys are abundant. However, the 2011 and 2012 NMFS benthic trawl surveys that occurred across the eastern Bering Sea continental shelf and slope does provide qualitative information on lamprey wounds observed on Pacific Cod. The incidence of lamprey wounds on the Pacific Cod that were examined was very low across the Bering Shelf (<10 lamprey wounds in a year), suggesting that Pacific Cod in this region do not frequently interact with Arctic Lampreys that are found in this region.

The inclusion of a multiple host species representing a variety of body sizes and the additional collection of health parameters such as gonado-somatic indices and blood chemistry parameters can improve our understanding of the relative health impacts lamprey parasitism causes to individual host fish and their populations (Pelenev et al. 2008; Pelenev et al. 2010; Sepulveda et al. 2012). Combining this type of field research with laboratory studies will be beneficial towards understanding preferences that lampreys exhibit when searching for hosts, as well as the potential impacts lampreys can have on individual hosts and populations. In addition, wounding rates could be incorporated into already occurring fisheries surveys as an additional means of monitoring trends in lamprey abundance in this region, though additional investigation into the relationships between lampreys and hosts will aid in the interpretation of this type of information. For example, it is unclear if a relative increase in lamprey abundance would be reflected in wounding rates, or if lamprey abundance is actually a function of host availability as suggested by Murauskas et al. (2013), which would result in a more consistent annual wounding rate. Multi-year investigations will be necessary to begin answering these types of questions.

This study takes an initial step towards understanding native lamprey-host interactions in the eastern Bering Sea, which has previously not been examined. Lamprey parasitism is a potential source of mortality to a variety of fishes in the eastern Bering Sea, and the size-dependent impacts of lampreys on different hosts should be further investigated to assess the potential for negative impacts to fisheries. In addition to freshwater threats to lampreys, variations in lamprey abundance may be related to the availability of hosts in the ocean (Lança et al. 2013; Murauskas et al. 2013), and this issue represents an ecosystem-based management concern not currently included in any marine fisheries management plans. Further investigation into the interactions of anadromous lampreys and host fishes in this region will increase our understanding of this important feeding period, thereby allowing for better informed management and conservation measures for lampreys and their hosts in the future.

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2.7 References

Abràmoff, M. D., P. J. Magalhães, and S. J. Ram. 2004. Image processing with ImageJ. Biophotonics International 11:36–42.

Beamish, R. J. 1980. Adult biology of the River Lamprey (*Lampetra ayresi*) and the Pacific Lamprey (*Lampetra tridentata*) from the Pacific coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 37:1906–1923.

Beamish, R. J., and C. E. M. Neville. 1995. Pacific salmon and Pacific Herring mortalities in the Fraser River plume caused by River Lamprey (*Lampetra ayresi*). Canadian Journal of Fisheries and Aquatic Sciences 52:644–650.

Bence, J. R., R. A. Bergstedt, G. C. Christie, P. A. Cochran, M. P. Ebener, J. F. Koonce, M. A. Rutter, and W. D. Swink. 2003. Sea Lamprey (*Petromyzon marinus*) parasite-host interactions in the Great Lakes. Journal of Great Lakes Research 29:253–282.

Bergstedt, R. A., C. P. Schneider, and R. O'Gorman. 2001. Lethality of Sea Lamprey attacks on Lake Trout in relation to location on the body surface. Transactions of the American Fisheries Society 130:336–340.

Cochran, P. A. 1985. Size-selective attack by parasitic lampreys: consideration of alternate null hypotheses. Oecologia 67:137–141.

Cochran, P. A. 1986. Attachment sites of parasitic lampreys: comparisons among species. Environmental Biology of Fishes 17:71–79.

Cochran, P. A., and J. Lyons. 2010. Attachments by parasitic lampreys within the branchial cavities of their hosts. Environmental Biology of Fishes 88:343–348.

Dunnett, C. W. 1980. Pairwise multiple comparisons in the unequal variance case. Journal of the American Statistical Association 75:796–800.

Ebener, M. P., E. L. King Jr., and T. A. Edsall. 2006. Application of a dichotomous key to the classification of Sea Lamprey marks on Great Lakes fish. Great Lakes Fishery Commission Miscellaneous Publication 2006-02, Ann Arbor, Michigan.

Edsall, C. C., and W. D. Swink. 2001. Effects of nonlethal Sea Lamprey attacks on the blood chemistry of Lake Trout. Journal of Aquatic and Animal Health 13:51–55.

Emlen, J. M. 1966. The role of time and energy in food preference. The American Naturalist 100:611–617.

Farley, E. V., Jr., J. Murphy, J. Moss, A. Feldmann, and L. Eisner. 2009. Marine ecology of western Alaska juvenile salmon. Pages 307–330 *in* C. C. Krueger and C. E. Zimmerman, editors. Pacific salmon: ecology and management of Western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.

Farmer, G. J. 1980. Biology and physiology of feeding in adult lamprey. Canadian Journal of Fisheries and Aquatic Sciences 37:1751–1761.

Farmer, G. J., and F. W. H. Beamish. 1973. Sea Lamprey (*Petromyzon marinus*) predation on freshwater teleosts. Journal of the Fisheries Research Board of Canada 30:601–605.

Farmer, G. J., F. W. H. Beamish, and G. A. Robinson. 1975. Food consumption of the adult landlocked Sea Lamprey, *Petromyzon marinus*. Comparative Biochemistry and Physiology 50A:753–757.

Hardisty, M. W., and I. C. Potter. 1971. The general biology of adult lampreys. Pages 127–206 *in* M. W. Hardisty and I. C. Potter, editors. The biology of lampreys, volume 1. Academic Press, London.

Hastie, T., and R. J. Tibshirani. 1990. Generalized additive models. Chapman and Hall/CRC, London.

Henry, E., E. Soderlund, C. L. Dykstra, T. O. Geernaert, and A. M. Ranta. 2013. 2012 standardized stock assessment survey. Pages 503–538 *in* L. Erikson, J. Forsberg, S. Keith, T. Kong, B. Leaman, T. Loher, L. Sadorus, and E. Soderlund, editors. Report of assessment and research activities 2012. International Pacific Halibut Commission, Seattle.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-258, Seattle.

Hope, A. C. A. 1968. A simplified Monte Carlo significance test procedure. Journal of the Royal Statistical Society: Series B 30:582–598.

King, E. L., Jr. 1980. Classification of Sea Lamprey (*Petromyzon marinus*) attack marks on Great Lakes Lake Trout (*Salvelinus namaycush*). Canadian Journal of Fisheries and Aquatic Sciences 37:1989–2006.

Lança, M., M. Machado, R. Ferreira, I. Alves-Pereira, B. Ruivo Quintella, and P. Raposo de Almeida. 2013. Feeding strategy assessment through fatty acid profiles in muscles of adult Sea Lampreys from the western Iberian coast. Scientia Marina 77:281–291.

Lauth, R. R., and D. G. Nichol. 2013. Results of the 2012 Eastern and Northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Department Lennon, R. E. 1954. Feeding mechanism of the Sea Lamprey and its effect on host fishes. U.S. Fish and Wildlife Fishery Service Bulletin 56:247–293.

Lennon, R. E. 1954. Feeding mechanism of the Sea Lamprey and its effect on host fishes. U.S. Fish and Wildlife Fishery Service Bulletin 56:247–293.

MacArthur, R. H., and E. R. Pianka. 1966 On optimal use of a patchy environment. The American Naturalist 100:603–609.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Mesa, M. G., and E. S. Copeland. 2009. Critical uncertainties and research needs for restoration and conservation of native lampreys in North America. Pages 311–321 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Murauskas, J. G., A. M. Orlov, and K. A. Siwicke. 2013. Relationships between the abundance of Pacific Lamprey in the Columbia River and their common hosts in the marine environment. Transactions of the American Fisheries Society 142:143–155.

Nichols, O. C., and U. T. Tscherter. 2011. Feeding of sea lampreys *Petromyzon marinus* on minke whales *Balaenoptera acutorostrata* in the St. Lawrence Estuary, Canada. Journal of Fish Biology 78:338–343.

Novomodnyy, G. V., and V. A. Belyaev. 2002. Predation by lamprey smolts *Lampetra japonica* as a main cause of Amur chum salmon and pink salmon mortality in the early sea period of life. North Pacific Anadromous Fish Commission, Technical Report No. 4, Vancouver, British Columbia.

Orlov, A. M., A. A. Baytalyuk, and D. V. Pelenev. 2014. Distribution and size composition of Arctic Lamprey *Lethenteron camtschaticum* in the North Pacific. Oceanology 54:180–194.

Orlov, A. M., R. J. Beamish, A. V. Vinnikov, and D. Pelenev. 2009. Feeding and prey of Pacific Lamprey in coastal waters of the western North Pacific. Pages 875–877 *in* A. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment, American Fisheries Society, Symposium 69, Bethesda, Maryland.

Orlov, A. M., V. F. Savinyh, and D. V. Pelenev. 2008. Features of the spatial distribution and size structure of the Pacific Lamprey *Lampetra tridentata* in the North Pacific. Russian Journal of Marine Biology 34:276–287.

Patrick, H. K., T. M. Sutton, and W. D. Swink. 2009. Lethality of Sea Lamprey parasitism on Lake Sturgeon. Transactions of the American Fisheries Society 138:1065–1075.

Pelenev, D., A. Orlov, and N. Klovach. 2008. Predator-prey relations between the Pacific Lamprey *Lampetra tridentata* and Pacific salmon (*Oncorhynchus* spp.). North Pacific Anadromous Fish Commission Document 1097, Vancouver, British Columbia.

Pelenev, D. V., A. M. Orlov, and A. V. Vinnikov. 2010. New data on impact of parasitism of Pacific Lamprey *Lampetra tridentata* to Pacific Cod *Gadus macrocephalus*. Problems of Fisheries 11:453–462. (In Russian with English summary.)

Potter, I. C., and R. W. Hilliard. 1987. A proposal for the functional and phylogenetic significance of differences in the dentition of lampreys (Agnatha: Petromyzontiformes). Journal of Zoology 212:713–737.

Prichard, C. G., and J. R. Bence. 2013. Estimating wounding of Lake Trout by Sea Lamprey in the upper Great Lakes: allowing for changing size-specific patterns. Journal of Great Lakes Research 39:110–119.

R Development Core Team. 2011. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Renaud, C. B. 1997. Conservation status of Northern Hemisphere lampreys (Petromyzontidae). Journal of Applied Ichthyology 13:143–148.

Renaud, C. B. 2011. Lampreys of the world: an annotated and illustrated catalogue of lamprey species known to date. Food and Agriculture Organization, Rome.

Renaud, C. B., H. S. Gill, and I. C. Potter. 2009. Relationships between the diets and characteristics of the dentition, buccal glands and velar tentacles of the adults of the parasitic species of lamprey. Journal of Zoology 278:231–242.

Rutter, M. A., and J. R. Bence. 2003. An improved method to estimate sea lamprey wounding rate on hosts with application to Lake Trout in Lake Huron. Journal of Great Lakes Research 29:320–331.

Sepulveda, M. S., T. M. Sutton, and H. K. Patrick. 2012. A single Sea Lamprey attack causes acute anemia and mortality of Lake Sturgeon. Journal of Aquatic Animal Health 24:91–99.

Shevlyakov, V. A., and V. A. Parensky. 2010. Traumatization of Kamchatka River Pacific salmon by lampreys. Russian Journal of Marine Biology 36:396–400.

Stapanian, M. A., C. P. Madenjian, and L. D. Witzel. 2006. Evidence that Sea Lamprey control led to recovery of the Burbot population in Lake Erie. Transactions of the American Fisheries Society 135:1033–1043.

Sutton, T. M., B. L. Johnson, T. D. Bills, and C. S. Kolar. 2004. Effects of mortality sources on population viability of Lake Sturgeon: a stage-structured model approach. Great Lakes Fishery Commission Technical Report, Ann Arbor, Michigan.

Swink, W. D. 2003. Host selection and lethality of attacks by Sea Lampreys (*Petromyzon marinus*) in laboratory studies. Journal of Great Lakes Research 29:307–319.

Thompson, G. G., and R. R. Lauth. 2012. Assessment of the Pacific Cod stock in the eastern Bering Sea and Aleutian Islands area. Pages 245–544 *in* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, Alaska.

Venables, W. N., and B. D. Ripley. 2002. Modern applied statistics with S. Fourth Edition. Springer, New York.

Welch, B. L. 1951. On the comparison of several mean values: an alternative approach. Biometrika 38:330–336.

Wood, S. N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73:3–36.

2.8 Figures

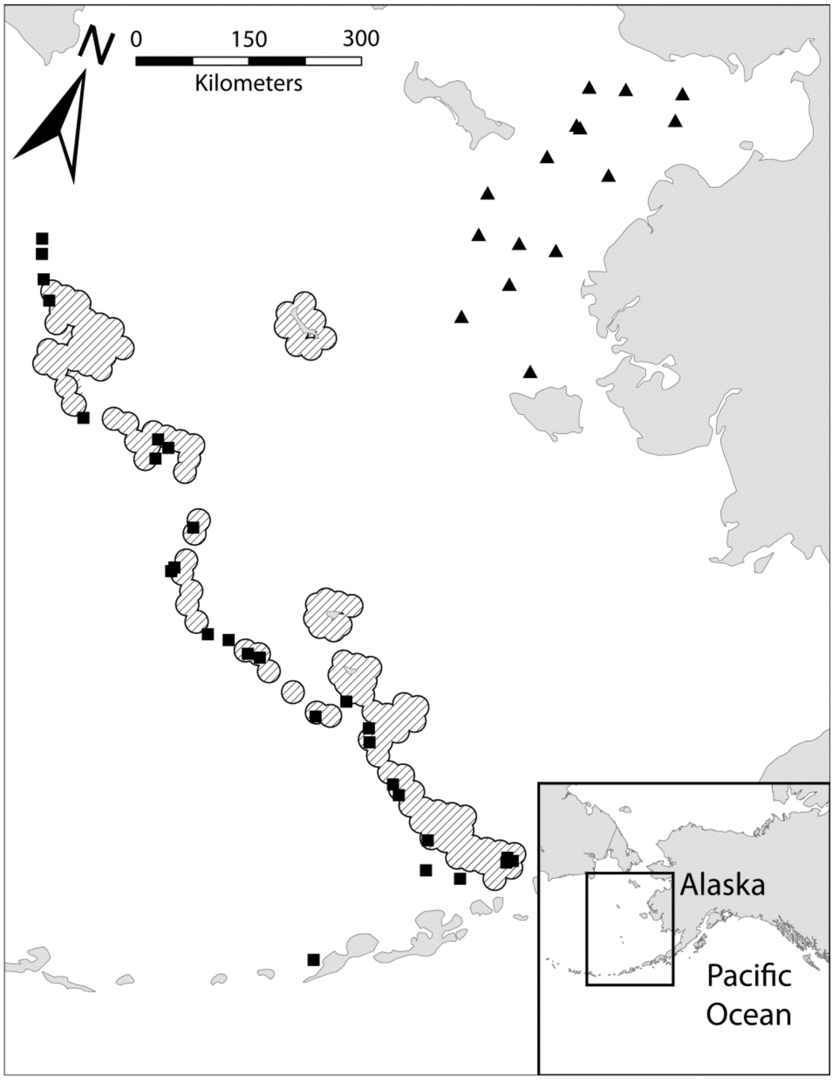

Figure 2.1. Map of the study region in the eastern Bering Sea (map extent indicated by rectangle on the lower right inset), displaying trawl stations where Arctic Lamprey (black triangles) and Pacific Lamprey (black squares) were collected in 2012 and longline stations where Pacific Cod were captured and scanned for lamprey wounds in 2011 and 2012 (diagonal lines indicate a 15-km buffer around stations for display purposes).

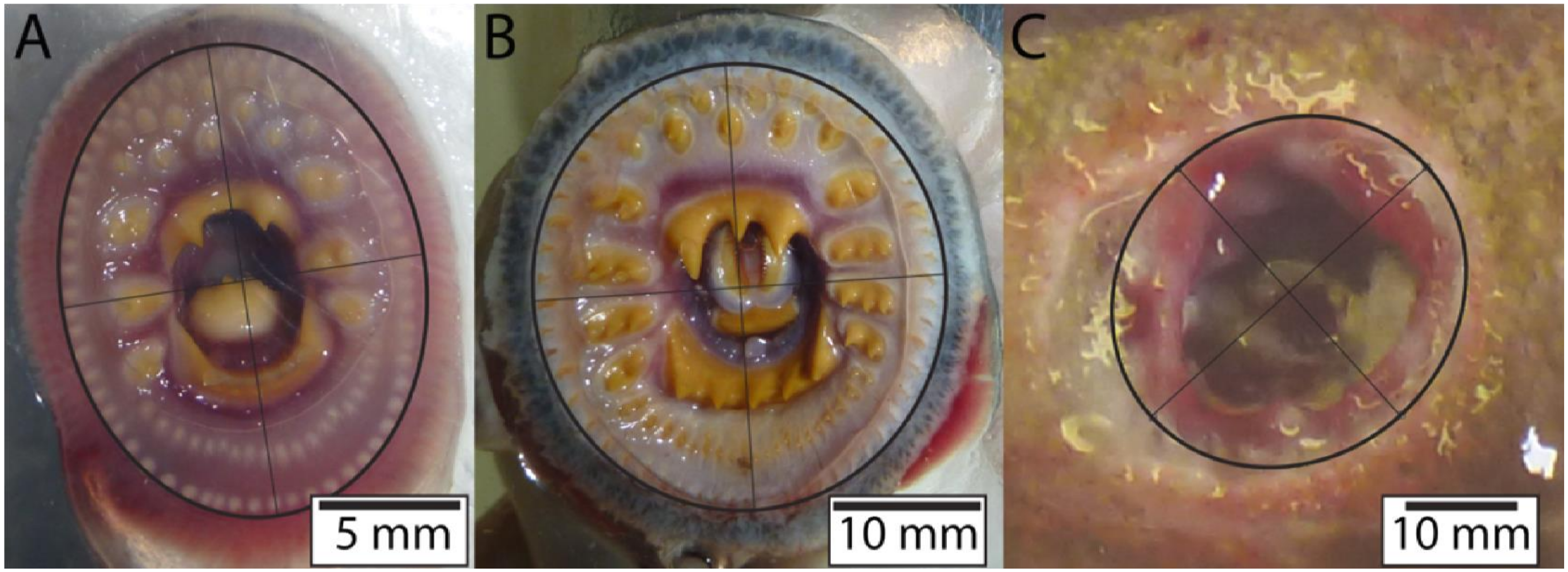

Figure 2.2. Examples of aspect ratio measurements for A) an Arctic Lamprey oral disc, B) a Pacific Lamprey oral disc, and C) a lamprey wound on a Pacific Cod.

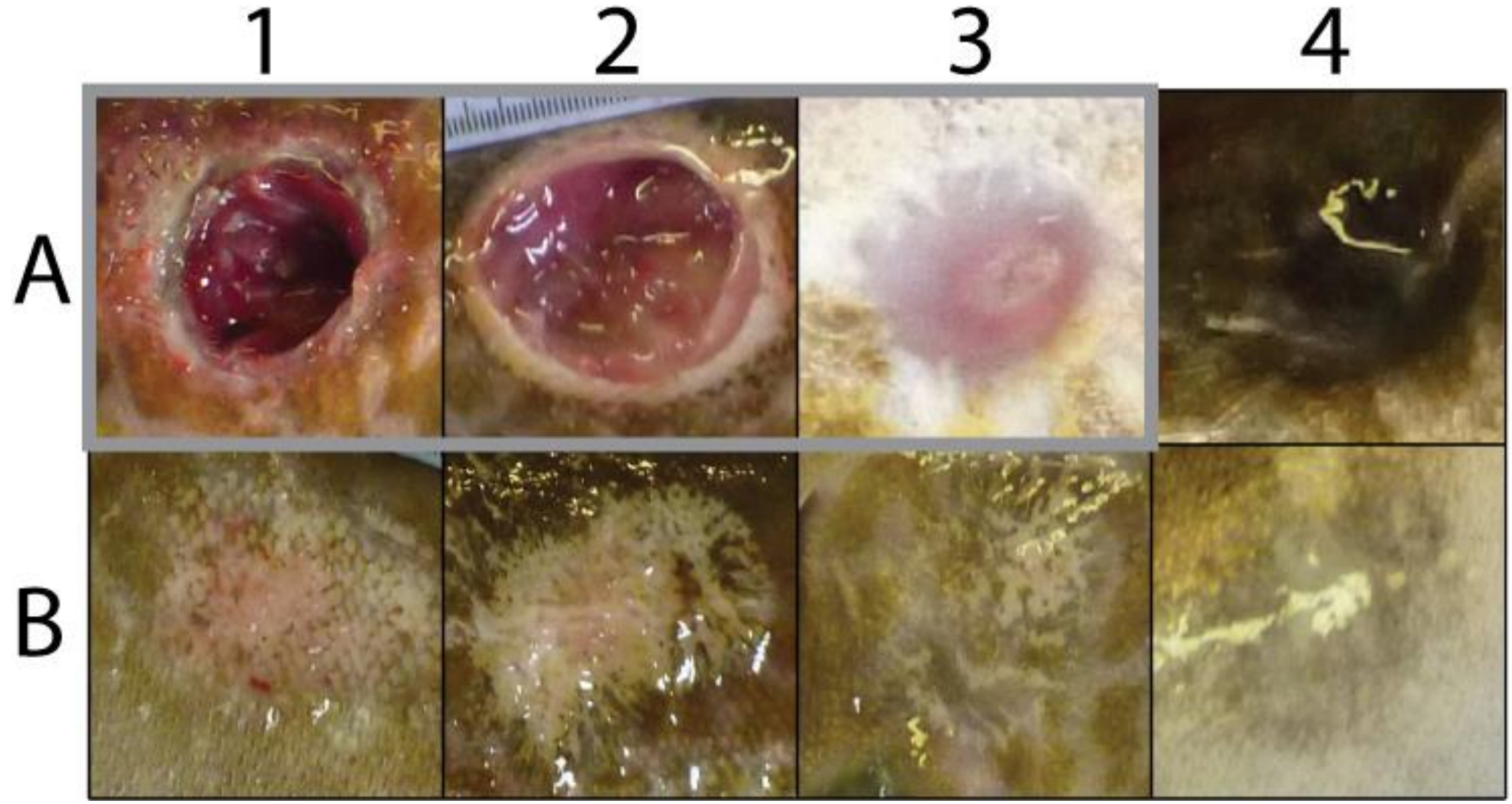

Figure 2.3. Examples of type-A and type-B lamprey wounds on Pacific Cod illustrating progressively healed stages 1 to 4 (left to right). Gray box indicates lamprey wounds that are referred to as “recent” in this study.

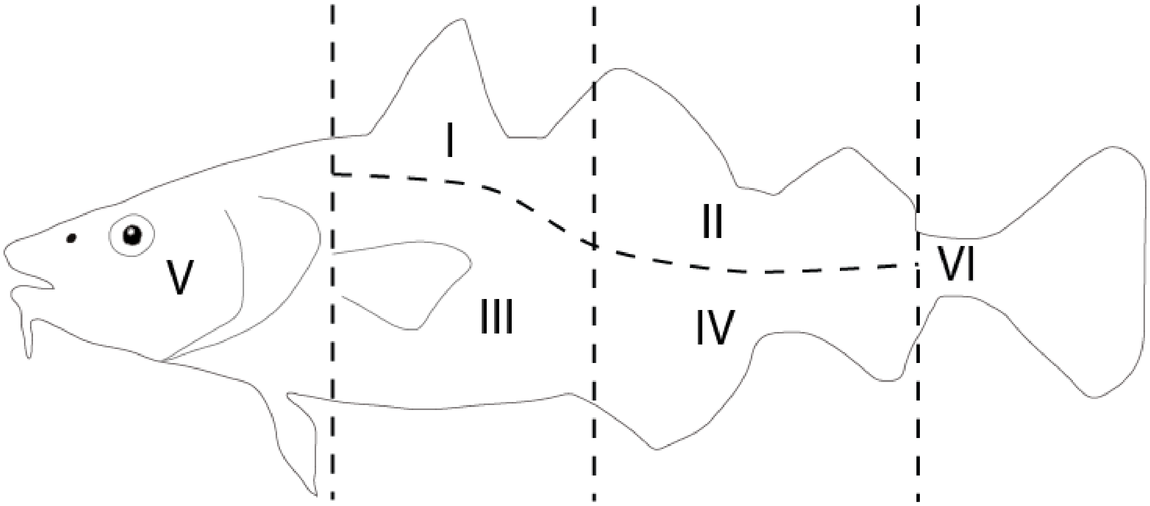

Figure 2.4. Pacific Cod body regions used to classify the locations of lamprey wounds.

(Adapted from Orlov et al. 2009)

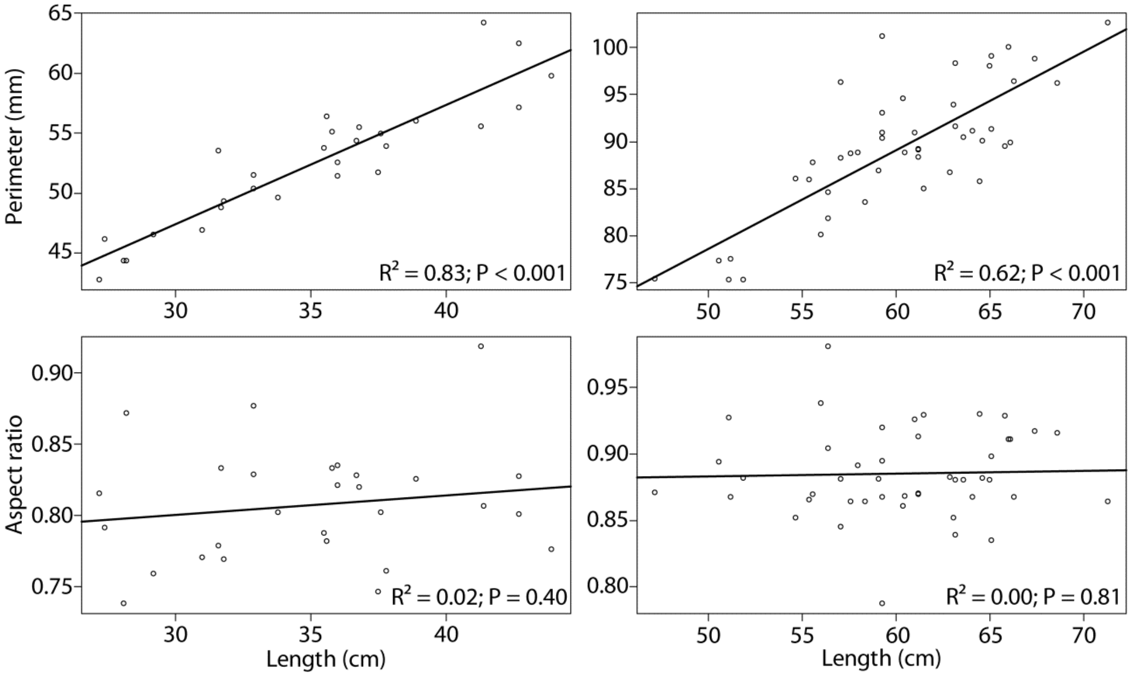

Figure 2.5. Correlations between lamprey length and oral disc measurements, showing perimeter (top) and aspect ratio (bottom) for Arctic Lamprey (left) and Pacific Lamprey (right). R-squared and p-values are shown in the lower right of each panel.

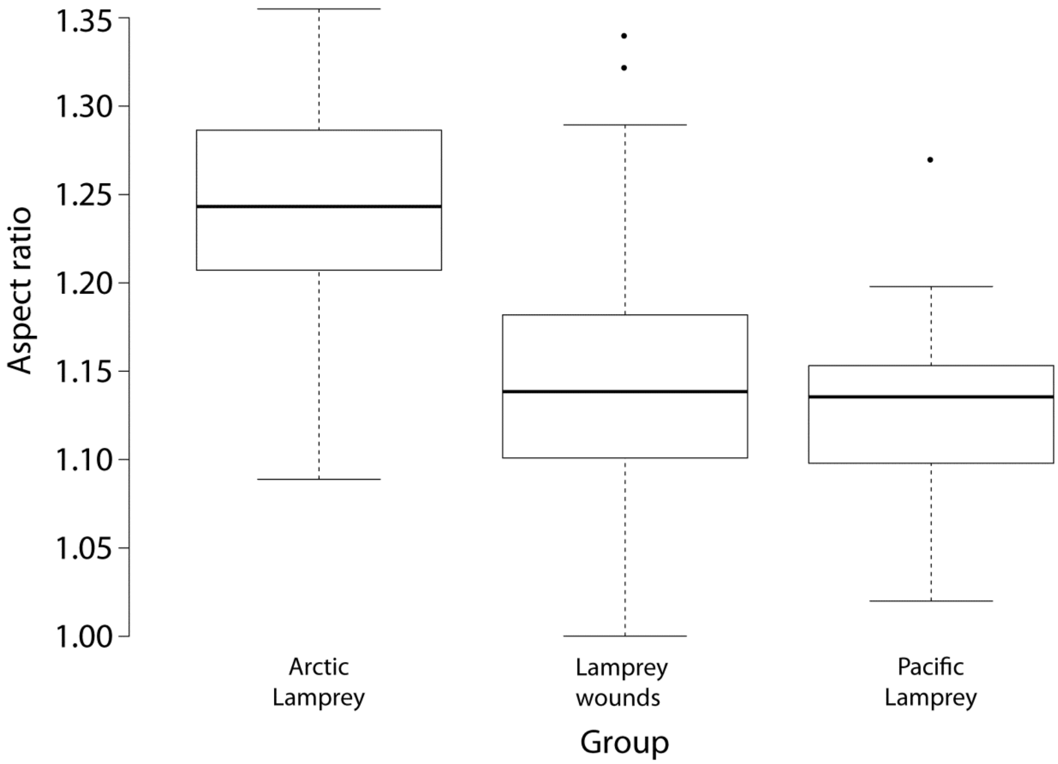

Figure 2.6. Box-and-whisker plot of lamprey oral disc and wound aspect ratios. For each group, the median is shown as the bold horizontal black line, the hinges of the box mark the first and third quartile, the whiskers designate a 1.5 interquartile range, and solid black circles indicate outliers.

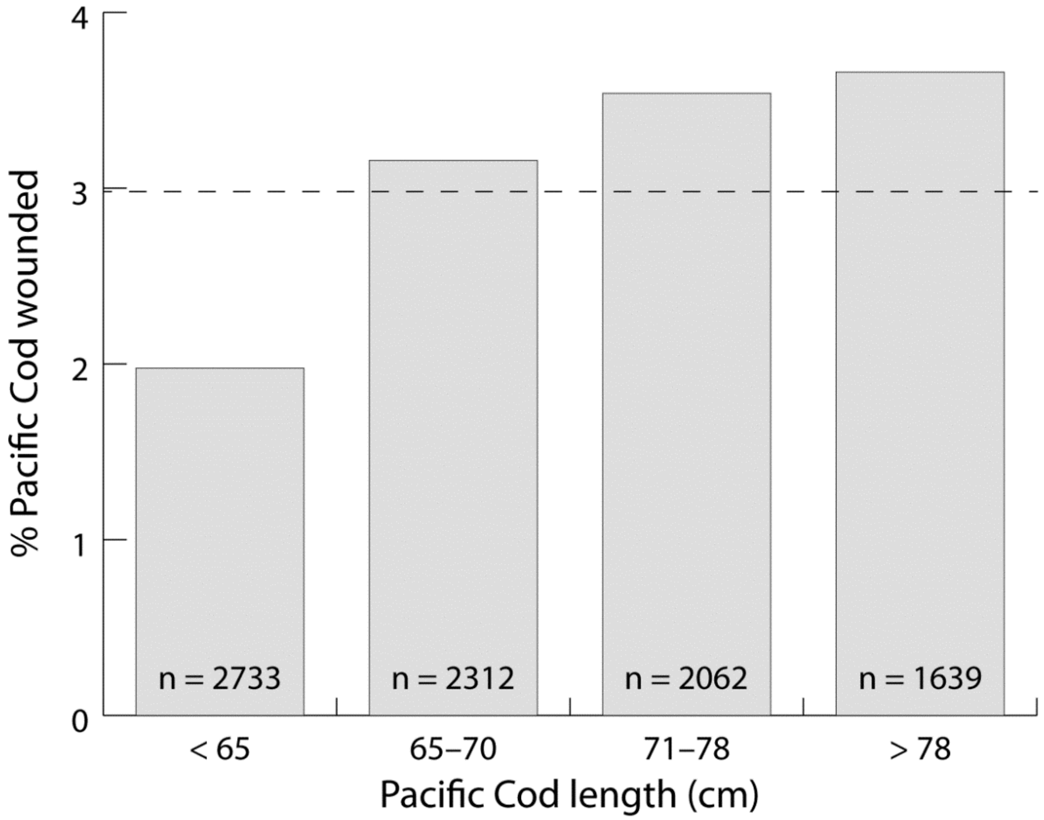

Figure 2.7. Percent of Pacific Cod exhibiting recent lamprey wounds for four length-based size-classes. Dashed line indicates the expected wounding rate from a chi-squared distribution.

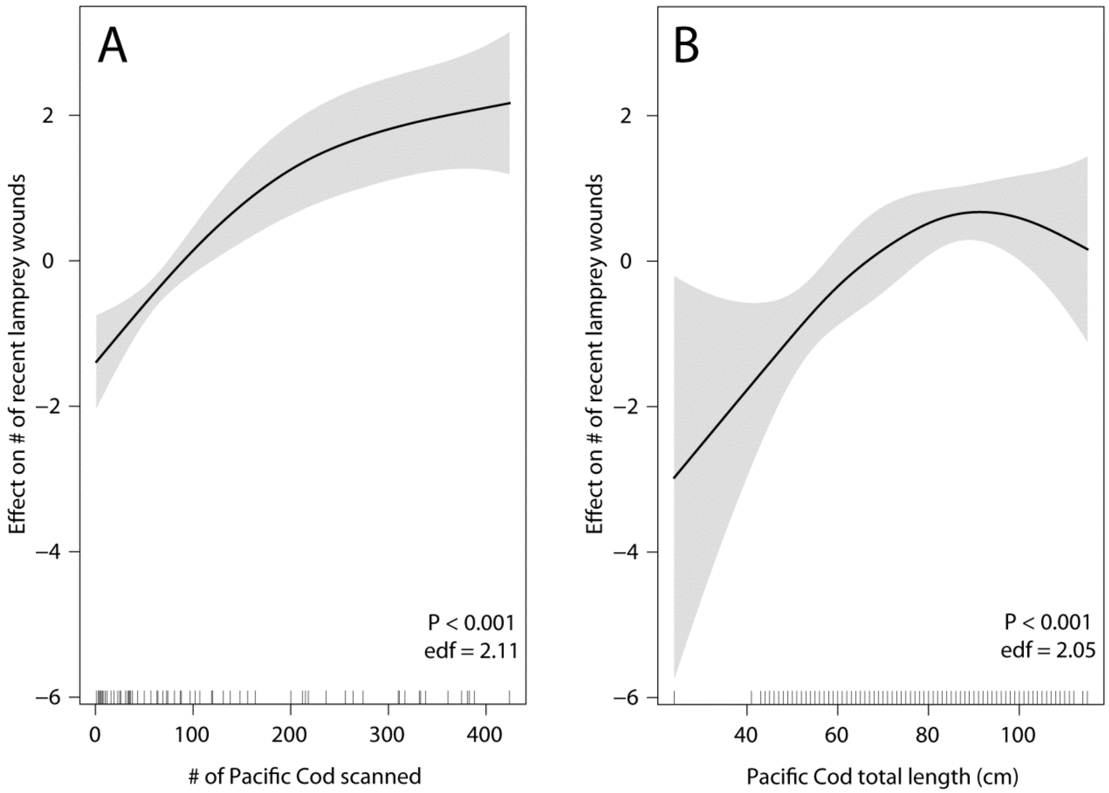

Figure 2.8. Generalized additive model (GAM) partial regression plots of wounds from lampreys exhibited on Pacific Cod. Smooth functions of A) the number of Pacific Cod scanned per length bin and B) the length of Pacific Cod are shown. Hash marks on x-axis indicate samples, and shaded regions indicate 95% confidence intervals. P-values based on chi-square test and estimated degrees of freedom (edf) are shown in the lower right.

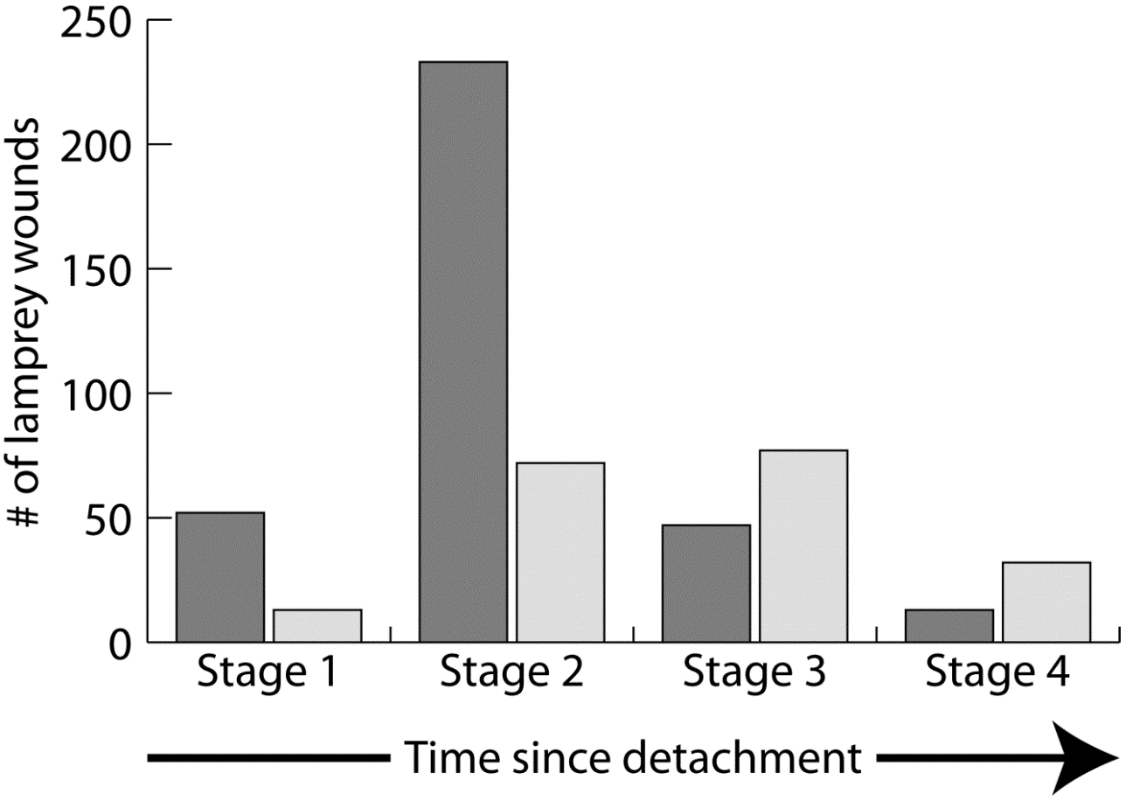

Figure 2.9. Frequency of lamprey wounds across four sequential healing stages, where penetrating type-A wounds are shown in dark gray and superficial type-B wounds are shown in light gray.

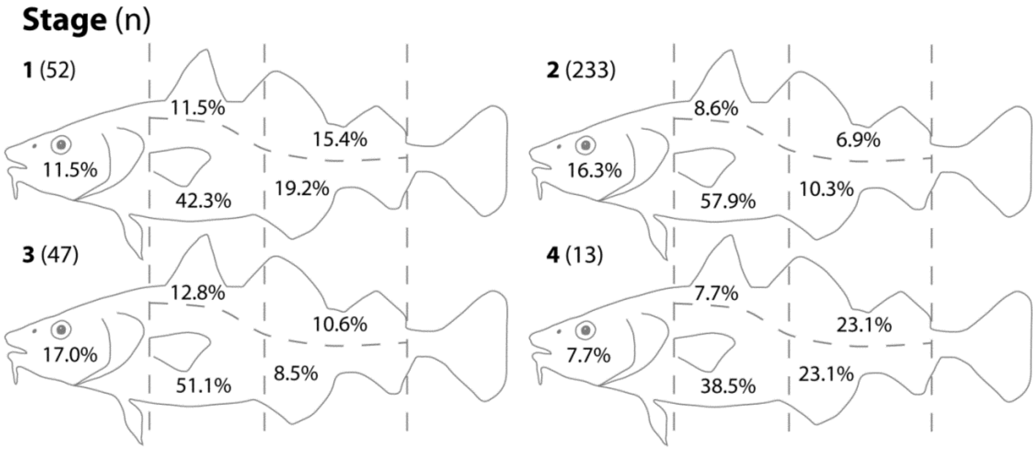

Figure 2.10. Locations and frequency of penetrating type-A lamprey wounds on Pacific Cod shown across four healing stages, a gradient in which stage 1 is most recently inflicted and stage 4 is completely healed.

General Conclusion

Lampreys represent an evolutionary success, and biologists and resource managers should take necessary steps to ensure the continued existence of this ecologically important group of organisms. Parasitic, anadromous lampreys have additional economic and cultural value, making these species particularly important to those cultures that harvest them. However, the period spent feeding in the ocean that unites anadromous lampreys, has largely been ignored by researchers. I have shown that opportunistically captured lampreys in the ocean provide a way to explore anadromous lamprey ecology and allow researchers to generate hypotheses for future directed studies. I found evidence that anadromous lampreys are distributed along geographically distinct areas in the eastern Bering Sea, and associations with different potential host fish is one possible reason for this observation. I also found that Pacific Lamprey native to the North Pacific Ocean may have a potentially negative impact on Pacific Cod that are parasitized, with host size being an important factor to consider. These results provide a starting point by which future research can reveal the nature of lamprey-host relationships in the North Pacific Ocean, and as the National Marine Fisheries Service progresses towards an ecosystem-based approach to fisheries management, consideration of lamprey-host interactions may become of greater concern to marine resource managers.

There is great potential to continue research on the lampreys in the North Pacific Ocean, especially in the ocean, and many of these opportunities would only require minor additions to already occurring fishery monitoring programs. In Alaska, additional research on lampreys at all stages is necessary to provide information for conservation and management of the resource (ADFG 2006), and lamprey information could be incorporated into existing stream and river surveys. In the ocean, the National Marine Fisheries Service Observer Program currently documents lampreys (AFSC 2013), but species identification is rare and could easily be improved by including dentition in observer training manuals. Furthermore, recording lamprey wounds on fish captured during marine surveys may aid in understanding which species and locations are important for lamprey feeding.

An improved understanding of oceanic ecology of lampreys may couple with freshwater sampling that is already occurring to improve our understanding of lamprey dynamics. For example, the Arctic Lamprey fishery on the Yukon River is annually sampled during the spawning run (L. DuBois, Alaska Department of Fish and Game, personal communication), which should be investigated for biological and ecological correlations that link samples of this species collected in the Bering Sea. Variations in the number, size, and condition of lampreys is variable in annual collections of lampreys from marine and freshwater surveys, and potential links between these variations as well as causes occurring at both freshwater and marine phases are likely. Additionally, there is no current forecasting of spawning run strength, which can make management difficult, especially during times of depressed run strength. However, host availability in the ocean was correlated with the number of spawning-phase Pacific Lamprey entering the Columbia River (Murauskas et al. 2013), not only providing a potential metric for predicting spawning run strength but also linking the marine and freshwater life-history stages of this species. This holistic type of approach will provide a more comprehensive understanding of lamprey population dynamics.

An increased understanding of the ecology of lampreys will have implications on human social systems in which lampreys play an important role. Athabaskan Alaskan Natives and members of Pacific Northwest Tribes, including Nez Perce, Umatilla, Yakama, Warm Springs, Yurok, and Karuk, have a long history of fishing for lampreys in North American rivers (Close et al. 2002; Brown et al. 2005; Petersen 2009). The development of commercial lamprey fisheries is currently occurring in western Alaska (Bue et al. 2011), and the hosts that lamprey feed on in the ocean are also commercially exploited (Murauskas et al 2013). As we begin to identify important regions utilized by lampreys in the ocean, we can begin to understand how environmental stressors in these regions may influence lamprey populations, informing future lamprey conservation and management efforts. In addition, the impact of lamprey parasitism on commercially important species in the eastern Bering Sea is not well understood, and identifying areas for potential interactions between lampreys and commercially important species is the first step towards addressing this potential conflict.

Many hosts of anadromous lampreys are targeted by commercial fisheries, and lamprey-induced mortality can be viewed as a threat to commercial fish resources (Orlov et al. 2008, 2014). In the current state of affairs, commercial fishermen in the USA do not view lamprey parasitism as a great source of mortality to their targeted species, nor do they view the value lost due to lamprey wounds as significant (Q. Fong, University of Alaska Fairbanks, personal communication). As such, they do not pay much attention to lamprey presence or parasitism beyond the novelty of these curious organisms. However, if we do not know the impacts lamprey parasitism has on commercial fish stocks, we should not ignore this potential interaction altogether as is the status quo.

Additionally, reductions in the abundance of marine fishes by commercial fisheries diminish the number of hosts available to adult trophic-phase lampreys, and this may cause declines in lamprey populations (Murauskas et al. 2013). However, research has been focused on freshwater problems and solutions related to lamprey declines, largely ignoring the adult trophic phase. Many of these freshwater issues are being addressed, such as the inclusion of lamprey friendly fish passageways (Moser et al. 2011) and transporting of spawning adults upriver of dams (Ward et al. 2012). These efforts may increase the number of adult lampreys spawning, but if a bottleneck during the adult trophic phase is hindering lamprey survival during this period, these efforts will be limited in their utility to ultimately restore lamprey populations. It is important to continue making efforts such as these as they can only benefit lamprey populations; however, if we can elucidate the importance of the adult trophic phase, we can better understand how all stages of the anadromous lamprey life cycle influence the overall success of a population. For example, the number of spawning-phase anadromous lampreys is likely a cumulative function of all previous life stages, the last of which is the adult trophic phase.

The lack of dialogue between marine resource users and freshwater lamprey fishermen precludes acknowledgement of the potential conflict between these user groups. Yet there is great potential for federal, state, and tribal agencies to work with marine resource users towards understanding the importance of the adult trophic phase to overall lamprey population health and work together to alleviate unnecessary pressures. For example, noting where lampreys are captured and with which fishes they are found will provide information on important locations and species for lamprey feeding. In turn, efforts can be made to target these species outside of important lamprey feeding periods, allowing increased availability of hosts when they are most needed for lampreys. Typical stock assessments of marine fisheries are drafted for single species, but in Alaska, ecosystem impacts are also addressed. To date, depletion of the lamprey prey base via commercial fishing is undoubtedly an ecosystem impact that is not currently acknowledged.

Balancing the needs of different user groups is a constant task of resource managers, and lampreys are no exception. As lamprey restoration programs seek to restore anadromous lamprey populations in need, they should consider those marine resources that are needed to support their goals. Likewise, successes in lamprey restoration may be met with adverse reactions by commercial fishermen that experience increases in parasitism. One proactive step that can be made is opening a dialogue between these groups, allowing a better understanding of the impacts of lampreys and their hosts have on one another. The findings of this study provide valuable first insights into lamprey-host interactions in the Bering Sea and hopefully will serve as a catalyst for future research on this topic. As we begin to understand these complex interactions between anadromous lampreys and their hosts, we can incorporate marine life-history into informed management and conservation decisions ensuring harvests of Arctic and Pacific lampreys for generations to come.

References

ADFG (Alaska Department of Fish and Game). 2006. Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources. ADFG, Juneau, Alaska.

AFSC (Alaska Fisheries Science Center). 2013. AFSC/FMA: web map observer groundfish data, Alaska, 1993–2012. Available: www.afsc.noaa.gov/maps/FMA/datamap/obsmap.html. (December 2013).

Brown, C. L., J. Burr, K. Elkin, and R. J. Walker. 2005. Contemporary subsistence uses and population distribution of non-salmon fish in Grayling, Anvik, Shageluk, and Holy Cross. U.S. Fish and Wildlife Service, Final Report 02-037-2, Anchorage, Alaska.

Bue, F., S. J. Hayes, E. Newland, D. F. Evenson, K. Clark, B. M. Borba, W. H. Harbor, and M. Horne-Brine. 2011. Annual management report for the Yukon and Northern Area, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 11-29, Anchorage, Alaska.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19–25.

Moser, M. L., M. L. Keefer, H. T. Pennington, D. A. Ogden, and J. E. Simonson. 2011. Development of Pacific Lamprey fishways at a hydropower dam. Fisheries Management and Ecology 18:190–200.

Murauskas, J. G., A. M. Orlov, and K. A. Siwicke. 2013. Relationships between the abundance of Pacific Lamprey in the Columbia River and their common hosts in the marine environment. Transactions of the American Fisheries Society 142:143–155.

Orlov, A. M., A. A. Baytalyuk, and D. V. Pelenev. 2014. Distribution and size composition of Arctic Lamprey *Lethenteron camtschaticum* in the North Pacific. Oceanology 54:180–194.

Orlov, A. M., V. F. Savinyh, and D. V. Pelenev. 2008. Features of the spatial distribution and size structure of the Pacific Lamprey *Lampetra tridentata* in the North Pacific. Russian Journal of Marine Biology 34:276–287.

Petersen, R. S. 2009. Yurok and Karuk traditional ecological knowledge: insights into Pacific Lamprey populations of the lower Klamath Basin. Pages 1–39 *in* L. R. Brown, S. D. Chase, P. B. Moyle, R. J. Beamish, and M. G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Ward, D. L., B. J. Clemens, D. Clugston, A. D. Jackson, M. L. Moser, C. Peery, and D. P. Statler. 2012. Translocating adult Pacific Lamprey within the Columbia River basin: state of the science. Fisheries 37:351–361.

Assessment of the Stranding of Benthic Fauna in the Wanapum Reservoir Due to Water Level Reduction - 2014

Presented by: Brett Tiller, Principal Scientist

Environmental Assessment Services (EAS), www.easbio.com

Presented To: Grant County PUD's Priest Rapids Fish Forum

Wenatchee, WA - March 04, 2015

EAS ENVIRONMENTAL ASSESSMENT SERVICES
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Acknowledgments

Mike Clement and
Tom Dresser

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PUBLIC UTILITY DISTRICT
Excellence in Service and Leadership

Mark Timko & Co.

BLUE LEAF
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Ed Johannes

Deixis
Consultants

Jeff Korth, Chad Jackson,
Bruce Baker, Peter Vernie,
Anita Victory

Washington
Department of
FISH and
WILDLIFE

Objectives

1) Characterize freshwater mollusk species composition and densities in areas that were dewatered as a result of the 2014 water-level reduction and describe potential effects of the reduced water level on these organisms.

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3) Document fishes and other organisms present in areas that were dewatered.

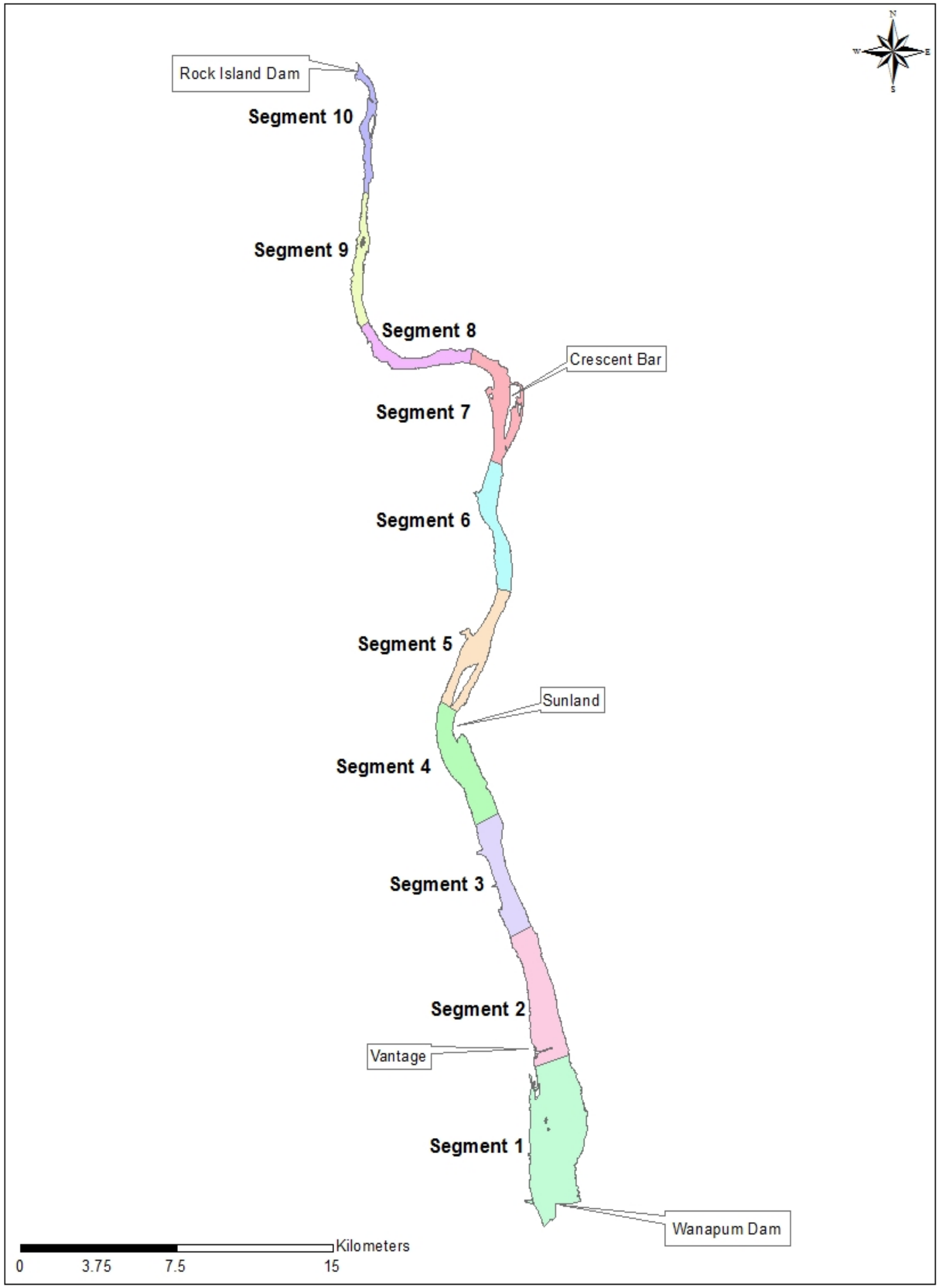
Overview

- Study Designs / Methods
- Results
    - Native Freshwater Mussels
    - Snails and Peaclams
- Other Observations
- Recovery Perspectives
- Summary
- Questions / Comments

Study Design:

Hydro-Geomorphic Stratification

- 60Km Long Study Area
- 10 River Segments
- 6Km per Segment



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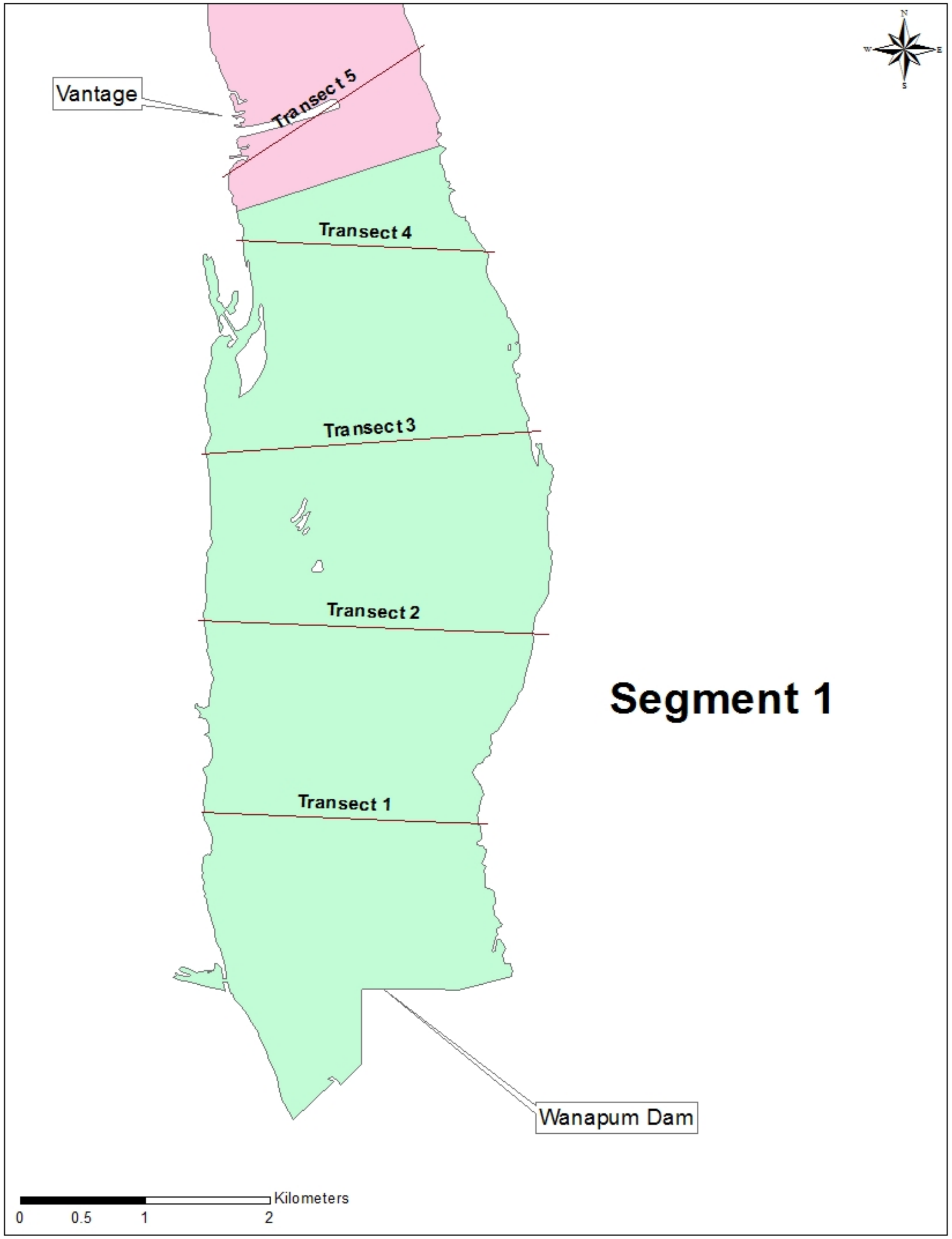
Study Design:

Systematic Transect Selection

- 1.5Km Intervals
- 4 Transects/River Segment
- Both Left Bank and Right Bank



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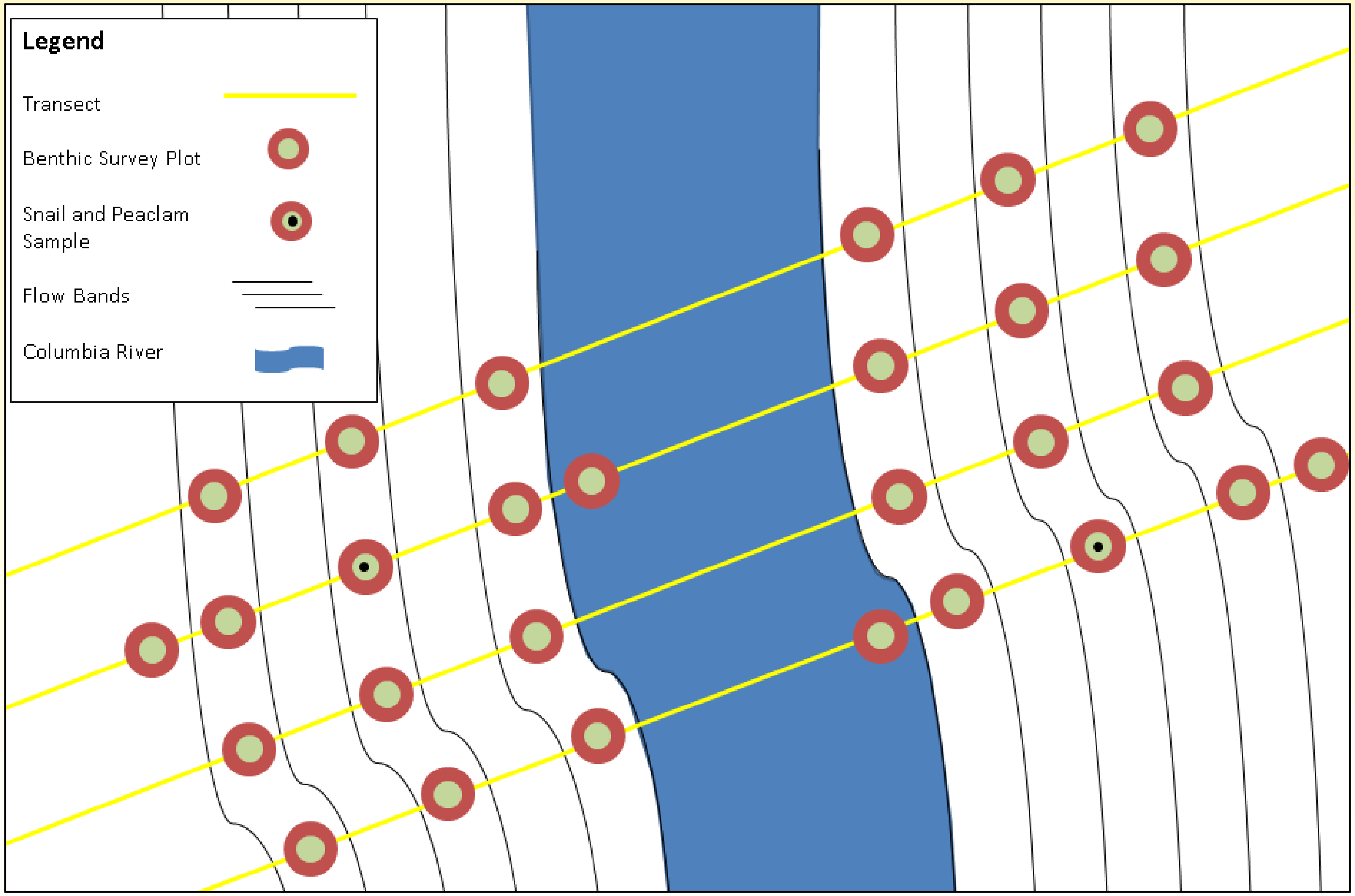
Study Design:

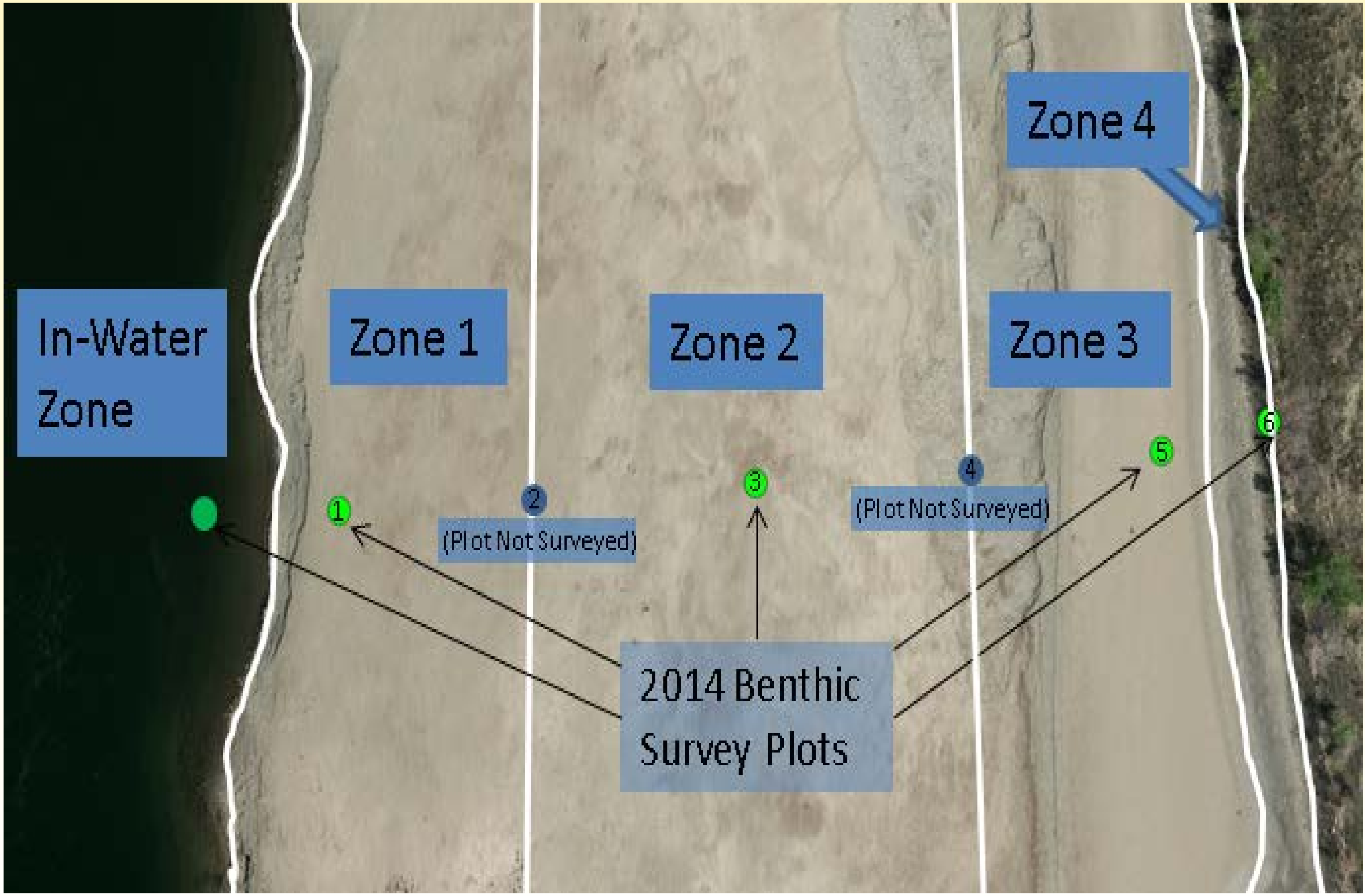
Benthic Survey Plot Stratification

- 1m – 4m radius plots (incl. substrate typing)
- $0.1m^2$ x 0.25m deep snail and peaclam sub-plots
- Left Bank and Right Bank



Study Design

Stratifying Dewatered Shoreline Zones

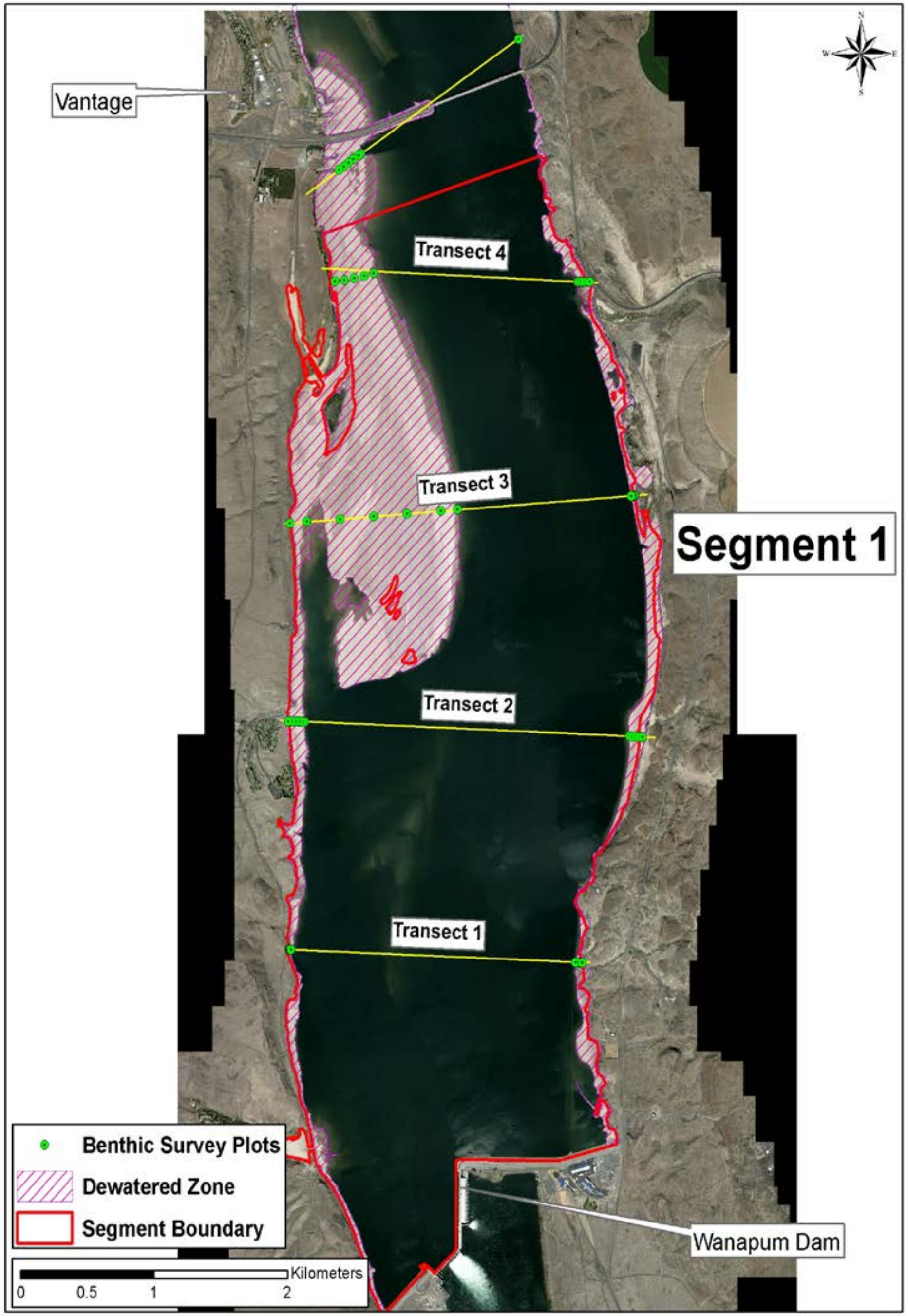


Methods

Mapping Dewatered Riverbed Areas

- 2014 Water edge break lines, digital elevation contours, and rectified aerial imagery

- GIS ESRI 3D Analyst extension: Interpolate Polygon To Multipatch tool



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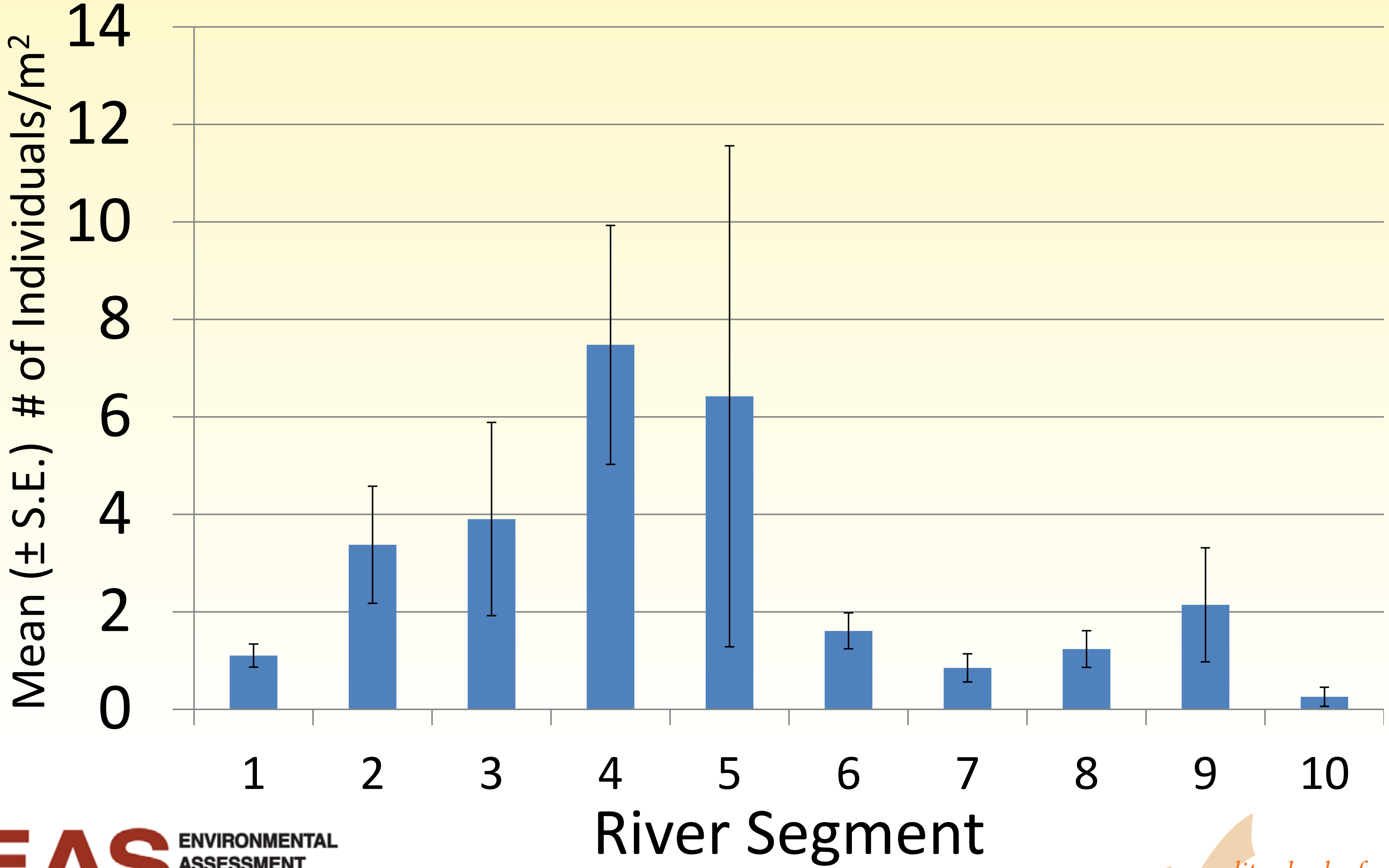
Sample Sizes

	River Segment										
	1	2	3	4	5	6	7	8	9	10	Total
Snails and fingernail clam Plots	6	0	3	1	4	2	4	3	3	2	28
Mussels Survey Plots	26	15	22	17	20	26	28	26	27	26	233

Zone	# Plots	Sum of Plot Area (m^2)
1	79	2499
2	68	2533
3	67	2714
4	19	314
Total	233	8060

Depth (ft) below Water Line	# Plots	Sum of Plot Area (m^2)
10	19	955
15	5	63
20	5	63
25	5	63
30	5	63
Total	39	1206

Results: Freshwater Mussels



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Results: Freshwater Mussels

Floater Mussel Clade 1

Anodonta Clade 1

(formerly *A. californiensis* or

A. nattalliana)

Floater Mussel Clade 2

Anodonta Clade 2

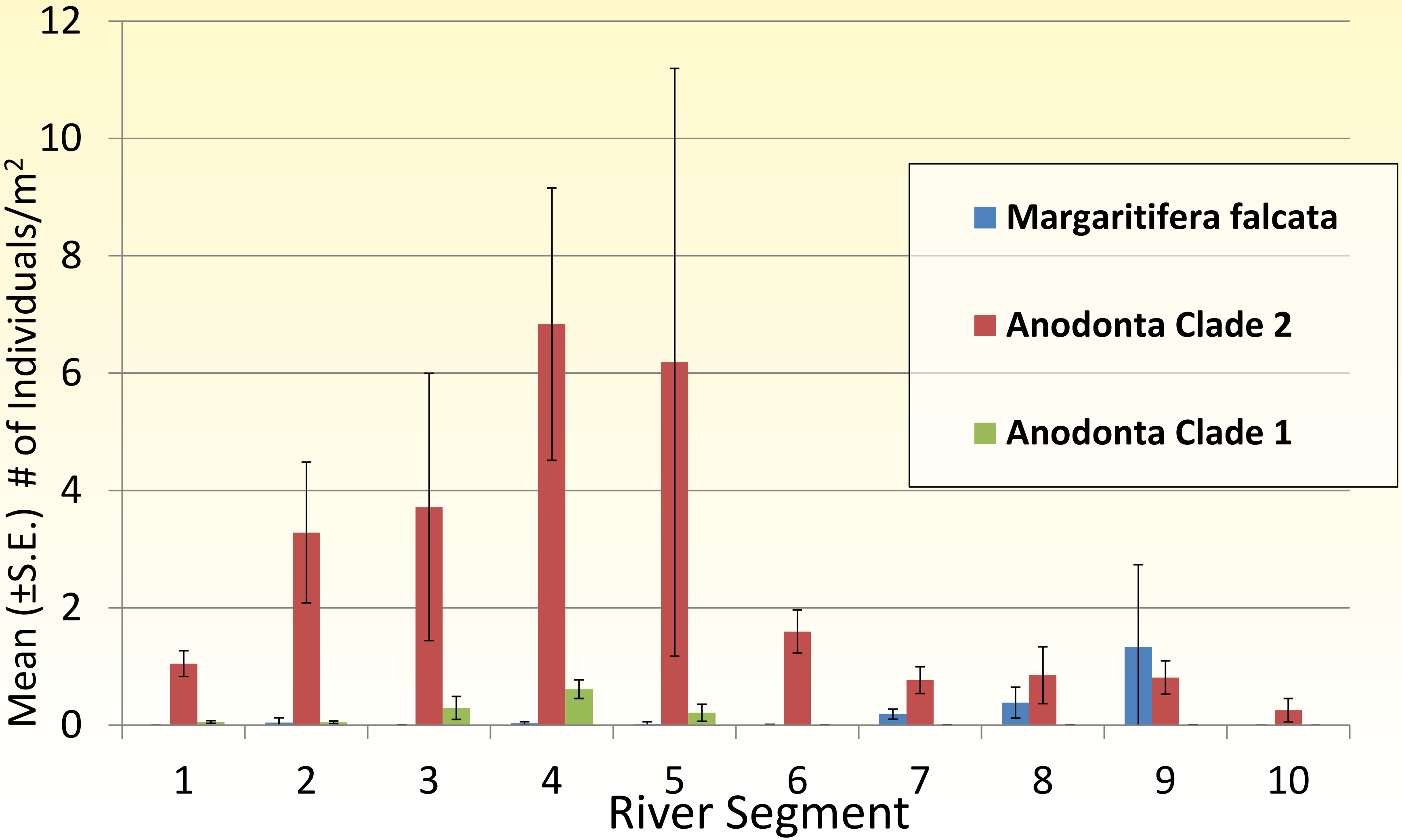
(formerly *A. kennerlyi* or

A. oregonensis)

Western Pearlshell

Margaritifera falcata

Results: Freshwater Mussels



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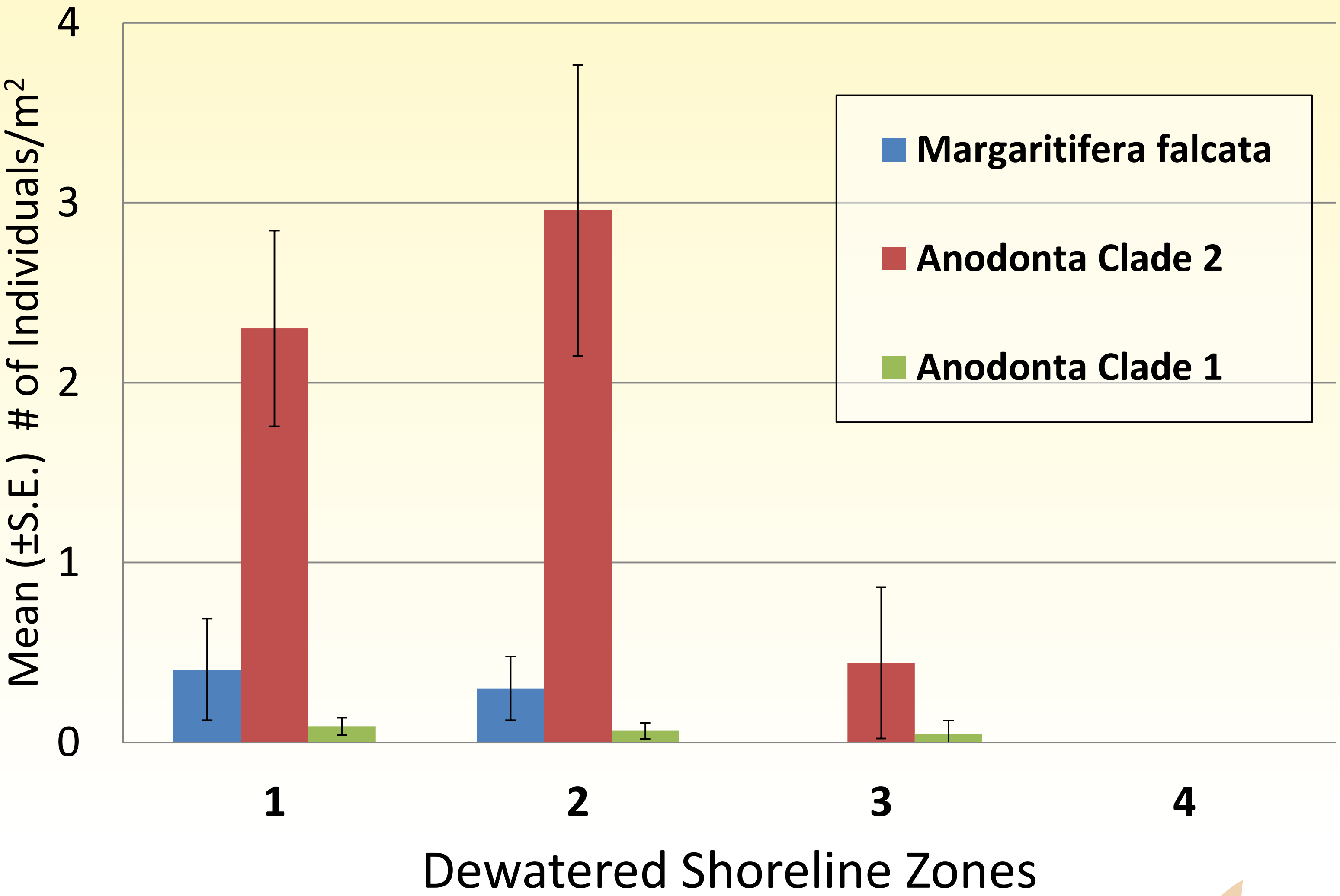
Results: Freshwater Mussels



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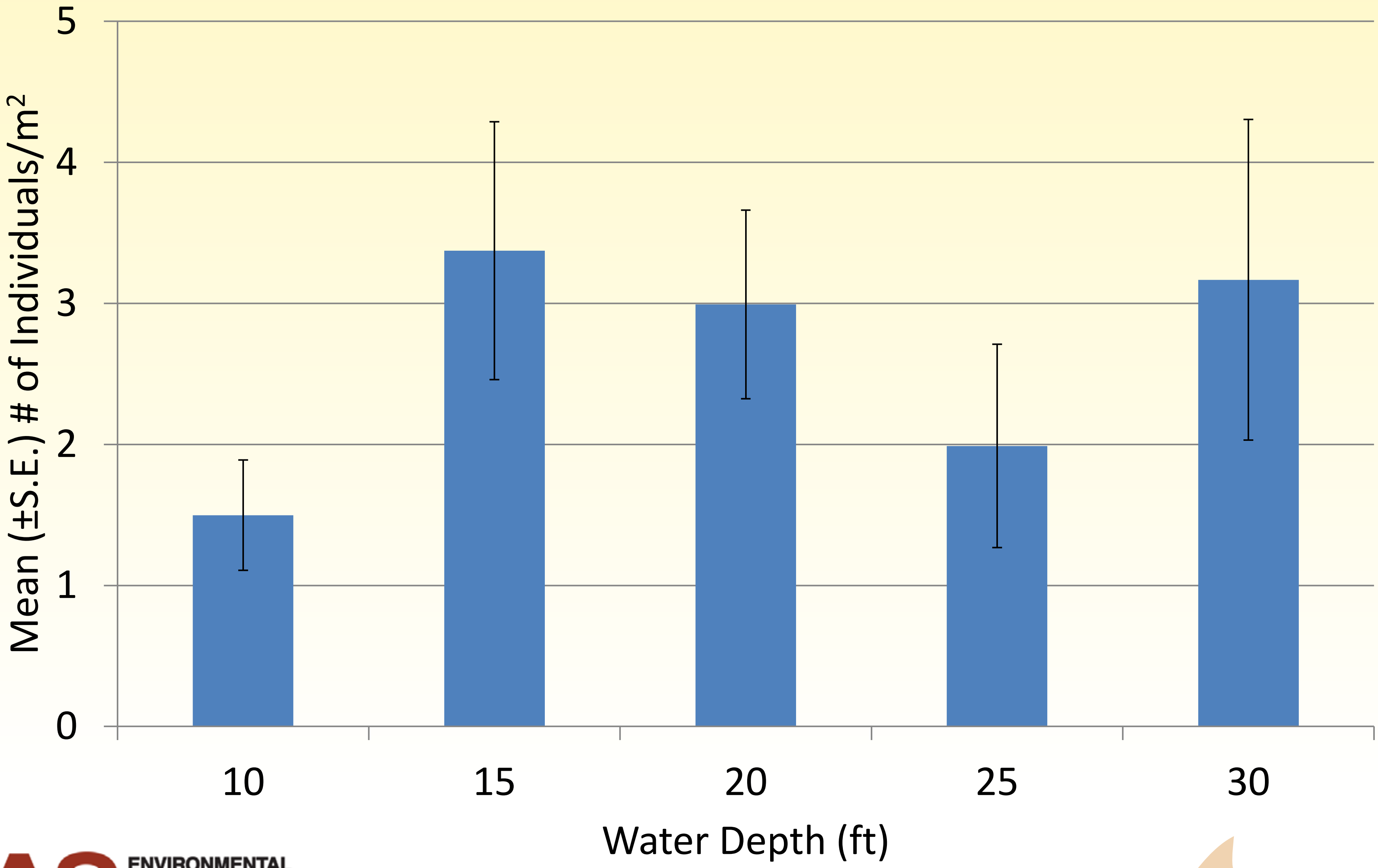
Results: Freshwater Mussels

River Segment	Area (m^2) Estimate of Dewatered Zones 1, 2, & 3
1	3,391,200
2	909,810
3	792,469
4	2,545,650
5	1,649,493
6	1,068,386
7	2,208,792
8	920,595
9	777,887
10	477,610
Totals	**14,741,890**

Mean (±2 S.E.) Estimated Number of Mussels Dewatered

Statistic	*Anodonta* Clade 1	*Anodonta* Clade 2	Western Pearlshell
Lower 95% C.I.	**1,020,439**	**9,970,191**	**0**
Mean (Average)	**1,899,320**	**33,110,694**	**2,106,203**
Upper 95% C.I.	**3,087,308**	**57,735,437**	**4,996,622**

Results: Freshwater Mussels



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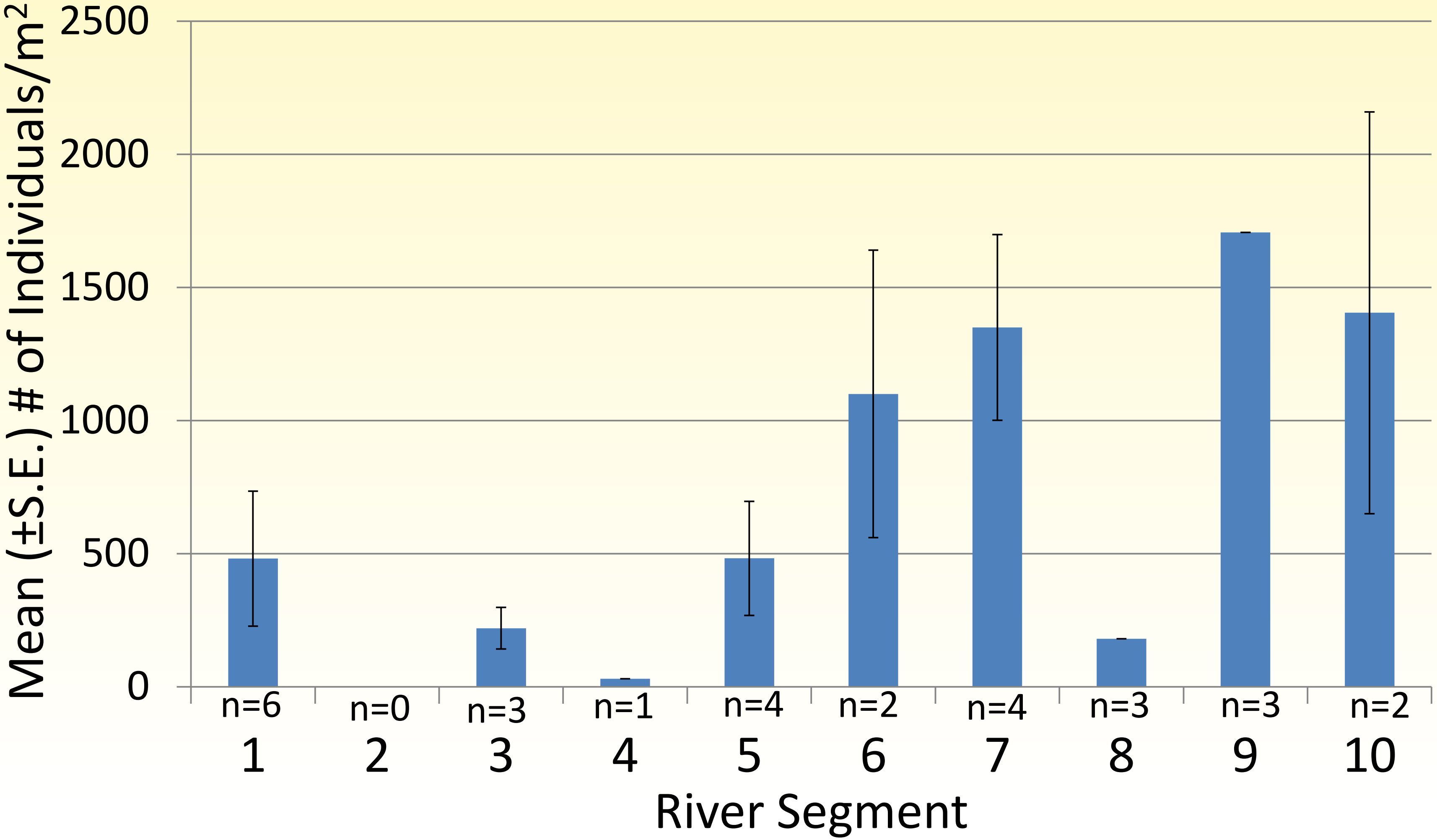
Results: Snails and Peaclams

Common Name	Scientific Name	Distribution	Relative Abundance
Ashy pebblesnail	***Fluminicola fuscus***	**Eastern Washington**	**Rare**
Unnamed pebblesnails	***Fluminicola n. sp.***	**Eastern Washington**	**Rare to Common**
Artemesian rams-horn	***Vorticifex effusa***	**W. Washington, N. Oregon, N.W. California**	**Uncommon**
Creeping ancylid	***Ferrissia rivularis***	**Central and eastern U.S., southern Canada**	**Uncommon**
Glossy valvata	*Valvata humeralis*	Pacific Northwest	Common
Three-ridge valvata	*Valvata tricarinata*	North America; mostly east of the continental divide	Common
Big-ear radix	*Radix auricularia*	Europe, Asia, Alaska?; likely introduced to N. America	Common
Prairie fossaria	*Bakerilymnaea bulimoides*	U.S. and Canada	Common
Golden fossaria	*Galba obrussa*	U.S. and Canada	Common
Unknown Lymnaeidae	*Lymnaeidae*	World wide	Common
Tadpole physa	*Physella gyrina*	North America	Common
Button sprite	*Menetus opercularis*	W. Washington, N. Oregon, N.W. California	Common
Ash gyro	*Gyraulus parvus*	North America	Abundant
Ubiquitous peaclam	*Pisidium casertaneum*	Northern Hemisphere	Abundant
Ridgebeak peaclam	*Pisidium compressum*	U.S., Southern Canada	Common
Triangular peaclam	*Pisidium variabile*	U. S., Southern Canada	Common
Asian clam	*Corbicula fluminea*	World wide	Common

Results: Snails and Peaclams



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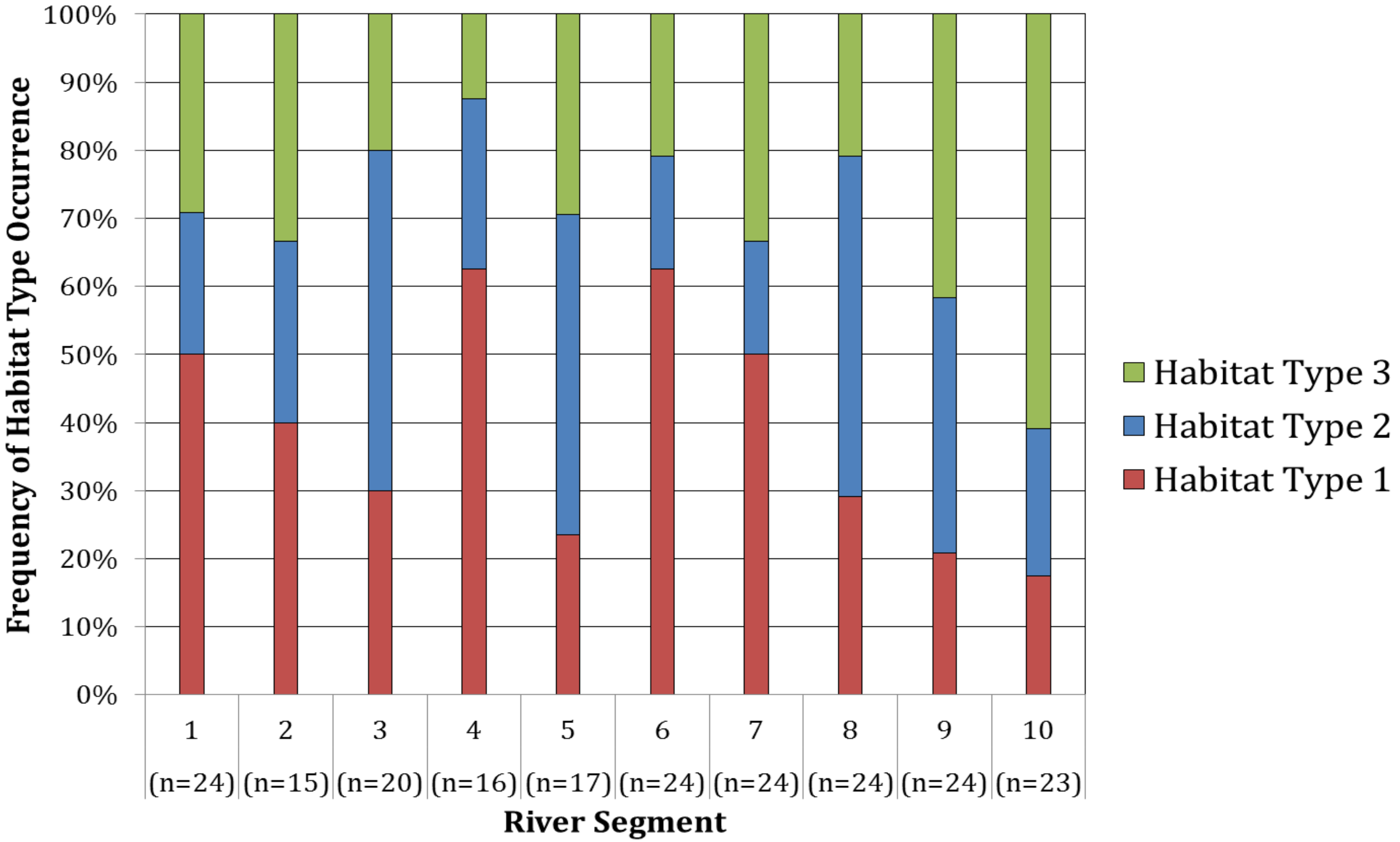
Results: Fish and Other Organisms

- crayfish
- lamprey
- redside shiner
- three-spine stickleback
- sculpin

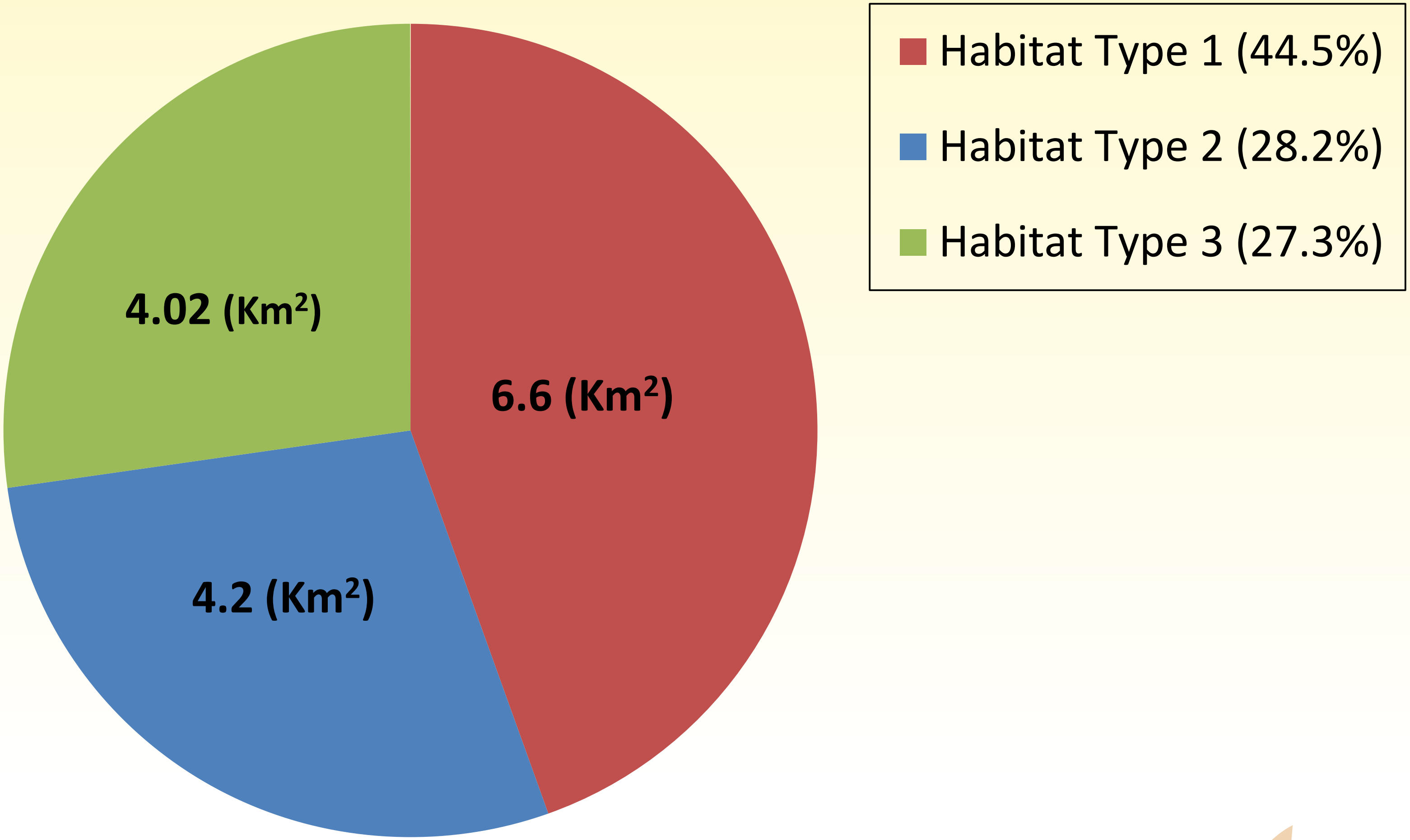
Dewatered Lamprey Habitat Estimates

Lamprey Habitat Type	Literature Based Lamprey Habitat Description ([1]Close and Aronsuu 2003, [2]Hansen et al 2003)	2014 Field-Based Substrate Classifications (Platts et. al. 1983)
Type 1	[1]Mixture of soft sediment particles including silt, clay, fine organic matter, and some sand [2]Preferred larval habitat that usually consists of sand, fine organic matter, and cover (detritus, aquatic vegetation), which is usually formed in areas of deposition	Dominant and Subdominant Substrates were both Type 1 Substrates
Type 2	[1]Similar to Type I habitat but with a larger component of sand [2]Acceptable, but not preferred, larval habitat that usually consists of shifting sand, gravel, or rubble, and very little or no fine organic matter, but is soft enough for larvae to burrow into	Either Dominant or Subdominant Substrate was classified as Type 1 Substrate or Substrate was Embedded 76-100% with Fines
Type 3	[1]Bedrock, hard clay, cobble, or coarse gravel substrates [2]Cannot be penetrated by larvae, so is unacceptable habitat, and usually consists of bedrock or hardpan clay, with rubble and coarse gravel	All other substrate combinations not described in Lamprey Habitat Type 1 and 2

Rearing Lamprey Habitat Types by Wanapum Rervoir River Segment



Cumulative Rearing Lamprey Habitat Types by Wanapum Rervoir



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Recovery Perspectives

Paucity of Molluscan Recolonization Rate Information Exists in the Pacific Northwest

However..,
~37 million mussels colonized Wanapum Project Area within 50 year period,

Thus, we might expect ~750,000/yr for ~14.7Km^2 Wanapum Project Area Dewatered (~0.05 individuals/m^2/yr)

Molluscan Recovery Perspectives

Taxon	Slow Recovery Rate	Interm. Recovery Rate	Fast Recovery Rate
PROSOBRANCH GASTROPODS			
Fluminicola	X		
Valvata		X	
PULMONATE GASTROPODS			
Bakerilymnaea			X
Galba			X
Stagnicola			X
Physella			X
Gyraulus			X
Menetus			X
Vorticifex		X	
Ferrissia		X	
UNIONIDS			
Anodonta	X		
Margaritifera	X		
Gonidea	X		
SPHAERIIDS			
Pisidium			X

Summary

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- Dewatered Regions Contained Relatively High Densities of Native Freshwater Mussels
- Up-river Segments Possessed a Several Relatively Rare or Uncommon Molluscan Taxa

Summary (cont'd)

- Dewatered Regions ~10Km^2 of Lamprey Types I and II Habitat

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- Dewatered Regions ~$10 Km^2$ of Lamprey Types I and II Habitat
- Native Freshwater Mussels Persisted in Non-Dewatered Regions

Summary (cont'd)

- Dewatered Regions ~10Km^2 of Lamprey Types I and II Habitat
- Native Freshwater Mussels Persisted in Non-Dewatered Regions
- Recolonization Rates of Rare or Uncommon Molluscan Taxa in Dewatered Regions Uncertain

Questions / Comments