JUVENILE SALMONID USE AND RESTORATION ASSESSMENT OF THE TIDAL PORTIONS OF SELECTED TRIBUTARIES TO HUMBOLDT BAY, CALIFORNIA, 2015-2017

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ABSTRACT

Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife staff sampled the stream-estuary ecotone (SEE) of selected Humboldt Bay tributaries to document their use by juvenile salmonids and to assess SEE habitat restoration projects. We sampled fish using seine nets and minnow traps baited with frozen salmon roe. Juvenile Coho Salmon (*Oncorhynchus kisutch*) was the most numerous salmonid captured but we also commonly captured Chinook Salmon (*O. tshawytscha*), steelhead trout (*O. mykiss*), and cutthroat trout (*O. clarkii clarkii*). Sub-yearling Coho Salmon were present from late March to December with peak catches occurring in the summer and fall. Their mean SEE residence time was one to two months but individual fish reared there for close to a year. Yearling-plus Coho Salmon were present primarily during the winter and spring. One group of Age 1+ Coho Salmon arrived in the SEE in the fall and reared there throughout the winter and into the spring. A later group of Age 1+ Coho Salmon emigrated through the SEE relatively quickly primarily during April and May. Juvenile Chinook Salmon were present primarily in Freshwater Creek Slough in the late spring and early summer. We captured juvenile steelhead trout and cutthroat trout throughout the year and some reared for months, and in the case of cutthroat trout, possibly years in the SEE. Mean growth rates of juvenile salmonids in the ecotone were typically 0.15 to 0.25 mm/day, which was higher than growth rates observed by other projects in stream habitats upstream of the SEE. However, juvenile salmonid growth rates in off channel ponds and in newly constructed slough channels in Wood Creek were usually higher. Juvenile salmonids sought out freshwater rather than brackish water habitat while rearing in the SEE. Juvenile salmonids, especially Coho Salmon, utilized newly constructed off channel habitat as soon as they were completed and fall/winter stream flow converted the areas to fresh water habitat. Finally, PSMFC staff developed a series of computer programs to more easily process, summarize, and analyze large data sets of PIT tag antenna data. This subject is covered in Section 2 of this report.

Introduction

Estuaries are important habitat for juvenile salmonids and other fish species. Numerous studies have documented extended estuarine residence by juvenile Chinook Salmon *Oncorhynchus tshawytscha*, (Reimers 1971; Healey 1982; Kjelson et al.1982; Healey 1991), Coho Salmon *O. kisutch* (Tschaplinski 1982; Miller and Sadro 2003; Koski 2009), steelhead trout *O. mykiss*, (Bond et al. 2008), and sea-run coastal cutthroat trout *O.clarkii clarkii*, (Trotter 1997; Northcote 1997). Faster growth in the estuary and larger size at ocean entrance for estuarine rearing salmonids has been shown to account for higher marine survival (Nicholas and Hankin 1989; Northcote 1997; Pearcy 1997; Trotter 1997).

Studies on Coho Salmon have shown that larger individuals like those rearing in tidal habitat, experience greater over-winter survival in stream and estuary habitats (Ebersole et al. 2006; Roni et al. 2012). Studies have identified the importance of the greater transition zone, or ecotone (Odum 1971), between fresh and brackish water to juvenile Coho Salmon (Tschaplinski 1982; Miller and Sadro 2003; Koski 2009; Jones et al. 2014; Wallace et al. 2015). Miller and Sadro (2003) defined this stream-estuary ecotone (SEE), and we adapted their definition. In our study, we defined the SEE as the wetland area of low gradient stream extending from where the stream entered the tidal plain, through the upper limit of tidal influence on stream habitat, downstream to the channel bordered by tidal mudflats. This definition of the SEE includes all side channels, off channel ponds, tidal channels, and fringing marsh habitats that are accessible to fish for at least some portion of the tidal cycle.

In California, most juvenile salmonid estuary studies were conducted in the Sacramento-San Joaquin Delta (Kjelson et al.1982; Sommer et al. 2001; Nobriga et al. 2005) or in coastal lagoons along the central coast (Bond et al. 2008; Hayes et al. 2008; Atkinson 2010). Some north-coast estuaries were also studied such as the Klamath River (Wallace and Collins 1997), Mattole River (Zedonis 1992; Busby and Barnhart 1995); however, they did not identify the importance of the SEE. More recent studies in Humboldt Bay tributaries (Wallace 2006; Wallace 2010; Wallace and Allen 2007, 2009, 2012, 2015), the Smith River estuary (Parish and Garwood 2016), the Eel River estuary (Renger and Blessing 2014), Mendocino County coast (Stillwater Sciences 2016), and Russian River estuary (CA Sea Grant 2014) have shown that juvenile salmonids, especially Coho Salmon, use SEE habitat throughout northern and central CA watersheds.

Recent studies conducted by Pacific States Marine Fisheries Commission (PSMFC) and California Department of Fish and Wildlife's (CDFW) Natural Stocks Assessment Project (NSA) in the tidal portions of Humboldt Bay tributaries showed that juvenile salmonids heavily utilize SEE habitat and routinely rear there for months (Wallace 2006; Wallace and Allen 2007, 2009, 2012, 2015; CDFG 2009, 2010; Wallace et al. 2015; Allen et al. 2016). CDFW estimated that about 40% of Coho Salmon smolts and 80 to 90% of large steelhead trout smolts originated from the SEE of Freshwater Creek in 2007 and 2008 (Ricker and Anderson 2011). CDFW studies also have shown that juvenile salmonids using this habitat grew faster and obtained a larger size than juvenile salmonids rearing in stream habitat (Wallace and Allen 2007, 2009, 2012, 2015; Ricker and Anderson 2011; CDFG 2006, 2007, 2008; Wallace 2006; Wallace et al. 2015; Allen et al. 2016).

Multiple salmonid recovery plans encourage estuary and marsh habitat restoration projects around Humboldt Bay (CDFG 2004; HBWAC 2005; NMFS 2014). The majority of tidal wetlands around Humboldt Bay have been diked and converted to pasture land during the past 150 years (HBWAC 2005). Most of the Humboldt Bay sloughs are now contained between levees. Their adjacent marshes have been converted to pasture land and consequently the historic connectivity between slough channels and marsh habitat has been lost.

Currently, former marshlands around Humboldt Bay are being acquired by various public agencies for the purpose of habitat restoration. Willing private landowners are partnering with local land trusts and other non-profit groups to restore wetlands. The result is numerous SEE restoration projects are being planned and implemented in Humboldt Bay's tributaries and sloughs including constructing off channel ponds. CDFW/PSMFC monitored the effects of marsh restoration projects in Wood Creek, Salmon Creek, Jacoby Creek, and Martin Slough on juvenile anadromous salmonid use and basic water quality conditions, specifically in the newly created off channel ponds.

The focus of this report is SEE sampling conducted during 2016- 2017 in Freshwater Creek and its tributaries Wood Creek and Ryan Creek, along with other Humboldt Bay tributaries including Salmon and Jacoby creeks (Figure 1). We also document the life history traits and use of SEE habitat by juvenile salmonids in addition to assessing the performance of estuarine habitat restoration projects.

STUDY AREA

Humboldt Bay is located 442 kilometers north of San Francisco, CA and its watershed area is 57,756 hectares (HBWAC 2005). Its four largest tributaries are Freshwater Creek, Elk River, Salmon Creek, and Jacoby Creek (Figure 2). Numerous smaller tributaries, sloughs, and tidal streams also drain into Humboldt Bay (Figure 2).

Freshwater Creek Slough enters Humboldt Bay just north of Eureka via Eureka Slough. Freshwater Creek is a fourth order stream with a drainage area of approximately 9227 hectares. NSA observed tidal influence approximately nine kilometers upstream of the mouth of Eureka Slough at our sampling sites (Figure 3). The sampling area of Freshwater Creek Slough is characterized primarily by tidal freshwater habitat with dense stands of riparian vegetation, primarily in the form of willow (*Salix* spp.) and alder (*Alnus* spp.) trees. Brackish water up to 20 parts per thousand (ppt) occurs during the summer and fall in the lower portion of this area but further penetration of brackish water is usually blocked by the concrete base of the Humboldt Fish Action Council (HFAC) weir at river kilometer (rKm) 8.7 (Figure 3). All sampling sites are primarily freshwater during the winter and early spring.

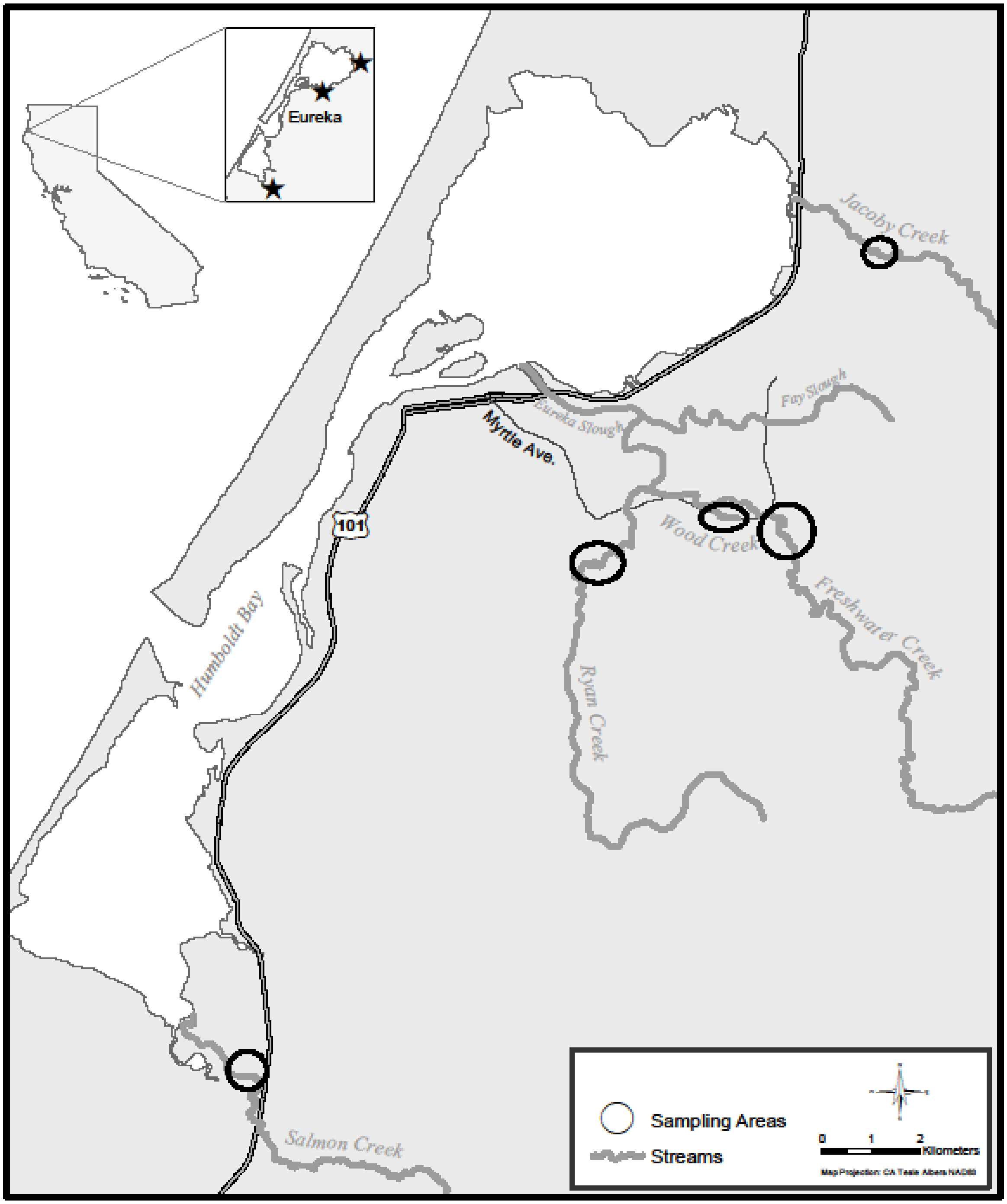


Figure 1. Sampling locations in the stream-estuary ecotone of Freshwater, Wood, Ryan, Salmon, and Jacoby creeks surveyed by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in 2016 and 2017, Humboldt Bay, California.

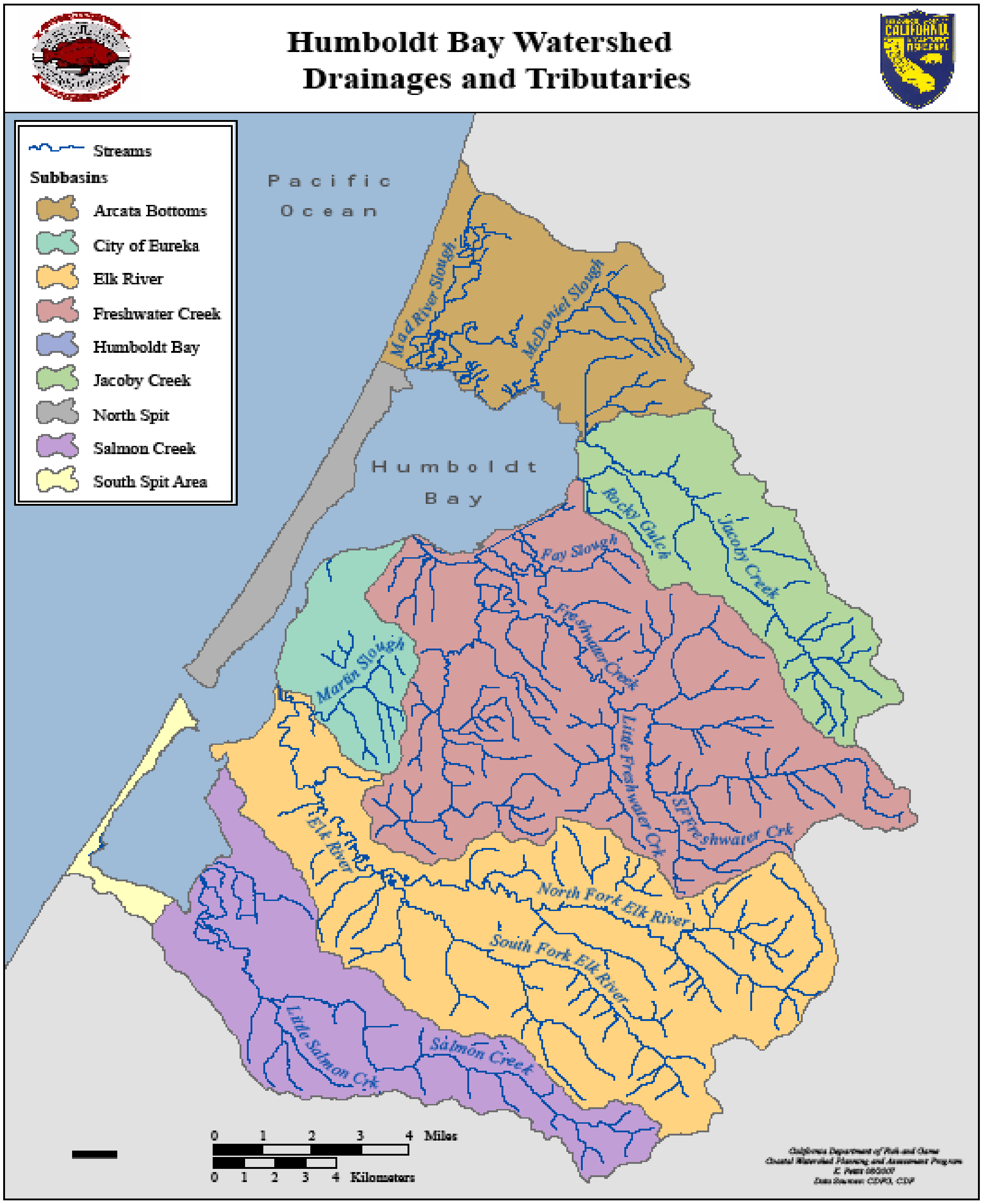


Figure 2. Map of Humboldt Bay, CA showing the names and locations of its largest tributaries.

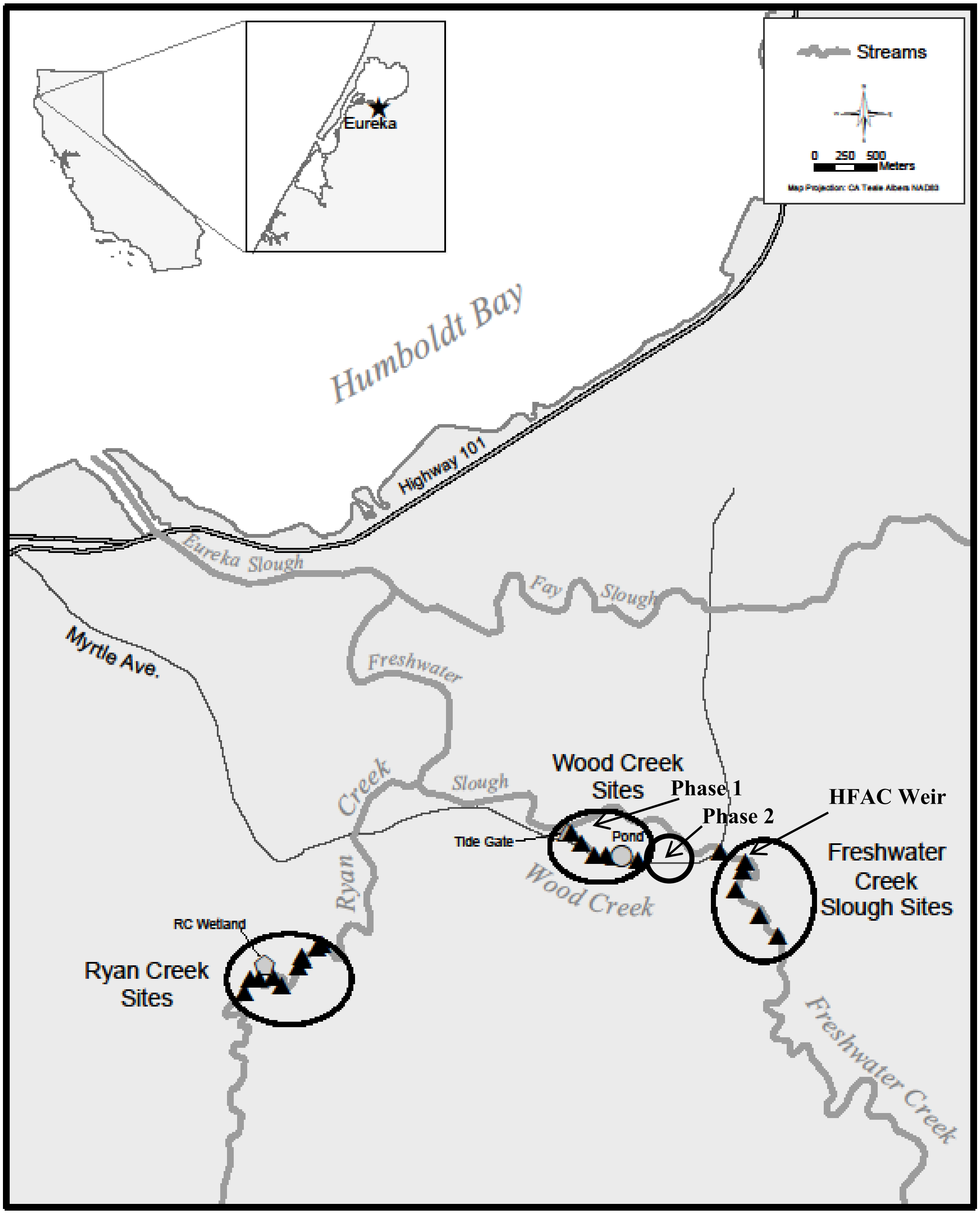


Figure 3. Sampling sites in the stream-estuary ecotone of Freshwater, Wood, and Ryan creeks surveyed by the Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife from 2016 and 2017.

Wood Creek is a small tributary that enters Freshwater Creek Slough at approximately rKm seven and drains about 150 hectares (Figure 3). Brackish water up to 25 ppt occurs during the summer and fall in much of the sampling area but it is primarily freshwater during winter and early spring. The Northcoast Regional Land Trust planned and implemented a two-phased estuarine enhancement project on their property in lower Wood Creek. Phase 1 was implemented in 2010 on the lower 14 hectares of Wood Creek near its confluence with Freshwater Creek Slough and included removal of the tide gate flap at the mouth of the creek, construction of tidal channels, removal of an undersized culvert in increase tidal prism in Wood Creek, and the construction an off-channel pond to increase rearing habitat for juvenile salmonids. Phase 2 was implemented in 2016 just upstream of the Phase 1 area and included the construction of multiple tidal channels to increase over winter rearing habitat for juvenile salmonids. Cattle continue to graze on part of the property, and the stream channel is low gradient, tidally influenced, and has limited riparian development.

Ryan Creek is the largest tributary of Freshwater Creek, and it enters Freshwater Creek Slough at about rKm six and drains about 3,315 hectares (Figure 3). The lower one kilometer of Ryan Creek is tidally influenced, confined by levees, and has limited riparian cover. The sampling area was recently acquired by Humboldt County from Green Diamond Resources Company (GDRC). About 1/3 of the sampling sites experience brackish water up to 20 ppt during the summer and fall. The remaining sampling sites occur upstream in tidal freshwater habitat with dense stands of riparian vegetation, primarily in the form of alder and young coniferous trees. We also sampled a large wetland adjacent to Ryan Creek that is periodically flooded during the winter (Figure 3).

Salmon Creek enters the bay at the extreme southern end of Humboldt Bay via Hookton Slough (Figure 4), and drains approximately 5060 hectares (HBWAC 2005). The tidal portion of Salmon Creek is contained within the Humboldt Bay National Wildlife Refuge (Refuge). Cattail Creek and an old tidal meander at the mouth of Cattail Creek named Long Pond are adjacent to Salmon Creek and are part of the Refuge complex (Figure 4). Newer fish-friendly tide gates are located at the mouths of Salmon and Cattail creeks where they enter Hookton Slough. The tide gates allow for effective fish movement and mute tidal influence in both creeks. Brackish water up to 35 ppt occurs from late spring to late fall in much of the sampling area, but the upstream portion is mostly fresh water during the winter and early spring. The Refuge implemented a large habitat restoration project in 2011 that included relocating and enlarging both creeks' stream channels and constructing five off channel ponds on Salmon Creek to provide over winter habitat for juvenile salmonids.

Jacoby Creek enters the northern end of Humboldt Bay and drains approximately 5,270 hectares (HBWAC 2005). The lower portion of Jacoby Creek flows through agricultural lands on City of Arcata property and is usually contained between levees except during high stream flows when it floods adjacent agricultural land. A seasonal off-channel pond on Jacoby Creek occurs upstream of tidal influence on Jacoby Creek Land Trust property and remains freshwater until it dries up in the late summer or fall (Figure 5).

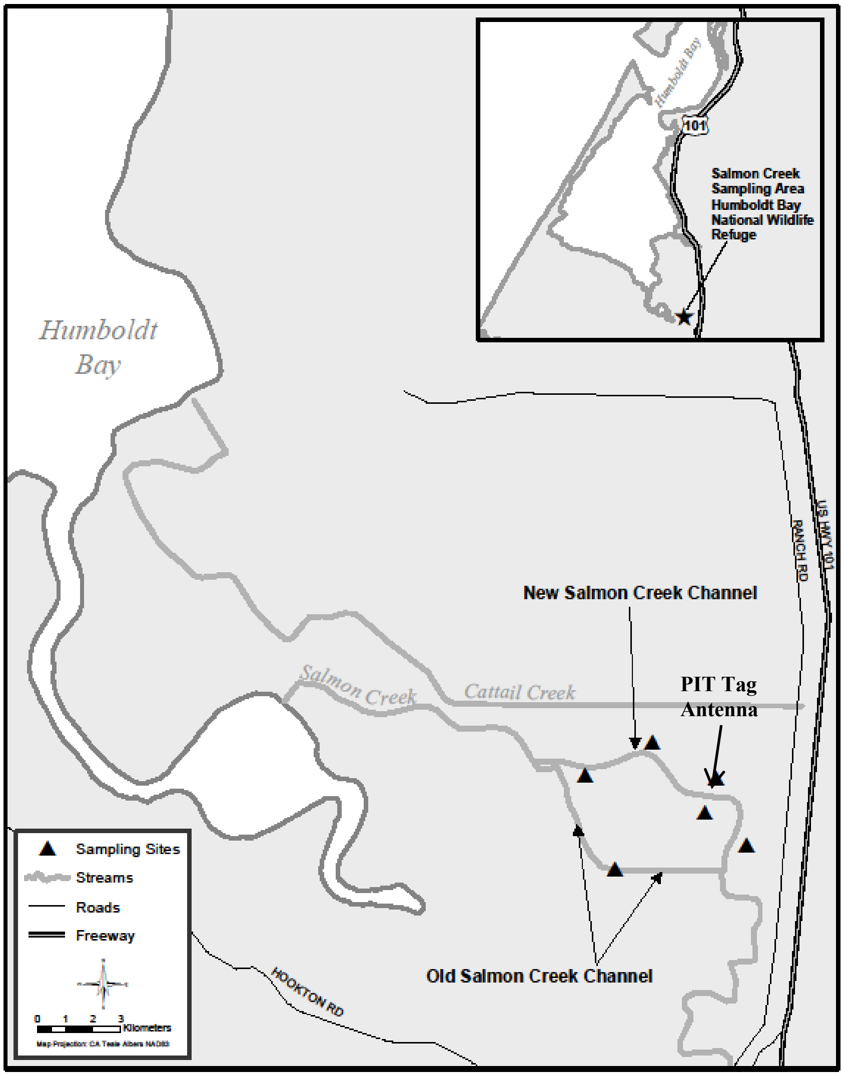
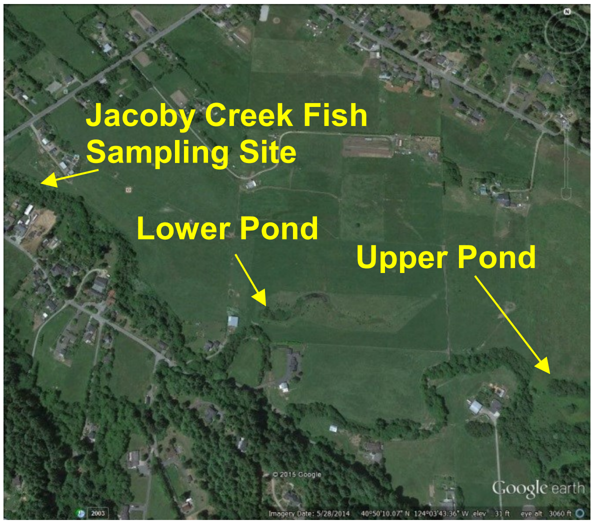


Figure 4. Sampling sites in the stream-estuary ecotone of Salmon Creek surveyed by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in 2016.



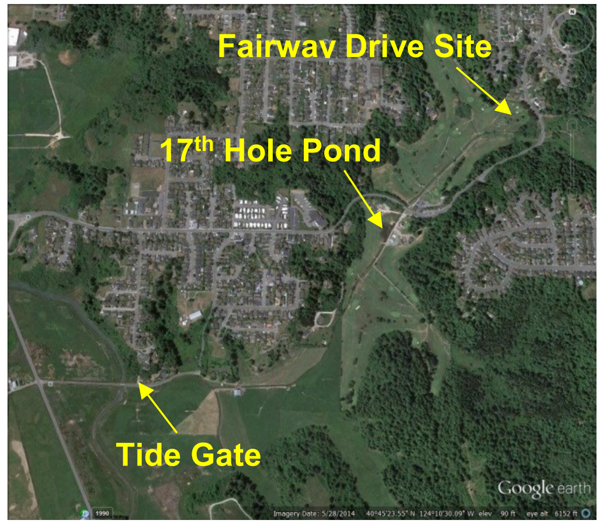


Figure 5. Approximate locations of fish and water quality sampling sites in Jacoby Creek (left) and Martin Slough (right) sampled by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in 2016 and 2017.

This pond (Lower Pond) was disconnected from Jacoby Creek except during the highest winter flows. The lower pond was modified in the summer/fall of 2015 by creating a better connection between it and the stream (Love 2014), and a second pond (Upper Pond) was constructed approximately 0.5 kilometers upstream to provide over-winter rearing habitat for juvenile salmonids. The stream channel is bordered by dense stands of riparian vegetation, primarily in the form of willow and alder trees. The lower pond has little riparian vegetation due to past cattle grazing.

Martin Slough is a tributary of Elk River Slough and enters Humboldt Bay via Swain Slough just east of Highway 101near rKm 2.5 (Figure 2) and flows through cattle grazing land and the Eureka Municipal Golf Course. A new fish friendly tide gate was installed in 2016 at the mouth of Martin Slough on NCRLT property to replace an old failing tide gate that had been in place for decades. The tide gate allows for effective fish movement and muted tidal influence in Martin Slough. Brackish water up to 30 ppt is usually present from late spring to late fall near the tide gate and is also present at 5 to 15 ppt at the 17th hole off-channel pond from mid-summer to late fall. Our sampling site at Fairway Drive remains fresh water throughout the year (Figure 5).

METHODS

In 2016 and 2017, we conducted bi-weekly or monthly sampling for juvenile salmonids in Freshwater, Wood, Ryan, and Jacoby creeks, and Martin Slough, while we sampled Salmon and Cattail creeks only 2016 (Table 1). Crews used a 9.1 meter (m) X 1.2 m seine net to sample six sites in Freshwater Creek Slough, five sites in Wood Creek Phase 2, two sites in Martin Slough, three to four sites in Jacoby Creek ponds, one site in Wood Creek pond, and two sites in Cattail Creek. Crews used a 30.5 m X 1.5 m seine net to sample the off-channel ponds on Salmon Creek and Martin Slough. They

Table 1. The sampling methods, frequency, and duration for Freshwater, Wood, Ryan, Salmon, Cattail, and Jacoby creeks, and Martin Slough sampled by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in 2016 and 2017.

Location	Method	Frequency	Duration
Freshwater Creek	9 m seine	bi-weekly	2016-2017
Wood Creek			
Phase 1	minnow traps (mt)	monthly	Jan-Oct 2016
Wood Cr Pond	9 m seine and mt	bi-weekly	2016-2017
Phase 2	9 m seine and mt	bi-weekly	Oct 2016-2017
Ryan Creek	mt	bi-weekly	2016-2017
Salmon Creek			
Ponds	30 m seine and mt	bi-weekly	Jan-July 2016
Cattail Creek	9 m seine and mt	monthly	Jan-July 2016
Martin Slough	30 and 9 m seines and mt	monthly	2016-2017
Jacoby Creek Ponds	9 m seine and mt	monthly	2016-2017

used minnow traps baited with frozen salmon roe to sample nine sites plus an adjacent wetland in Ryan Creek, eight sites in Wood Creek, four sites in Cattail Creek, three sites in Martin Slough, one site in Jacoby Creek, two sites in each of the constructed off-channel ponds in Wood and Salmon creeks, and 12 sites in the Jacoby Creek off-channel ponds (Table 1). We used minnow traps to sample heavily vegetated areas where we could not seine effectively.

Field crews anaesthetized, counted, and examined all juvenile salmonids for marks and tags. They also documented the life stage of each salmonid. We designated Coho Salmon as “sub-yearling” or “yearling-plus” based on clear size differences between the smaller sub-yearling and larger yearling-plus fish. Coho Salmon designated as sub-yearling fish prior to December 31 of each year were designated as yearling-plus fish starting January 1. For yearling-plus Coho Salmon, steelhead trout, and cutthroat trout, we designated their development stage as parr (heavy parr marks present), pre-smolt (faded parr marks and silvery color), smolt (no parr marks visible and black fin edges), or adult. Field crews also measured fork lengths (FL) to the nearest millimeter (mm), weights to the nearest 0.1 gram (g), and collected scales from the left side of all juvenile salmonids $\geq$ 50 mm except when the number of fish captured or environmental conditions made it dangerous to process the fish.

We applied Passive Integrated Transponder (PIT) tags to all healthy juvenile salmonids to gather residency, movement, and growth information while they were in the SEE. Per our NMFS 4(d) permit, the minimum size of fish tagged was $\geq$ 55 mm FL in prior to 2015 and $\geq$ 60 mm FL 2015 to 2017. We applied PIT tags by making a small incision and inserting the tag into the body cavity. All fish $\geq$ 60 mm and $\leq$ 69mm FL received an 8.5 mm FDX tag and those $\geq$ 70 mm FL received an 11.5 mm HDX or FDX tag. Once processed, we allowed the fish to recover and released them back into the sampling site. For fish already containing tags or marks we measured FL, weighed, scale sampled on their right side, and recorded their mark or tag number. We also captured fish containing PIT Tags applied by CDFW's Anadromous Fisheries Research and Monitoring Program (AFRAMP) throughout Freshwater Creek basin. We combined records of all tag codes applied by our project and AFRAMP to identify all tag codes recovered by our project.

Our project maintained one paired PIT tag antenna array at the midpoint of our sampling area in Ryan Creek (Figure 6) and, until July 2016, at the opening of the second-most upstream pond in Salmon Creek (Figure 4). Our project also maintained two paired PIT tag antenna arrays in Wood Creek, one at the entrance of the constructed off-channel pond and one in the tide gate structure at the mouth of the creek (Figure 7). However, we removed the antenna array at the pond in July 2016 so it would not be damaged by Phase 2 construction. After construction was completed, we installed a new antenna station near the mid-point of the Phase 2 area and installed a

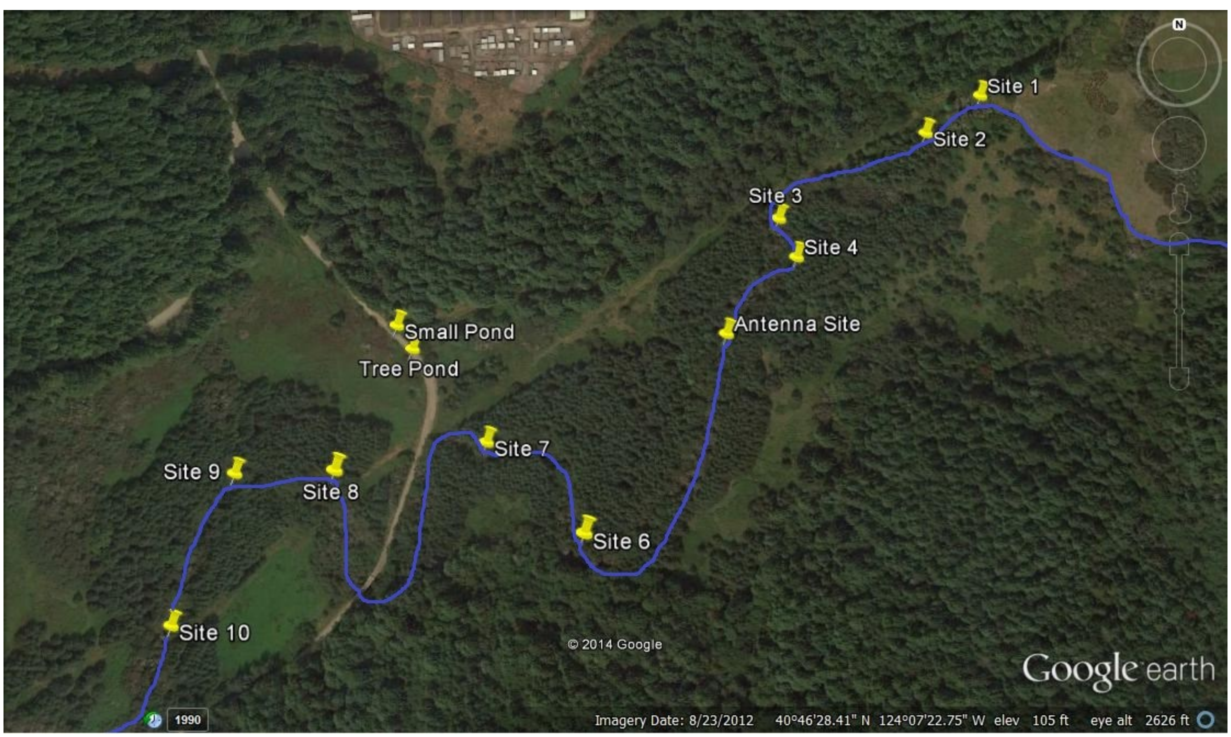


Figure 6. Fish sampling and PIT tag antenna locations in Ryan Creek Slough. Site 1 is at the downstream end of our sampling area.

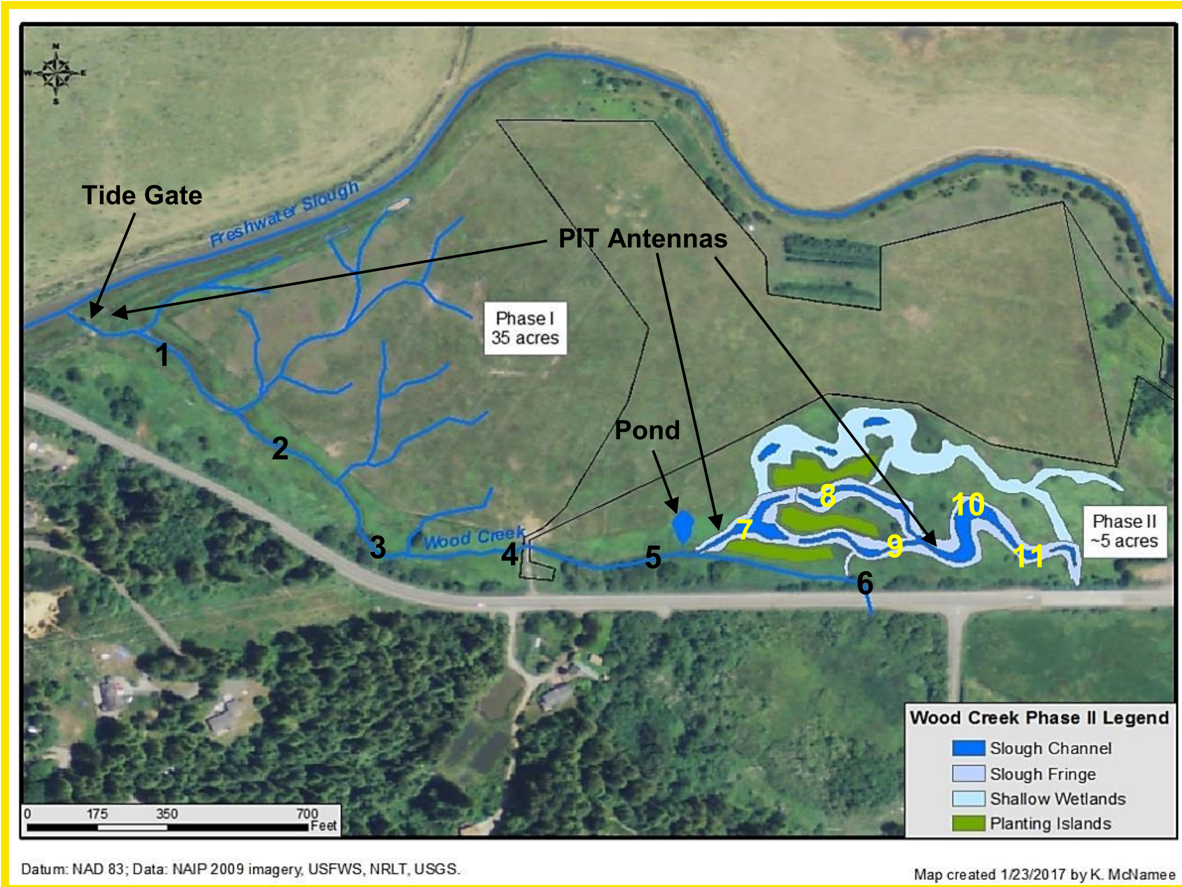


Figure 7. Approximate fish sampling locations in the Phase 1 (in black) and Phase 2 (in yellow) habitat restoration areas of Wood Creek, and approximate locations of the tide gate, Phase 1 constructed off-channel pond, and PIT tag antennas. Base map provided by Northcoast Regional Land Trust.

paired antenna near the downstream end of Phase 2 and another paired antenna near the upstream end of Phase 2 (Figure 7). PIT tag detections were automatically stored on a data logger, and field staff downloaded these data every one to two weeks. We transferred the data into Excel spreadsheets for future analyses.

We calculated the duration of estuarine residence for fish PIT-tagged in the SEE as the number of days between tagging and last capture or detection. For fish tagged outside the SEE (by other projects), we calculated estuarine residence as the number of days between first capture or detection in the SEE and last capture or detection. We calculated growth rates for fish PIT-tagged in the SEE as the change in FL between tagging and last capture divided by the number of days between tagging and last recapture. For fish tagged outside the SEE, we calculated growth rates as the change in FL between first and last captures in the SEE divided by the number of days between first and last captures.

We also conducted water quality sampling bi-weekly in the off-channel ponds in Wood and Salmon creeks and monthly in Wood, Jacoby, and Cattail creeks, Martin Slough, and in both Jacoby Creek off-channel ponds with YSI Professional Plus hand-held meters. Beginning in October 2016, we conducted bi-weekly WQ sampling in the Phase 1 and 2 areas of Wood Creek and we ended WQ sampling in Salmon and Cattail creeks in July 2016. We collected water temperature, salinity, and dissolved oxygen data in the ponds and adjacent slough habitat. Due to stratification between fresh and brackish water, water samples were collected at surface, mid, and bottom elevations when water depths ≥ 0.91 m, surface and bottom elevations when water depth was ≥ 0.46 m, and < 0.91 m, and bottom elevation when depths were < 0.46 m.

RESULTS

Freshwater Creek Slough

Freshwater Creek Slough 2016 to 2017

In 2016, the peak monthly catch-per-unit-effort (CPUE) for sub-yearling Coho Salmon was 6.83 fish/set in June (Table 2). Sub-yearling Coho Salmon monthly mean FL increased from 41 mm in April to 78 mm in October and then dropped to 77 mm in November (Table 3). The peak monthly CPUE for yearling-plus Coho Salmon was 9.83 fish/set in April (Table 2). Yearling-plus Coho Salmon monthly mean FL increased from 98 mm in February to 116 mm in April and then ranged from 106 to 116 mm May-November (Table 3). We captured sub-yearling Chinook Salmon in April and May and their monthly CPUE was 0.08 fish/set both months (Table 2). Their monthly mean FL increased from 44 mm in April to 62 mm in May (Table 3). We captured juvenile steelhead trout throughout the year with a peak monthly CPUE of 0.42 fish/set in November (Table 2). Their monthly mean FL ranged from 82 to 192 mm (Table 4). We captured cutthroat trout throughout the year with a peak monthly CPUE of 0.25 fish/set in April (Table 2). Their monthly mean FL ranged from 140 to 238 mm (Table 4).

In 2017, we captured sub-yearling Coho Salmon April to August and their peak monthly CPUE occurred in July at 7.71 fish/set (Table 5). Sub-yearling Coho Salmon monthly mean FL increased from 37 mm in April to 72 mm when we ceased sampling in August (Table 6). We captured yearling-plus Coho Salmon April to June and their peak monthly CPUE of 2.79 fish/set occurred in May (Table 5). Their monthly mean FL ranged from 109 to 112 mm (Table 6). We captured sub-yearling Chinook Salmon in May and June and their peak monthly CPUE occurred in June at 0.25 fish/set (Table 5). Sub-yearling Chinook Salmon monthly mean FL increased from 56 mm in May to 72 mm in June (Table 6). The peak monthly CPUE of juvenile steelhead trout was 0.95 fish/set in August (Table 5). Their monthly mean FL ranged from 83 to 114 mm (Table 7). The peak monthly CPUE of cutthroat trout was 0.25 fish/set in May (Table 5). Their monthly mean FL ranged from 182 to 256 mm (Table 7).

Table 2. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile Coho and Chinook Salmon and steelhead and cutthroat trout captured by seine nets in Freshwater Creek Slough, 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	0	-	-	-	-	-
February	22	0.32	0	0.09	0	0
March	12	1.08	0.08	0	0.08	0
April	12	9.83	2.00	0.08	0.25	0.08
May	36	1.78	3.03	0.31	0.11	0.08
June	24	0.13	6.83	0.33	0.08	0
July	24	0	5.96	0.38	0.21	0
August	24	0.04	5.33	0.33	0.13	0
September	24	0.08	5.04	0.25	0.21	0
October	24	0	4.63	0.17	0.08	0
November	12	0.08	1.75	0.42	0.17	0
December	0	-	-	-	-	-

Table 3. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by seine nets in Freshwater Creek Slough, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	-	-	-	-	-	-	-	-	-
February	7	98	11.3	0	-	-	0	-	-
March	13	108	16.9	1	41	-	0	-	-
April	105	116	11.7	22	43	4.1	1	44	-
May	63	113	12.1	109	57	10.2	3	62	11.1
June	3	106	4.9	164	71	8.1	0	-	-
July	0	-	-	143	74	7.1	0	-	-
August	1	113	-	128	76	6.8	0	-	-
September	2	110	7.1	121	77	7.0	0	-	-
October	0	-	-	110	78	7.3	0	-	-
November	1	116	-	21	77	9.4	0	-	-
December	-	-	-	-	-	-	-	-	-

Table 4. Number measured, mean fork-length (FL), and standard deviation (SD) of juvenile steelhead and cutthroat trout captured by seine nets in Freshwater Creek Slough, 2016.

Month	No. Steelhead Trout	Mean FL Steelhead Trout	SD Steelhead Trout	No. Cutthroat Trout	Mean FL Cutthroat Trout	SD Cutthroat Trout
January	-	-	-	-	-	-
February	2	147	26.9	0	-	-
March	0	-	-	1	217	-
April	1	192	-	3	140	46.9
May	11	112	26.4	4	184	52.0
June	7	82	24.8	2	178	53.0
July	10	112	48.0	5	198	42.2
August	8	103	38.5	3	193	26.5
September	5	122	42.9	4	188	43.4
October	4	154	48.3	2	229	38.2
November	5	107	51.4	2	238	12.7
December	-	-	-	-	-	-

Table 5. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile Coho and Chinook Salmon and steelhead and cutthroat trout captured by seine nets in Freshwater Creek Slough, 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	12	0	0	0	0.08	0
February	0	-	-	-	-	-
March	0	-	-	-	-	-
April	16	2.19	0.38	0.13	0	0
May	24	2.79	1.42	0.67	0.25	0.04
June	24	0.46	5.38	0.71	0.17	0.25
July	24	0	7.71	0.67	0.13	0
August	36	0	4.97	0.95	0.17	0

Table 6. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by seine nets in Freshwater Creek Slough, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-	-
April	34	110	16.43	5	37	1.67	0	-	-
May	67	109	10.00	34	45	6.83	1	56	-
June	11	112	12.15	129	60	7.73	6	72	7.94
July	0	-	-	184	68	6.79	0	-	-
August	0	-	-	178	72	7.53	0	-	-

Table 7. Number measured, mean fork-length (FL), and standard deviation (SD) of juvenile steelhead and cutthroat trout captured by seine nets in Freshwater Creek Slough, 2017.

Month	No. Steelhead Trout	Mean FL Steelhead Trout	SD Steelhead Trout	No. Cutthroat Trout	Mean FL Cutthroat Trout	SD Cutthroat Trout
January	-	-	-	-	-	-
February	-	-	-	-	-	-
March	-	-	-	-	-	-
April	2	90	16.97	0	-	-
May	16	109	12.68	6	182	51.09
June	17	114	17.25	4	198	66.42
July	16	83	28.94	3	187	61.21
August	34	88	35.00	3	256	46.70

Recaptured PIT Tagged Fish 2016 and 2017

In 2016, we applied PIT tags to 310 sub-yearling Coho Salmon in Freshwater Creek Slough and recaptured 161 (51.9%) of them (Table 8[6]). The mean length of estuarine residence for recaptured fish was 67 days and ranged from 13-156 days (Table 8). The mean growth rate of recaptured sub-yearling Coho Salmon was 0.10 mm/day and ranged from -0.07 to 0.47 mm/day (Table 8). We also applied PIT tags to 165 yearling-

[6] Table 8 includes PIT information from 2016, 2017, and the previous 10 years.

Table 8. Summarized information for sub-yearling Coho Salmon PIT tagged by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in Freshwater Creek Slough including number tagged, number and percent recaptured, mean and range of days at liberty (DAL) of recaptured fish, and mean and range of recaptured Coho Salmon growth rate (mm/day).

Year	No. Tagged	No. Recaptured	Percent Recaptured	Mean DAL	Range DAL	Mean Growth Rate	Range Growth Rate
2006	237	57	24.1	33	5-106	0.15	0.00-0.29
2007	65	12	18.5	68	6-167	0.17	0.12-0.45
2008	11	0	0	-	-	-	-
2009	152	69	45.4	60	13-175	0.20	0.00-0.68
2010	60	12	20.0	41	16-113	0.23	0.12-0.48
2011	520	74	14.2	52	12-165	0.25	0.00-0.93
2012	555	303	54.6	58	12-140	0.17	-0.07-0.63
2013	201	99	49.3	45	6-140	0.20	-0.07-0.86
2014	61	27	44.3	62	13-140	0.16	0.00-0.40
2015	252	120	47.6	71	13-152	0.08	0.00-0.27
2016	310	161	51.9	67	13-156	0.10	-0.07-0.47
2017*	233	112	48.1	30	13-70	0.19	0.00-0.57

*Sampling ended in August so mean DAL biased low.

plus Coho Salmon in 2016 and recaptured 12 (7.3%) of them (Table 9). The mean length of estuarine residence for recaptured fish was 24 days and ranged from 12-71 days (Table 9). The mean growth rate for recaptured yearling-plus Coho Salmon was 0.40 mm/day and ranged from 0 to 0.50 mm/day (Table 9). We also recaptured 13 Coho Salmon tagged by AFRAMP at the HFAC weir (11 in 2016 and two in 2015); three Coho Salmon tagged by AFRAMP in the Freshwater Creek basin in the fall of 2015; and two Coho Salmon tagged by our project in Freshwater Creek Slough in 2015. We applied PIT tags to 43 juvenile steelhead trout in 2016 and recaptured seven (16.3%). They were at-large between 13-153 days and they grew 0 to 7 mm (0.00 to 0.29 mm/day) during that time. We applied PIT tags to 21 cutthroat trout in 2016 and we recaptured three (14.3%) of them. They were at-large between 57-69 days and they grew 0 to 3 mm (0.00 to 0.04 mm/day) during that time. Our project also captured one cutthroat trout that our project tagged in Freshwater Creek Slough in 2015. It was at large 343 days and grew 50 mm (0.15 mm/day) during that time.

In 2017, we applied PIT tags to 233 sub-yearling Coho Salmon in Freshwater Creek Slough and recaptured 112 (48.1%) fish (Table 8). The mean length of estuarine residence for recaptured fish was 30 days and ranged from 13-70 days (Table 8). The mean growth rate of recaptured sub-yearling Coho Salmon was 0.19 mm/day and ranged from 0 to 0.57 mm/day (Table 8). The mean DAL for sub-yearling Coho Salmon is biased low because we ended field sampling in August and therefore did not have the opportunity to recapture tagged fish the rest of 2017 or into the winter and spring of

Table 9. Summarized information for yearling-plus Coho Salmon PIT tagged by Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife in Freshwater Creek Slough including number tagged, number and percent recaptured, mean and range of days at liberty (DAL) of recaptured fish, and mean and range of recaptured Coho Salmon growth rate (mm/day).

Year	No. Tagged	No. Recaptured	Percent Recaptured	Mean DAL	Range DAL	Mean Growth Rate	Range Growth Rate
2016	165	12	7.3	24	12-71	0.40	0.00-0.50
2017	87	10	11.5	25	14-36	0.40	0.20-0.64

2018. We applied PIT tags to 87 yearling-plus Coho Salmon and recaptured 10 (11.5%) fish. We also recaptured 13 yearling-plus Coho Salmon that were tagged by AFRAMP or by our project the previous year. The mean length of estuarine residence for yearling-plus Coho Salmon tagged and recaptured in 2017 was 25 days range (14-36 days). Their mean growth rate was 0.40 mm/day and ranged from 0.20 to 0.64 mm/day (Table 9). We applied PIT tags to 66 juvenile steelhead trout in 2017 and recaptured 16 (24.2%). We also recaptured one steelhead trout that was tagged by AFRAMP or by our project the previous year. The mean length of estuarine residence for steelhead trout tagged and recaptured in 2017 was 37 days (range 14-98 days). Their mean growth rate was 0.23 mm/day and ranged from 0.07 to 0.71 mm/day. We applied PIT tags to 16 cutthroat trout in 2017 and did not recapture any of them. However, we recaptured two cutthroat trout that were tagged by AFRAMP or by our project in previous years. It is likely that some of the cutthroat trout captured by our project were resident adult fish.

WOOD CREEK

Wood Creek 2016 and 2017

In 2016, juvenile Coho Salmon were the most abundant salmonids captured in Wood Creek and Wood Creek pond. We captured 39 yearling-plus and 35 sub-yearling Coho Salmon during minnow trapping in the Phase 1 restoration area of Wood Creek (Table 10). We captured yearling-plus Coho Salmon January to May and one individual in December and sub-yearling Coho Salmon in June and October to December (Table 10). Peak catches of yearling-plus and sub-yearling Coho Salmon occurred in February and December, respectively (Table 10). While seining Wood Creek pond, we captured only one yearling-plus Coho Salmon in January and two sub-yearling Coho Salmon in April (Table 11). We began fish sampling the Phase 2 restoration area in October 2016. We captured seven sub-yearling Coho Salmon using minnow traps, all in November and December (Table 12). We captured 168 sub-yearling Coho Salmon using seine nets, 123 in November and 45 in December. Peak CPUE of sub-yearling Coho Salmon occurred in November and was 6.47 fish/set (Table 13).

Table 10. Monthly effort (number of traps) and number of juvenile salmonids captured by minnow traps in Wood Creek Phase 1 restoration area, January-December 2016. Note sampling effort changed from monthly sampling at six sites January to mid-October to biweekly sampling at three sites mid-October to December.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	8	1	0	0	0	0
February	8	15	0	0	0	0
March	8	9	0	0	0	0
April	8	12	0	0	0	0
May	8	1	0	0	0	0
June	8	0	1	0	0	0
July	7	0	0	0	0	0
August	7	0	0	0	0	0
September	7	0	0	0	0	0
October	9	0	1	0	0	0
November	5	0	13	0	0	0
December	9	1	20	0	0	0
Total	**92**	**39**	**35**	**0**	**0**	**0**

Table 11. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Wood Creek pond Phase 1 restoration area, January-December 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	3	0.33	0	0	0	0
February	1	0	0	0	0	0
March	1	0	0	0	0	0
April	4	0	0.50	0	0	0
May	3	0	0	0	0	0
June	2	0	0	0	0	0
July	3	0	0	0	0	0
August	3	0	0	0	0	0
September	3	0	0	0	0	0
October	1	0	0	0	0	0
November	2	0	0	0	0	0
December	4	0	0	0	0	0

Table 12. Monthly effort (number of traps) and number of juvenile salmonids captured by minnow traps in Wood Creek Phase 2 restoration area, October-December 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
October	7	0	0	0	0	0
November	14	0	3	0	0	0
December	18	0	4	0	0	0
Total	**39**	**0**	**7**	**0**	**0**	**0**

Table 13. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Wood Creek Phase 2 restoration area, October-December 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
October	10	0	0	0	0	0
November	19	0	6.47	0	0	0
December	30	0	1.50	0	0	0

Monthly mean FL of minnow trapped fish varied from 72-115 mm for yearling-plus Coho Salmon and 72-89 mm for sub-yearling Coho Salmon (Table 14). Monthly mean FL for seined sub-yearling Coho Salmon varied from 40 to 76 mm (Table 15).

In 2017, yearling-plus Coho Salmon were the most abundant salmonids captured in the Phase 1 restoration area of Wood Creek. We captured 51 yearling-plus Coho Salmon, 12 sub-yearling Coho Salmon, and three cutthroat trout in minnow traps (Table 16). We captured yearling-plus Coho Salmon January to May, sub-yearling Coho Salmon May to August, and cutthroat trout in May and July (Table 16). Peak catches of yearling-plus and sub-yearling Coho Salmon occurred in April and July, respectively (Table 16). We did not capture any salmonids while seining Wood Creek pond in 2017. In the Phase 2 restoration area, we captured 14 yearling-plus Coho Salmon in March and April and one sub-yearling Coho Salmon in May using minnow traps (Table 17). While seining we captured yearling-plus Coho Salmon from January to May and their peak CPUE of 2.65 fish/set occurred in March (Table 18). We captured sub-yearling Coho Salmon April to June and their peak CPUE of 8.50 fish/set occurred in May (Table 18). We did not capture any other salmonid species in Phase 2 in 2017.

The monthly mean FL for yearling-plus Coho Salmon captured by minnow traps in Phase 1 and 2 areas combined increased from 94 mm in January to 110 mm in May

Table 14. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by minnow traps in Wood Creek, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	1	72	-	0	-	-	0	-	-
February	15	88	9.0	0	-	-	0	-	-
March	9	94	11.8	0	-	-	0	-	-
April	12	102	10.2	0	-	-	0	-	-
May	1	98	-	0	-	-	0	-	-
June	0	-	-	1	72	-	0	-	-
July	0	-	-	0	-	-	0	-	-
August	0	-	-	0	-	-	0	-	-
September	0	-	-	0	-	-	0	-	-
October	0	-	-	1	89	-	0	-	-
November	0	-	-	16	73	6.8	0	-	-
December	1	115	-	24	89	10.4	0	-	-

Table 15. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by seine in Wood Creek, 2016. Note sampling effort changed from seining one site January to mid-October to seining six sites mid-October to December.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	0	-	-	0	-	-	0	-	-
February	0	-	-	0	-	-	0	-	-
March	0	-	-	0	-	-	0	-	-
April	0	-	-	2	40	3.5	0	-	-
May	0	-	-	0	-	-	0	-	-
June	0	-	-	0	-	-	0	-	-
July	0	-	-	0	-	-	0	-	-
August	0	-	-	0	-	-	0	-	-
September	0	-	-	0	-	-	0	-	-
October	0	-	-	0	-	-	0	-	-
November	0	-	-	123	72	8.8	0	-	-
December	0	-	-	45	76	9.5	0	-	-

Table 16. Monthly effort (number of traps) and number of juvenile salmonids captured by minnow traps in Wood Creek Phase 1 restoration area, January-August 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	7	6	0	0	0	0
February	6	2	0	0	0	0
March	6	4	0	0	0	0
April	5	31	0	0	0	0
May	9	8	2	0	2	0
June	6	0	2	0	0	0
July	6	0	7	0	1	0
August	6	0	1	0	0	0
Total	**51**	**51**	**12**	**0**	**3**	**0**

Table 17. Monthly effort (number of traps) and number of juvenile salmonids captured by minnow traps in Wood Creek Phase 2 restoration area, January-August 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	12	0	0	0	0	0
February	10	0	0	0	0	0
March	10	4	0	0	0	0
April	10	10	0	0	0	0
May	15	0	1	0	0	0
June	10	0	0	0	0	0
July	10	0	0	0	0	0
August	10	0	0	0	0	0
Total	**87**	**14**	**1**	**0**	**0**	**0**

Table 18. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Wood Creek Phase 2 restoration area, January-August 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	21	0.14	0	0	0	0
February	20	0.15	0	0	0	0
March	20	2.65	0	0	0	0
April	20	2.10	0.05	0	0	0
May	20	0.90	8.50	0	0	0
June	20	0	0.70	0	0	0
July	19	0	0	0	0	0
August	18	0	0	0	0	0

(Table 19), while those captured by seining increased from 88 mm in January to 112 mm in March and April and then dropped to 109 in May (Table 20). The monthly mean FL for sub-yearling Coho Salmon captured by minnow traps increased from 54 mm FL in May to 73 mm in July (Table 19), while those captured by seining increased from 42 mm in April to 61 mm in June (Table 20). The three captured cutthroat trout ranged from 95 to 116 mm FL.

Recaptured PIT Tagged Fish 2016 and 2017

In 2016, we applied PIT tags to 36 yearling-plus Coho Salmon in Wood Creek and recaptured three (8.3%) fish. The recaptured fish were at large 35 days, and they grew 2 to 8 mm (0.06 to 0.23 mm/day) during that time. We tagged and recaptured all three yearling-plus Coho Salmon at Site 6.

In 2016, we applied PIT tags to 195 sub-yearling Coho Salmon in Wood Creek and recaptured three (1.5%) fish. We tagged 193 (99.0%) of these fish in November and December. The recaptured fish were at large 13-183 days, and they grew 1 to 33 mm (0.08 to 0.18 mm/day) during that time. We tagged and recaptured all three yearling-plus Coho Salmon in the Phase 1 area at Sites 4 and 6. We also recaptured three sub-yearling Coho Salmon tagged in locations outside of Wood Creek. One was tagged by our project in Freshwater Creek Slough, was at large 8/23 to 12/14/16 (113 days), and grew 9 mm (0.08 mm/day). The other two recaptured Coho Salmon were tagged by CDFW's AFRAMP project upstream of the estuary in October 2016.

We did not apply any PIT tags to other species to calculate estuarine residence or growth rates.

Table 19. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by minnow traps in Wood Creek, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	6	94	9.0	0	-	-	0	-	-
February	2	105	9.9	0	-	-	0	-	-
March	8	103	8.1	0	-	-	0	-	-
April	42	105	9.9	0	-	-	0	-	-
May	7	110	6.8	2	54	4.2	0	-	-
June	0	-	-	2	57	12.7	0	-	-
July	0	-	-	7	73	3.7	0	-	-
August	0	-	-	1	66	-	0	-	-

Table 20. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by seine in Wood Creek, 2017. Note sampling effort changed from seining one site January to mid-October to seining six sites mid-October to December.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	3	88	4.4	0	-	-	0	-	-
February	3	101	12.2	0	-	-	0	-	-
March	53	112	12.0	0	-	-	0	-	-
April	42	112	11.9	1	42	-	0	-	-
May	18	109	10.7	169	50	7.7	0	-	-
June	0	-	-	14	61	8.3	0	-	-
July	0	-	-	0	-	-	0	-	-
August	0	-	-	0	-	-	0	-	-

In 2017, we applied PIT tags to 153 yearling-plus Coho Salmon in Wood Creek and recaptured 15 fish (9.8%). The 15 recaptured fish had a mean residency time of 21 days (range 13-58). They grew 2 to 35 mm while at large and their average growth rate was 0.50 mm/day (range 0.13 to 0.93). We also recaptured seven yearling-plus Coho Salmon that were tagged by our project in Wood Creek in 2016 and these seven fish were at large 97 to 167 days, and they grew 23 to 53 mm (0.16 to 0.55 mm/day) during that time. We also captured three yearling-plus Coho Salmon that were tagged by a Humboldt State University graduate student in Wood Creek and these three fish were at large 50 to 93 days and grew 33 to 57 mm (0.61 to 0.66 mm/day) during that time. All 26 recaptured yearling-plus Coho Salmon combined had a mean residency time of 59 days (range 13-167), grew 2 to 57 mm, and their mean growth rate was 0.45 mm/day (range 0.13 to 0.93 mm/day). These growth rates are among the fastest our project has observed anywhere in the Humboldt Bay SEE. We also PIT tagged two sub-yearling Coho Salmon and three cutthroat trout and did not recapture any of them.

<u>PIT Tag Antenna Detections Wood Creek 2015/16 Season</u>

From September 2015 to July 2016, the pond antenna detected 32 Coho Salmon and one steelhead trout. The antenna was offline for equipment upgrades 10/15-16/15. We removed the antenna from the pond on 7/6/16 so it would not be damaged by Phase 2 construction. The antenna first detected individual Coho Salmon on 11/25/15 and last detected them on 3/15/16. The number of first detections peaked in December and January (n=13 and 8 respectively). The 32 Coho Salmon detected in the pond were comprised of 22 tagged in Freshwater Creek basin by AFRAMP during the fall of 2015, five tagged by NSA in Freshwater Creek Slough in the summer and fall of 2015, three tagged in Wood Creek pond in December 2015, and two tagged in Wood Creek in January 2016 (Table 21). Fourteen of the 32 Coho Salmon were detected in the pond on more than one day. These fish had an average time between first and last detection (a surrogate for residence time) of 14 days (1 to 44 days). The juvenile steelhead was detected at the pond antenna from 12/19/15 to 3/7/16 (79 days). It was originally tagged by our project in Freshwater Creek Slough on 7/8/15 so it likely reared in the SEE for at least 243 days.

From September 2015 to August 2016, the tide gate antenna detected 258 juvenile Coho Salmon, seven adult/grill Coho Salmon, four juvenile steelhead trout, six cutthroat trout, two unidentified trout species, and six Pacific lamprey. The antenna was offline for repairs on 10/10/15, for equipment upgrades on 10/20/15, and malfunctioned 11/5-15/15. The antenna first detected individual Coho Salmon on 9/12/15 and last detected them on 7/20/16. Most Coho Salmon were first detected in December 2015 (n=142) indicating a large redistribution from stream to SEE habitat occurred in the fall after the first rains. Another smaller peak in detections occurred in April (n=32) and May (n=25) 2016 corresponding with the traditional spring out-migration. Most individual fish were last detected in December and April, lending additional evidence that late fall and spring were the times of peak movement of Coho Salmon out of Freshwater Creek to the SEE.

The 258 Coho Salmon detected at the tide gate were comprised of 148 tagged in the fall by AFRAMP upstream of the SEE in Freshwater Creek basin (171 in 2015 and one in 2014), 42 tagged at the HFAC weir (37 tagged in 2016 and five tagged in 2015), 27 tagged by NSA in Freshwater Creek Slough (21 in 2015 and six in 2016), 24 tagged by AFRAMP in the SEE, 16 tagged by NSA in Wood Creek, and one fish tagged by NSA and released into Wood Creek pond (Table 22). The 148 fish tagged by AFRAMP upstream of the SEE were comprised of 106 from Freshwater Creek (42 from the

Table 21. Origin of PIT tagged juvenile Coho Salmon tagged in Freshwater Creek basin detected at Wood Creek pond antennas during January to September 2010, October 2010 to October 2011, October 2011 to July 2012, September 2012 through August 2013, and September 2013 through August 2014, September 2014 to August 2015, and September 2015 through August 2016, and Wood Creek Phase 2 antennas September 2016 to August 2017.

Fish Origin	**2010**	**10/11**	**11/12**	**12/13**	**13/14**	**14/15**	**15/16**	**16/17**
Stream Estuary Ecotone	7	1	-	1	0	1	3	6
Lower Mainstem Freshwater Cr	11	6	26	2	0	6	1	11
Middle Mainstem Freshwater Cr	-	11	16	1	1	4	8	11
Upper Mainstem Freshwater Cr	7	6	12	4	0	4	1	8
Little Freshwater Creek	12	-	-	-	-	-	-	-
Cloney Gulch	9	4	6	4	0	1	3	6
South Fork Freshwater Creek	-	0	10	2	0	1	6	6
Freshwater Creek (total)	46	28	70	14	1	17	22	48
Wood Creek Pond	74	8	199	42	5	2	3	270*
Wood Creek	27	19	20	11	11	13	2	41**
Ryan Slough/Creek	0	0	7	3	0	0	0	1
Freshwater Creek Slough	5	0	8	6	0	2	5	25
HFAC Weir	1	0	2	0	4	1	0	1
Estuary Ecotone (total)	107	27	236	62	20	18	10	338
Grand Total	153	55	306	76	21	35	32	386

*Wood Creek Phase 2 restoration sites
** Wood Creek Phase 1 restoration sites

middle mainstem, 35 from the lower mainstem, and 29 from the upper mainstem), 21 from Cloney Gulch, and 21 from South Fork Freshwater Creek (Table 22).

The antenna detected 77 of the 258 juvenile Coho Salmon on more than one day. These fish had an average time between first and last detection (a surrogate for residence time) of 41 days (1 to 180 days). Overall, the tide gate antenna detected 175 Coho Salmon that were either tagged upstream of the SEE and then detected multiple times in the SEE, or were tagged in the SEE so that we could calculate a minimum SEE residence time for these fish. Their mean residence time in the SEE was 63 days (range 1 to 322 days).

The four steelhead trout detected at the tide gate were first detected between September 2015 and June 2016. We detected two of them on only one day and one of them over a two-day period. We detected final steelhead at the tide gate between 12/15/15 and 2/6/16 (51 days). All four steelhead were tagged in the summer of 2015 by NSA, three in Freshwater Creek Slough and one in Ryan Creek. Their length of SEE

Table 22. Origin of PIT tagged juvenile Coho Salmon tagged in Freshwater Creek basin detected at Wood Creek tide gate antennas during January to September 2010, October 2010 to September 2011, October 2011 to July 2012, September 2012 through August 2013, September 2013 through August 2014, September 2014 to August 2015, September 2015 through August 2016, and September 2016 to August 2017.

Fish Origin	**2010**	**10/11**	**11/12**	**12/13**	**13/14**	**14/15**	**15/16**	**16/17**
Stream Estuary Ecotone	9	30	-	11	16	3	24	18
Lower Mainstem Freshwater Cr	11	49	75	29	32	25	35	21
Middle Mainstem Freshwater Cr	-	79	51	31	43	16	42	21
Upper Mainstem Freshwater Cr	10	59	34	26	35	19	29	26
Little Freshwater Cr	13	-	-	-	-	-	-	-
Cloney Gulch	8	45	23	33	30	13	21	26
South Fork Freshwater Cr	-	13	31	23	16	10	21	17
Freshwater Creek (total)	51	275	214	153	172	86	172	129
Wood Creek Pond	33	3	138	22	5	2	1	200*
Wood Creek	48	35	69	89	44	43	16	48**
Ryan Slough/Cr	26	5	71	95	56	3	0	6
Freshwater Creek Slough	11	10	67	86	47	19	27	80
HFAC Weir	165	123	155	221	104	109	42	4
Estuary Ecotone (total)	283	176	501	513	256	176	86	338
Grand Total	334	451	715	666	428	262	258	467

*Wood Creek Phase 2 restoration sites
** Wood Creek Phase 1 restoration sites

residence ranged from 71 to 267 days. We detected the six cutthroat trout from May 2015 to June 2016. Three were tagged in Freshwater Creek Slough, two in Ryan Creek, and one at the HFAC weir. Four were detected on only one day at the tide gate and the other two were detected over 35 and 175-day periods. The cutthroat trout were at large in the SEE 23 to 883 days. At least three of the detected cutthroat trout were likely adult fish. The two unidentified trout were detected at the tide gate in May and June. They were both tagged at the HFAC weir in April and May and were at large 26 to 36 days. The six Pacific lamprey were detected at the tide gate in April and May 2016. All six were tagged at the HFAC weir in April and May 2016 and were at large 0 to 30 days.

<u>PIT Tag Antenna Detections Wood Creek 2016/17 Season</u>

We installed a paired PIT tag antenna array in the Phase 2 restoration area and it became operational on October 20, 2016. From October 2016 to July 2017, the Phase 2 antenna detected 386 Coho Salmon, one steelhead trout, one cutthroat trout, and 10 unidentified PIT tags. The antenna was offline for repairs from 11/12-17/16. The antenna first detected individual Coho Salmon on 10/28/16 and last detected them on 7/2/17. The number of first detections peaked in November (n=146) illustrating a significant fall redistribution of juvenile Coho Salmon to the SEE. The 386 Coho Salmon detected in the Phase 2 area were comprised of 270 tagged by NSA in the Phase 2 area of Wood Creek, 48 tagged by AFRAMP in the Freshwater Creek basin, 41 tagged by NSA in other areas of Wood Creek, 25 tagged by NSA in Freshwater Creek Slough, one tagged at the HFAC weir, and one tagged by NSA in Ryan Creek (Table 21). The 48 fish tagged by AFRAMP were comprised of 30 from Freshwater Creek (11 from the middle mainstem, 11 from the lower mainstem, and eight from the upper mainstem), six from the SEE, six from Cloney Gulch, and six from South Fork Freshwater Creek (Table 21).

Of the 386 Coho Salmon detected at the Phase 2 antennas, we detected 269 on more than one day. These fish had an average time between first and last detection (a surrogate for residence time) of 28 days (1 to 184 days). We detected the juvenile steelhead at the Phase 2 antenna on 12/16/16. We originally tagged it in Freshwater Creek Slough on 4/28/15 and recaptured it on 6/24/15, so it may have migrated to the ocean or reared in the SEE for at least 565 days. We detected the juvenile cutthroat at the Phase 2 antenna from 5/16/17 to 5/26/17. We tagged it on 5/3/17 in Wood Creek so it had reared at least 23 days in Wood Creek.

From September 2016 to August 2017, the tide gate antenna detected 467 juvenile Coho Salmon, one juvenile Chinook Salmon, four juvenile steelhead trout, eight cutthroat trout, and 65 unidentified tags. The antenna was offline for repairs from 5/16-25/17. The antenna first detected individual Coho Salmon on 10/14/16 and last detected them on 7/3/17. Most Coho Salmon were first detected in November 2016 (n=166) and April 2017 (n=113), indicating a large redistribution from stream to SEE habitat occurred in the fall after the first rains, followed by the traditional spring out-migration.

The 467 Coho Salmon detected at the tide gate were comprised of 200 tagged by NSA in the Phase 2 area of Wood Creek, 111 tagged by AFRAMP upstream of the SEE in Freshwater Creek basin, 80 tagged by NSA in Freshwater Creek Slough, 48 tagged by NSA in Wood Creek, 18 tagged by AFRAMP in the SEE, six tagged by NSA in Ryan Creek, and four tagged at the HFAC weir (Table 22). The 111 fish tagged by AFRAMP upstream of the SEE were comprised of 68 from Freshwater Creek (26 from the upper mainstem, 21 from the lower mainstem, and 21 from the middle mainstem), 26 from Cloney Gulch, and 17 from South Fork Freshwater Creek (Table 22). Many of the unidentified tag codes are likely fish tagged at the HFAC weir in the spring of 2017.

Overall, the tide gate antenna detected 404 juvenile Coho Salmon that were either tagged upstream of the SEE and then detected multiple times in the SEE, or were tagged in the SEE so that we could calculate a minimum SEE residence time for these fish. Their mean residence time in the SEE was 64 days (range 1 to 340 days). We also detected a Coho Salmon that was at large 525 days that was likely a returning “jack” or potentially a juvenile that reared for two years in the SEE. We detected one sub-yearling Chinook Salmon at the tide gate antenna on 6/30/17. NSA tagged it on 6/21/17 in Freshwater Creek Slough so it had reared at least nine days in the SEE. We detected four steelhead at the tide gate antenna between 10/24/16 and 12/27/16. All four were tagged by NSA in Freshwater Creek Slough in 2015 and 2016 and were at large 75 to 635 days. We detected eight cutthroat trout at the tide gate antenna between 10/18/16 and 6/29/17. NSA originally tagged five in Freshwater Creek Slough, two in Wood Creek, and one in Ryan Creek. They had been at large 10 to 1,119 days.

RYAN CREEK SLOUGH

Ryan Creek Slough 2016 and 2017

In 2016, yearling-plus and sub-yearling Coho Salmon were the most abundant salmonids captured in Ryan Creek Slough and the adjacent wetland (Table 23). NSA captured 102 yearling-plus Coho Salmon, 100 sub-yearling Coho Salmon, and 12 cutthroat trout (Table 23). This is the first year we captured no juvenile steelhead trout in Ryan Creek since we began sampling in 2007. NSA captured yearling-plus Coho Salmon January to May and sub-yearling Coho Salmon from May to December with peak catches occurring in February and August, respectively (Table 23). We captured very small numbers of cutthroat trout from March to October with most being captured July to September (Table 23).

Table 23. Effort (number of traps) and number of juvenile salmonids captured by minnow traps in Ryan Creek Slough, 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	10	17	0	0	0	0
February	33	46	0	0	0	0
March	11	7	0	0	1	0
April	22	10	0	0	0	0
May	22	22	1	0	1	0
June	22	0	9	0	1	0
July	22	0	10	0	3	0
August	33	0	48	0	2	0
September	22	0	18	0	3	0
October	22	0	9	0	1	0
November	13	0	4	0	0	0
December	11	0	1	0	0	0
Total	**243**	**102**	**100**	**0**	**12**	**0**

Monthly mean FLs for yearling-plus Coho Salmon increased from 77 mm in January to117 mm in March, and then dropped to 105 mm in May (Table 24). Yearling-plus Coho Salmon captured in the adjacent wetland were smaller than those captured in mainstem Ryan Creek. In January and February 2016, the months we captured Coho Salmon in the wetlands, their mean FL's were 82 $\pm$ 13 mm (n=32) from the wetland and 101 $\pm$ 15 mm (n=31) from the stream. We have observed this fish size difference between the wetland and stream habitat during every year of our survey. The monthly mean FL of sub-yearling Coho Salmon increased from 61 mm in May to 98 mm in November (Table 24). There was no apparent pattern in cutthroat trout mean monthly FL's (Table 25) and their individual FL's ranged from 84 to 142 mm.

In 2017, juvenile Coho Salmon were the most abundant salmonids captured in Ryan Creek Slough and the adjacent wetland. NSA captured 37 yearling-plus Coho Salmon, 18 sub-yearling Coho Salmon, two steelhead trout, and 11 cutthroat trout (Table 26). NSA captured yearling-plus Coho Salmon January to May and sub-yearling Coho Salmon June through August with peak catches occurring in February and August, respectively (Table 26). Peak catches occurred in July for steelhead trout and cutthroat trout (Table 26).

Monthly mean FL for yearling-plus Coho Salmon increased from 94-95 mm in January and February to 116-120 mm in April and May (Table 27). Yearling-plus Coho Salmon captured in the adjacent wetland were slightly smaller than those captured in Ryan Creek. In January to March 2017, the months Coho Salmon were captured in the

Table 24. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by minnow traps in Ryan Creek Slough, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. Yoy Coho	Mean FL Yoy Coho	SD Yoy Coho	No. Yoy CH	Mean FL Yoy CH	SD Yoy CH
January	17	77	13.1	0	-	-	0	-	-
February	46	96	15.7	0	-	-	0	-	-
March	7	117	17.4	0	-	-	0	-	-
April	10	111	9.1	0	-	-	0	-	-
May	16	105	7.2	1	61	-	0	-	-
June	0	-	-	9	70	8.1	0	-	-
July	0	-	-	10	81	11.6	0	-	-
August	0	-	-	48	84	7.2	0	-	-
September	0	-	-	18	87	6.6	0	-	-
October	0	-	-	9	88	9.0	0	-	-
November	0	-	-	5	98	8.4	0	-	-
December	0	-	-	0	-		0	-	-

Table 25. Number measured, mean fork-length (FL), and standard deviation (SD) of juvenile steelhead and cutthroat trout captured by minnow traps in Ryan Creek Slough, 2016.

Month	No. Steelhead Trout	Mean FL Steelhead Trout	SD Steelhead Trout	No. Cutthroat Trout	Mean FL Cutthroat Trout	SD Cutthroat Trout
January	0	-	-	0	-	-
February	0	-	-	0	-	-
March	0	-	-	1	134	-
April	0	-	-	0	-	-
May	0	-	-	1	142	-
June	0	-	-	1	125	-
July	0	-	-	2	134	4.2
August	0	-	-	2	89	7.1
September	0	-	-	3	106	4.6
October	0	-	-	5	134	15.1
November	0	-	-	1	90	-
December	0	-	-	0	-	-

Table 26. Monthly effort (number of traps) and number of juvenile salmonids captured by minnow traps in Ryan Creek Slough, 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	24	2	0	0	1	0
February	33	16	0	0	0	0
March	22	11	0	0	2	0
April	22	4	0	0	1	0
May	22	4	0	0	0	0
June	22	0	3	0	1	0
July	22	0	4	2	5	0
August	33	0	11	0	1	0
Total	**200**	**37**	**18**	**2**	**11**	**0**

Table 27. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (yoy CH) captured by minnow traps in Ryan Creek Slough, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. yoy CH	Mean FL yoy CH	SD yoy CH
January	2	95	19.8	0	-	-	0	-	-
February	16	94	12.8	0	-	-	0	-	-
March	11	104	9.9	0	-	-	0	-	-
April	3	120	7.8	0	-	-	0	-	-
May	4	116	18.6	0	-	-	0	-	-
June	0	-	-	3	62	3.6	0	-	-
July	0	-	-	4	71	14.0	0	-	-
August	0	-	-	11	78	7.8	-	-	-

wetlands, the mean FL's of Coho Salmon was 97 $\pm$ 13 mm (n=19) from the wetland and 99 $\pm$ 14 mm (n=9) from the stream. In all previous years juvenile Coho Salmon captured in the wetlands were substantially smaller than those captured in the stream (see 2016 above; Allen et al. 2016; Wallace and Allen 2015; Wallace and Allen 2012). The monthly mean FL of sub-yearling Coho Salmon increased from 62 mm in June to 78 mm in August (Table 27). The FL's for the two captured steelhead trout were 125 and 142 mm. The monthly mean FL's for cutthroat trout ranged from 114 to 146 mm (Table 28).

Recaptured PIT Tagged Fish 2016 and 2017

In 2016, we applied PIT tags to 80 sub-yearling Coho Salmon in Ryan Creek Slough and recaptured 13 (16.3%). The recaptured sub-yearling Coho Salmon had a mean residence time of 44 days and were at-large 14 to 139 days. They grew 0 to 31 mm and their mean growth rate was 0.16 mm/day (0 to 0.36 mm/day). NSA applied PIT tags to 86 yearling-plus Coho Salmon in Ryan Creek Slough and recaptured six (7.0%). We also recaptured one yearling-plus Coho Salmon tagged our project in Freshwater Creek Slough in September 2015 and one tagged by AFRAMP in the middle mainstem of Freshwater Creek in the fall of 2015. The six recaptured yearling-plus Coho Salmon resided in Ryan Creek Slough for 26 to 57 days. They grew 6 to 27 mm while at large and their growth rates ranged from 0.23 to 0.72 mm/day (five of the six fish had growth rates >0.4 mm/day). The recaptured Coho Salmon tagged by our project in Freshwater Creek Slough was at large 237 days and grew 36 mm (0.15 mm/day).

In 2016, we applied PIT tags to nine cutthroat trout and recaptured two (22.2%). One recaptured cutthroat trout was at large 41 days and grew 6 mm (0.15 mm/day) and the

Table 28. Number measured, mean fork-length (FL), and standard deviation (SD) of juvenile steelhead and cutthroat trout captured by minnow traps in Ryan Creek Slough, 2017.

Month	No. Steelhead Trout	Mean FL Steelhead Trout	SD Steelhead Trout	No. Cutthroat Trout	Mean FL Cutthroat Trout	SD Cutthroat Trout
January	0	-	-	1	146	-
February	0	-	-	0	-	-
March	0	-	-	2	128	6.4
April	0	-	-	1	125	-
May	0	-	-	0	-	-
June	0	-	-	1	114	-
July	2	134	12.0	5	130	4.8
August	0	-	-	1	136	-

other was at large 14 days and grew three mm (0.21 mm/day). We did not apply PIT tags to any juvenile steelhead trout in Ryan Creek Slough in 2016.

In 2017, we applied PIT tags to 15 sub-yearling Coho Salmon in Ryan Creek Slough and recaptured two (13.3%). They were at large 14 and 42 days and grew 1-17 mm (0.07 and 0.41 mm/day) respectively while at large. We applied PIT tags to 29 yearling-plus Coho Salmon and recaptured three (10.3%). They were at large 26 to 44 days and grew 8 to 20 mm (0.31-0.46 mm/day) while at large. We also recaptured one yearling-plus Coho Salmon that was tagged by AFRAMP in the South Fork Freshwater Creek in October 2016. We also recaptured one cutthroat trout that was at large 25 days and grew 7 mm (0.28 mm/day).

PIT Tag Antenna Detections Ryan Creek Slough 2015/16 Season

From September 2015 to August 2016, the antenna detected 204 juvenile Coho Salmon, 18 adult/grille Coho Salmon, two juvenile steelhead trout, one adult steelhead trout, 20 cutthroat trout, and one adult Pacific lamprey. The antenna detected individual Coho Salmon from 9/14/15 to 8/4/16. The 204 juvenile Coho Salmon detected at the antenna were comprised of 115 (56.4%) tagged upstream of our sampling sites in Freshwater Creek by AFRAMP during the fall of 2015, 70 (34.3%) tagged by NSA in Ryan Creek Slough (50 in 2016 and 20 in 2015), 15 (7.4%) tagged by NSA in Freshwater Creek Slough in 2015, and four tagged by AFRAMP at the HFAC weir on Freshwater Creek Slough (three in 2016 and one in 2015) (Table 29).

The number of juvenile Coho Salmon first detections peaked in December (n=100) and corresponded with the first large rains of the wet season and fall redistribution of juvenile Coho Salmon to the SEE. Of the 204 Coho Salmon detected at the antenna, 135 were detected greater than one day after tagging or first observation in the SEE.

Table 29. Origin of PIT tagged juvenile Coho Salmon detected at Ryan Creek Slough antennas during February to August 2013, September 2013 through August 2014, September 2014 through August 2015, September 2015 through August 2016, and September 2016 to August 2017.

Fish Origin	**12/13**	**13/14**	**14/15**	**15/16**	**16/17**
Stream Estuary Ecotone	-	3	2	22	3
Lower Mainstem Freshwater Creek	6	5	14	28	8
Middle Mainstem Freshwater Creek	3	14	17	26	2
Upper Mainstem Freshwater Creek	-	9	10	20	3
Little Freshwater Creek	-	-	-	-	-
Cloney Gulch	-	2	2	7	2
South Fork Freshwater Creek	3	1	13	12	2
Freshwater Creek (total)	12	34	58	115	20
Green Diamond Resources Fall Tagging	32	42	4	-	-
Wood Creek Pond	0	0	0	0	12*
Wood Creek	1	2	4	0	3**
Ryan Slough/Creek	134	131	90	70	64
Freshwater Creek Slough	15	14	9	15	24
HFAC Weir	3	16	36	4	3
Green Diamond Resources Screw Trap	441	448	51	-	-
Estuary Ecotone (total)	594	611	190	89	106
Grand Total	638	687	252	204	126

*Wood Creek Phase 2 restoration sites
** Wood Creek Phase 1 restoration sites

These fish had an average time between first and last detection (a surrogate for residence time) of 113 days (range 1 to 295 days) in Ryan Creek and 124 days (range 1 to 356 days) in the entire SEE.

We detected cutthroat trout throughout the sampling season. Of the 20 cutthroat trout detected at the antenna, we tagged 19 of them in Ryan Creek and one in Freshwater Creek Slough. We tagged 12 of them in 2015, six in 2014, and two in 2013. The cutthroat trout were at large 121 to 988 days (mean=439 days). We do not know if they remained in Ryan Creek Slough the entire time they were at large, though it seems likely some moved upstream or downstream of the SEE while at large. We did not capture any steelhead trout in Ryan Creek this year or detect any PIT tagged steelhead from other Freshwater Creek basin locations.

We detected 18 adult/grille Coho Salmon from 12/3/15 to 2/2/16. Eight were tagged as smolts by GDRC in Ryan Creek April to June 2014, six were tagged as adults by CDFW at the HFAC weir in December 2015, two were tagged as juveniles by CDFW in the Freshwater Creek basin (one each in 2013 and 2014), and one was tagged as a juvenile by CDFW at the HFAC weir in April 2014. The individuals tagged as adults at the HFAC weir were at large 24 to 54 days and those tagged as juveniles were at large 464 to 838 days.

We detected one adult steelhead trout on 12/12/15 that was tagged by our project in Ryan Creek Slough on 8/19/13. It was at large 872 days.

We detected one adult Pacific lamprey on 3/16/16 that was tagged by CDFW at the HFAC weir on 3/15/16. During the one day it was at large it moved approximately two rkm downstream Freshwater Creek Slough to Ryan Slough and then about 1 rkm upstream Ryan Slough to our antenna location.

PIT Tag Antenna Detections Ryan Creek Slough 2016/17 Season

From September 2016 to August 2017, the antenna detected 126 juvenile Coho Salmon, four adult/grilse Coho Salmon, 14 cutthroat trout, and 20 unidentified tag codes. However, the antennas were off-line intermittently from 10/10/16 to 11/4/16, were not reading HDX platform tags from 3/17/17 to 4/16/17, and were off-line again from 4/20/17 to 4/25/17. Therefore, we did not collect data during these time periods and likely contributed to the lower number of tag detections compared to other years. Individual Coho Salmon were first detected on 9/3/16 and last detected on 7/5/17. The 126 juvenile Coho Salmon detected at the antenna were comprised of 64 (50.8%) tagged by NSA in Ryan Creek Slough, 24 (19.0%) tagged by NSA in Freshwater Creek Slough, 17 (13.5%) tagged upstream of our sampling sites in Freshwater Creek by AFRAMP during the fall of 2016, 12 (9.5%) tagged by NSA in the Phase 2 area of Wood Creek, three (2.4%) tagged by NSA in the Phase 1 area of Wood Creek, three (2.4%) tagged by AFRAMP in the SEE, and three (2.4%) tagged by AFRAMP at the HFAC weir on Freshwater Creek Slough (Table 29).

The number of first detections peaked in October and November (n= 23 and 22 respectively) and April and May (n=20 and 26 respectively) and corresponded with the Coho Salmon fall redistribution and peak Coho Salmon smolt emigration from Ryan Creek in the spring. The peak of Coho Salmon first detections in the fall corresponded with the first large rains of the wet season and fall redistribution of juvenile Coho Salmon to the SEE. Of the 126 Coho Salmon detected at the antenna, 90 were detected greater than one day at the antenna. These fish had an average time between first and last detection (a surrogate for residence time) of 141 days (range 1 to 349 days) in Ryan Creek. Based on tag detections and observations, juvenile Coho Salmon residence time in the entire SEE (Ryan-Freshwater-Wood combined) for fish detected greater than one day (n=122) was 164 days (range 4 to 353 days).

We detected two adult Coho Salmon in January 2017 that were tagged by AFRAMP upstream of the SEE in the fall of 2014. They had been at large >800 days. We detected one adult Coho Salmon in May of 2017 that was tagged by AFRAMP at the

HFAC weir in May 2015. It had been at large 713 days and the late detection date suggests the detected tag was in a carcass or loosely drifting down stream. We also detected a Coho Salmon in January 2017 tagged by AFRAMP upstream of the SEE in the fall of 2015. It had been at large 447 days and was likely a “jack” returning to Freshwater/Ryan Creek.

We detected cutthroat trout from 9/19/16 to 6/8/17. Thirteen were tagged in Ryan Creek Slough by NSA (four in 2017, five in 2016, three in 2015, and one in 2014) and one was tagged by GDRC at the Ryan Creek screw trap in April 2014. The cutthroat trout tagged by NSA were at large 24 to 1,092 days while the one tagged by GDRC at the screw trap was at large 1,451 days. Obviously, some of the cutthroat trout were adults.

Salmon Creek

Salmon Creek 2016

In 2016, we ended sampling in Salmon Creek after July to concentrate more sampling effort on Jacoby Creek off-channel ponds and pending Wood Creek Phase 2 sites. During 2016, we captured 18 yearling-plus Coho Salmon and 30 juvenile steelhead trout by seining and one juvenile steelhead by minnow trapping in the Salmon Creek and Cattail Creek complex. In Salmon Creek, we captured Coho Salmon from January to June (except for April) and their monthly CPUE ranged from 0 to 0.45 fish/set with peak catches occurring in May (Table 30). We captured steelhead trout from January to June and their monthly CPUE ranged from 0 to 1.70 fish/set (Table 30). In minnow traps, we captured one juvenile steelhead trout in February and it was 56 mm FL. Captured yearling-plus Coho Salmon increased in size from 80-81 mm in January and February to 119 mm in May (Table 31). Most of the captured steelhead trout were <100

Table 30. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Salmon Creek ponds, 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	10	0.30	0	1.70	0	0
February	14	0.29	0	0.43	0	0
March	12	0.33	0	0.25	0	0
April	12	0	0	0.08	0	0
May	11	0.45	0	0.18	0	0
June	15	0.13	0	0.07	0	0
July	7	0	0	0	0	0

Table 31. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by seine in Salmon Creek estuary, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January	3	81	2.3	0	-	-	17	68	12.1
February	4	80	1.8	0	-	-	6	60	9.6
March	4	96	7.2	0	-	-	3	80	5.5
April	0	-	-	0	-	-	1	161	-
May	5	119	13.1	0	-	-	2	129	0
June	2	106	0	0	-	-	1	144	-
July	0	-	-	0	-	-	0	-	-

mm FL. The mean FL's of all fish captured in 2016 were 98 mm (range 78 to 133) for yearling-plus Coho Salmon and 77 mm (range 47 to 161) for juvenile steelhead trout (Table 31). We did not capture any salmonids in Cattail Creek in 2016.

Recaptured PIT Tagged Fish 2016

In 2016, we applied PIT tags to 15 yearling-plus Coho Salmon and recaptured one (6.7%). Our project tagged and recaptured it in the second-most upstream pond (Pond 1). It was at-large 14 days and grew 14 mm (1.00 mm/day). We also applied PIT tags to 21 juvenile steelhead trout and did not recapture any of them.

PIT Tag Antenna Detections 2015/16 Season

Between September 2015 and August 2016, NSA detected 13 Coho Salmon and 17 steelhead trout at the antenna site. One Coho Salmon detected in December 2015 was likely an adult/grilse fish tagged by our project in May 2014 and had been at large 560 days. The antenna detected the remaining 12 juvenile Coho Salmon from 1/7/16 to 5/19/16. The antenna detected 10 of the remaining 12 Coho Salmon on more than one day. These fish had an average time between first and last detection (a surrogate for residence time) of 40 days (range 1 to 88 days) in Salmon Creek. The antenna detected steelhead trout from 1/11/16 to 5/30/16. All 17 steelhead trout were detected at the antenna on more than one day and had an average time between first and last detection (a surrogate for residence time) of 49 days (range 1 to 139 days).

JACOBY CREEK POND

Jacoby Creek and Off Channel Pond 2016 to 2017

In 2016, we sampled upper and lower Jacoby Creek ponds and mainstem Jacoby Creek at Kokte Ranch monthly with seine nets and minnow traps. Due to heavy aquatic vegetation in the lower pond, we seined only one site in the pond and used minnow traps at the remaining sites. We used seines and minnow traps throughout the upper pond, and only minnow traps in Jacoby Creek. Both ponds became dry during the summer and early fall, so we sampled only the confluence of the ponds with Jacoby Creek or did not sample the ponds at all during those months (Tables 32 and 33).

At the mainstem Jacoby Creek site, we captured one yearling-plus Coho Salmon, the same sub-yearling Coho Salmon twice, and 10 juvenile steelhead trout (Table 32). We captured the yearling-plus Coho Salmon in April and it was 92 mm FL (Table 34). We captured the sub-yearling Coho Salmon in September at 89 mm FL and the same fish again in October at 90 mm FL (Table 34). We captured steelhead trout sporadically throughout the year (Table 32) and they ranged from 91 to 146 mm FL (Table 34).

In the lower pond, we captured three yearling-plus and two sub-yearling Coho Salmon in minnow traps (Table 32), and three yearling-plus and three sub-yearling Coho Salmon by seine (Table 33). We captured all of the yearling-plus Coho Salmon by both methods January to March and all but one sub-yearling Coho Salmon in April and May (Tables 32 and 33). The monthly mean FL of yearling-plus Coho Salmon increased from January to March (Table 35) and the sub-yearling Coho Salmon we captured in November was >20 mm larger than the fish we captured in April and May (Table 35).

In the upper pond, we captured 64 yearling-plus Coho Salmon, 129 sub-yearling Coho Salmon, and five juvenile steelhead trout with minnow traps (Table 32). During seining, we captured 277 yearling-plus Coho Salmon, 1,101 sub-yearling Coho Salmon, and 24 juvenile steelhead trout. Yearling-plus Coho Salmon peak monthly CPUE of 14.2 fish/set occurred in February; sub-yearling Coho Salmon peak monthly CPUE of 121.5 fish/set occurred in November; and steelhead trout peak monthly CPUE of 1.0 fish/set occurred in February (Table 33). We recaptured many of these fish multiple times. Peak catches of yearling-plus Coho Salmon occurred January to March by both methods. The catches of sub-yearling Coho Salmon peaked twice, once in May and June and again in November and December (Tables 32 and 33). We captured most of the steelhead trout February to June (Tables 32 and 33).

Fish captured by seine nets and minnow traps were similar in size. The monthly mean FL of yearling-plus Coho Salmon increased from 78 mm in January to 106 mm in June (Table 36). The monthly mean FL of sub-yearling Coho Salmon increased about 20 mm between April and July and then by another 20 mm by November and December (Table 36). The FL’s of juvenile steelhead trout captured in upper Jacoby Creek pond in 2016 ranged from 74 to 157 mm. Their monthly mean FL ranged from 79 to 138 mm and they tended to be largest in May and June (Table 36).

Table 32. The monthly number of juvenile salmonids captured by minnow traps in Jacoby Creek and off-channel ponds and monthly percentage of yearling-plus and sub-yearling (yoy) Coho Salmon containing PIT tags, January to December 2016. Bi-weekly sampling occurred May-July in the upper pond.

Month	Yearling Coho	% PIT Tagged	YOY Coho	% PIT Tagged	Steelhead /RT	Cutthroat Trout
Jacoby Creek						
January	0	-	0	-	2	0
February	0	-	0	-	0	0
March	0	-	0	-	0	0
April	1	0	0	-	0	0
May	0	-	0	-	1	0
June	0	-	0	-	0	0
July	0	0	0	-	2	0
August	0	-	0	-	0	0
September	0	-	1	0	2	0
October	0	-	1	100	0	0
November	0	-	0	-	0	0
December	0	-	0	-	3	0
Lower Pond						
January	1	0	0	-	0	0
February	2	0	0	-	0	0
March	0	-	0	-	0	0
April	0	-	0	-	0	0
May	0	-	1	-	0	0
June	0	-	0	-	0	0
July*	0	-	0	-	0	0
August*	0	-	0	-	0	0
September	-	-	-	-	-	-
October*	0	-	0	-	0	0
November	0	-	1	0	0	0
December	0	-	0	-	0	0
Upper Pond						
January	19	0	0	-	0	0
February	25	20.0	0	-	1	0
March	19	42.1	0	-	1	0
April	1	100	2	0	0	0
May	0	-	5	0	0	0
June	0	-	11	25.0	2	0
July	0	-	4	0	0	0
August*	0	-	3	0	0	0
September*	0	-	0	-	0	0
October*	0	-	0	-	0	0
November	0	-	51	0	1	0
December	0	-	53	26.4	0	0

*We sampled only the alcove at confluence of pond and Jacoby Creek; main pond was dry.

Table 33. Monthly catch-per-unit-effort (number of fish per set) of juvenile salmonids captured by beach seine in Jacoby Creek off-channel ponds and monthly percentage of yearling-plus and sub-yearling Coho Salmon containing PIT tags, January to December 2016. Bi-weekly sampling occurred May to July in the upper pond. Note seining effort in the lower pond was much less compared to seining effort in the upper pond.

Month	Yearling Coho	% PIT Tagged	YOY Coho	% PIT Tagged	Steelhead /RT	Cutthroat Trout
Lower Pond						
January	0.5	0	0	-	0	0
February	0	-	0	-	0	0
March	0.5	0	0	-	0	0
April	0	-	1.0	0	0	0
May	0	-	1.0	0	0	0
June	-	-	-	-	-	-
July	-	-	-	-	-	-
August	-	-	-	-	-	-
September	-	-	-	-	-	-
October	-	-	-	-	-	-
November	0	-	0	-	0	0
December	0	-	0	-	0	0
Upper Pond						
January	8.0	0	0	-	0.2	0
February	14.2	12.9	0	-	1.0	0
March	11.8	21.1	0	-	0.8	0
April	7.5	37.0	7.7	0	0.7	0
May	0.9	83.3	23.5	27.8	0.2	0
June	1.1	75.0	23.4	65.9	0.3	0
July	0	-	1.6	84.6	0	0
August	0	-	0	-	0	0
September	-	-	-	-	-	-
October	-	-	-	-	-	-
November	0	-	121.5	0	0	0
December	0.3	0	64.5	12.0	0.8	0

Table 34. Number measured, mean fork-length in mm (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by minnow trap in Jacoby Creek, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January	0	-	-	0	-	-	2	141	7.8
February	0	-	-	0	-	-	0	-	-
March	0	-	-	0	-	-	0	-	-
April	1	92	-	0	-	-	0	-	-
May	0	-	-	0	-	-	1	119	-
June	0	-	-	0	-	-	0	-	-
July	0	-	-	0	-	-	2	130	17.7
August	0	-	-	0	-	-	0	-	-
September	0	-	-	1	89	-	2	102	14.8
October	0	-	-	1	90	-	0	-	-
November	0	-	-	0	-	-	0	-	-
December	0	-	-	0	-	-	3	126	14.2

Table 35. Number measured, mean fork-length in mm (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured in Jacoby Creek lower pond, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January	3	78	18.5	0	-	-	0	-	-
February	2	101	7.8	0	-	-	0	-	-
March	1	113	-	0	-	-	0	-	-
April	0	-	-	2	50	5.7	0	-	-
May	0	-	-	1	49	-	0	-	-
June	0	-	-	0	-	-	0	-	-
July	0	-	-	0	-	-	0	-	-
August	0	-	-	0	-	-	0	-	-
September	0	-	-	0	-	-	0	-	-
October	0	-	-	0	-	-	0	-	-
November	0	-	-	1	73	-	0	-	-
December	0	-	-	0	-	-	0	-	-

Table 36. Number measured, mean fork-length in mm (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by minnow trap (MT) or seine (S) in Jacoby Creek upper pond, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January									
MT	19	78	13.8	0	-	-	0	-	-
S	48	78	8.9	0	-	-	1	80	-
February									
MT	25	88	7.1	0	-	-	1	101	-
S	85	87	8.0	0	-	-	6	79	11.8
March									
MT	19	92	7.0	0	-	-	1	125	-
S	71	93	6.3	0	-	-	5	90	10.7
April									
MT	1	98	-	2	44	0.7	0	-	-
S	45	102	5.3	45	49	2.7	1	80	-
May									
MT	0	-	-	6	65	8.6	0	-	-
S	10	104	4.4	258	66	5.1	2	135	31.8
June									
MT	0	-	-	5	65	8.5	1	134	-
S	12	106	5.3	227	68	4.2	3	138	24.0
July									
MT	0	-	-	4	58	3.7	0	-	-
S	0	-	-	13	68	3.0	0	-	-
August									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	0	-	-	0	-	-
September									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	0	-	-	0	-	-
October									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	0	-	-	0	-	-
November									
MT	0	-	-	49	79	8.1	1	75	-
S	0	-	-	243	78	7.2	0	-	-
December									
MT	0	-	-	53	84	7.2	0	-	-
S	0	-	-	195	88	9.8	1	142	-

In 2017, we sampled upper and lower Jacoby Creek ponds and mainstem Jacoby Creek at Kokte Ranch monthly with seine nets and minnow traps. Due to heavy aquatic vegetation in the lower pond, we seined only one site in the pond and used minnow traps at the remaining sites. We used seines and minnow traps throughout the upper pond, and only minnow traps in Jacoby Creek. Both ponds became dry by August, after which we ceased field sampling (Tables 37 and 38).

At the Jacoby Creek site, we captured one sub-yearling Coho Salmon and one juvenile steelhead trout in July (Table 37). The sub-yearling Coho Salmon was 78 mm FL and the steelhead trout was 133 mm FL (Table 39).

In the lower pond, we captured three yearling-plus Coho Salmon, four sub-yearling Coho Salmon, and two juvenile steelhead trout in minnow traps (Table 37) and none by seine (Table 38). We captured all of the yearling-plus Coho Salmon January to April, all of the sub-yearling Coho Salmon in April and May, and the steelhead in March and April (Tables 37 and 38). The monthly mean FL of yearling-plus Coho Salmon and juvenile steelhead trout increased from January to April and April to May, respectively (Table 40). The mean FL of sub-yearling Coho Salmon was 55 mm in May (Table 40).

In the upper pond, we captured 23 yearling-plus Coho Salmon, 74 sub-yearling Coho Salmon, and three juvenile steelhead trout with minnow traps (Table 37), and 225 yearling-plus Coho Salmon, 744 sub-yearling Coho Salmon, and 27 juvenile steelhead trout by seine (Table 38). We recaptured many of these fish multiple times. Peak catches by both methods occurred February to April for yearling-plus Coho Salmon and juvenile steelhead trout and May to July for sub-yearling Coho Salmon (Tables 37 and 38). Fish captured by seine nets and minnow traps were similar in size (Table 41). The monthly mean FL of seine caught yearling-plus Coho Salmon increased from 89 mm in January to 112 mm in April (Table 41). The monthly mean FL of sub-yearling Coho Salmon increased 23 mm between April and July (Table 41). Steelhead monthly mean FL ranged from 75 mm in February to 125 mm in April with individual fish in the 140 to 150 mm range in June and July (Table 41).

<u>Recaptured PIT Tagged Fish 2016 and 2017</u>

We applied PIT tags to 265 yearling-plus and 693 sub-yearling Coho Salmon in 2016 and all but two yearling-plus and six sub-yearling Coho Salmon were tagged in upper Jacoby Creek pond. In 2016, we observed two distinct pulses of sub-yearling Coho Salmon in the upper pond (Table 33), so we tagged one group in May and June and the second group in November and December. We captured and tagged all the yearling-plus Coho Salmon January to June. We recaptured 59 (22.4%) yearling-plus Coho Salmon, all in the upper pond, and their mean residence time in the upper pond was 41 days (range 13-132 days). They grew 0 to 42 mm while at large and their mean growth rate was 0.30 mm/day (range 0 to 0.53 mm/day). We tagged 185 sub-yearling Coho Salmon in May and June and recaptured 140 (75.7%) of them; however, we did not capture any of the May/June tagged fish after July when the upper pond became dewatered. We tagged 507 sub-yearling Coho Salmon in November and December

Table 37. The monthly number of juvenile salmonids captured by minnow traps in Jacoby Creek and off-channel ponds and monthly percentage of yearling-plus and sub-yearling (yoy) Coho Salmon containing PIT tags, January to December 2017. Bi-weekly sampling occurred May-July in the upper pond.

Month	Yearling Coho	% PIT Tagged	YOY Coho	% PIT Tagged	Steelhead /RT	Cutthroat Trout
Jacoby Creek						
January	-	-	-	-	-	-
February	0	-	0	-	0	0
March	0	-	0	-	0	0
April	0	-	0	-	0	0
May	0	-	0	-	0	0
June	0	-	0	-	0	0
July	0	-	1	0	1	0
August	0	-	0	-	0	0
Lower Pond						
January	1	0	0	-	0	0
February	0	-	0	-	0	0
March	0	-	0	-	1	0
April	2	0	0	-	1	0
May	0	-	4	0	0	0
June	0	-	0	-	0	0
July*	0	-	0	-	0	0
August*	0	-	0	-	0	0
Upper Pond						
January	0	0	0	-	0	0
February	12	25.0	0	-	0	0
March	6	66.6	0	-	2	0
April	5	25.0	0	-	1	0
May	0	-	29	0	0	0
June	0	-	33	18.2	0	0
July	0	-	12	16.7	0	0
August	0	-	0	-	0	0

*We sampled only the alcove at confluence of pond and Jacoby Creek; main pond was dry.

Table 38. Monthly number of juvenile salmonids captured by beach seine in Jacoby Creek off-channel ponds and monthly percentage of yearling-plus and sub-yearling Coho Salmon containing PIT tags, January to December 2017. Bi-weekly sampling occurred in May- July in the upper pond. Note seining effort was much less in the lower pond compared to the upper pond.

Month	Yearling Coho	% PIT Tagged	YOY Coho	% PIT Tagged	Steelhead /RT	Cutthroat Trout
<u>Lower Pond</u>						
January	0	-	0	-	0	0
February	0	-	0	-	0	0
March	0	-	0	-	0	0
April	0	-	0	-	0	0
May	0	-	0	-	0	0
June	-	-	-	-	-	-
July	-	-	-	-	-	-
August	-	-	-	-	-	-
<u>Upper Pond</u>						
January	10	10.0	0	-	0	0
February	105	11.4	0	-	12	0
March	82	37.8	0	-	7	0
April	27	25.9	4	0	6	0
May	1	0	298	0	0	0
June	0	-	229	13.7	1	0
July	0	-	217	15.3	1	0
August	0	-	0	-	0	0

Table 39. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by minnow trap in mainstem Jacoby Creek, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January	0	-	-	0	-	-	0	-	-
February	0	-	-	0	-	-	0	-	-
March	0	-	-	0	-	-	0	-	-
April	0	-	-	0	-	-	0	-	-
May	0	-	-	0	-	-	0	-	-
June	0	-	-	0	-	-	0	-	-
July	0	-	-	1	78	-	1	133	-
August	0	-	-	0	-	-	0	-	-

Table 40. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured in Jacoby Creek lower pond by minnow trap, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January	1	94	-	0	-	-	0	-	-
February	0	-	-	0	-	-	0	-	-
March	0	-	-	0	-	-	1	98	-
April	2	111	12.0	0	-	-	1	116	-
May	0	-	-	4	55	9.8	0	-	-
June	0	-	-	0	-	-	0	-	-
July	0	-	-	0	-	-	0	-	-
August	0	-	-	0	-	-	0	-	-

2016 (293 in November) and recaptured 45 of the November tagged fish in December (15.4% of November tagged fish) and we continued to recapture fish tagged in November/December in 2017. The mean residence time in the upper pond for May/June tagged fish was 31 days (range 13-59 days). They grew -1 to 10 mm while at large and their mean growth rate was 0.07 mm/day (range -0.08 to 0.47 mm/day; n=118). The upper pond residence time of all recaptured fish tagged in November/December was 28 days (n=45). They grew 0 to 11 mm while at large and their mean growth rate was 0.12 mm/day (range 0 to 0.39 mm/day; n=33). We also recaptured one sub-yearling Coho Salmon in the mainstem Jacoby Creek at Kokte Ranch on October 6. We originally tagged it at the same location 28 days earlier (September 8) and while at large, it grew one mm (0.04 mm/day).

We applied PIT tags to 19 steelhead trout and recaptured three (15.8%) in the upper pond and tagged eight steelhead trout and recaptured one (12.5%) in mainstem Jacoby Creek at Kokte Ranch. Their residence time ranged from 13 to 30 days in the upper pond and was 62 days in Jacoby Creek. They grew 10 to 13 mm (0.39 to 0.43 mm/day) while at large in the pond during February to April but the one in Jacoby Creek decreased two mm (-0.03 mm/day) while at large May to July.

We applied PIT tags to 188 yearling-plus Coho Salmon in 2017 and we tagged all but three in upper Jacoby Creek pond. We captured and tagged most of the yearling-plus Coho Salmon January to April (Tables 40 and 41). We recaptured 32 of the 188 (17.0%) yearling-plus Coho Salmon tagged in 2017 and their mean residence time in the upper pond was 33 days (range 27-91 days). They grew 5 to 40 mm while at large and their mean growth rate was 0.37 mm/day (range 0.15-0.73 mm/day). We also captured 18 yearling-plus Coho Salmon tagged by our project in November and December 2016. Their mean residence time was 107 days (range 70-155 days). They grew 6 to 45 mm while at large and their mean growth rate was 0.22 mm/day (range

Table 41. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling-plus Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by minnow trap (MT) or seine (S) in Jacoby Creek upper pond, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January									
MT	0	-	-	0	-	-	0	-	-
S	10	89	6.7	0	-	-	0	-	-
February									
MT	12	90	3.6	0	-	-	0	-	-
S	104	93	8.2	0	-	-	12	75	9.9
March									
MT	6	102	2.8	0	-	-	2	104	4.2
S	82	99	7.8	0	-	-	7	103	32.9
April									
MT	4	105	8.2	0	-	-	2	113	7.8
S	27	112	8.0	4	45	2.2	6	125	29.1
May									
MT	0	-	-	28	59	7.4	0	-	-
S	1	107	-	189	60	7.1	0	-	-
June									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	173	67	7.4	1	148	-
July									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	120	68	6.8	1	144	-
August									
MT	0	-	-	0	-	-	0	-	-
S	0	-	-	0	-	-	0	-	-

0.09-0.29 mm/day). All told, we recaptured 50 yearling-plus Coho Salmon tagged during the 2016/17 SEE over-winter rearing season and they had a mean residence time of 60 days (range 27-155 days), grew 5 to 45 mm while at large, and their mean growth rate was 0.32 mm/day (range 0.09-0.73 mm/day).

We tagged 76 sub-yearling Coho Salmon in 2017, all but two in upper Jacoby Creek pond. In 2017, we captured large numbers of sub-yearling Coho Salmon in the upper pond May to July (Table 41), and ceased sampling prior to the anticipated fall redistribution of Coho Salmon in November/December. We tagged 76 sub-yearling Coho Salmon on May 17 and recaptured 36 (47.3%) of them during the remainder of the sampling season. We applied tags only once because based on 2016 data we anticipated that the sub-yearling Coho Salmon would become trapped in the pond and perish during the summer so we did not want to "waste" additional tags. However, we felt it was important to have a marked group to estimate their residence time and growth in the pond and to track them in case some left the pond before they were trapped (we found no pond marked sub-yearling Coho Salmon in Jacoby Creek in 2016 or 2017). We did not capture any of the May tagged fish after July when the upper pond became dewatered. We recaptured PIT tagged sub-yearling fish during subsequent sampling on 6/14/17 and 7/11/17 and their mean residence time in the upper pond was 45 days (range 28-55 days). They grew 5 to 13 mm while at large and their mean growth rate was 0.22 mm/day (range 0.09 to 0.32 mm/day; n=21). Their growth rates appear to slow substantially between June and July when they ranged from 0.04 to 0.15 mm/day (n=4).

We applied a total of 32 PIT tags to steelhead trout in the sampling area, 29 in the upper pond, two in the lower pond, and one in Jacoby Creek. We did not recapture any of them.

<u>Jacoby Creek and Off Channel Pond Water Quality 2016 and 2017</u>

In 2016, mainstem Jacoby Creek provided good water quality conditions for juvenile salmonids the entire year while the off channel ponds provided good water quality on only a seasonal basis and were essentially dry from August to October. Jacoby Creek had dissolved oxygen (DO) levels $\geq$7 mg/l in all months but August to October when they ranged from 5.68 to 6.70 mg/l (Table 42). DO in the upper pond was >7 mg/l January to May and November and December while in the lower pond it was > 6 mg/l only January to March (Table 42). Water temperatures in Jacoby Creek were good for juvenile salmonids and ranged from 9.0 to 14.7°C. Water temperatures in both ponds were higher than in Jacoby Creek in all months they were sampled (Table 42).

In 2017, we were unable to sample mainstem Jacoby Creek in January due to high flows and ceased field sampling after August. Mainstem Jacoby Creek provided good water quality conditions for juvenile salmonids the entire year while the off channel ponds provided good water quality on only a seasonal basis and began to dry by August (Table 43). Jacoby Creek had dissolved oxygen (DO) levels $\geq$7 mg/l in all months but April and August when they were 5.98 to 6.82 mg/l, respectively (Table 43). DO in the upper pond was >7 mg/l January to May and >5 mg/l June to August while in the lower pond it was > 5 mg/l only in January (Table 43). Water temperatures in mainstem Jacoby Creek were good for juvenile salmonids and ranged from 9.2 to 15.2°C. Water temperatures in both ponds were higher than in Jacoby Creek in all months they were sampled (Table 43).

Table 42. Water quality measurements collected at the surface in Jacoby Creek and at the surface of the downstream end of lower and upper Jacoby Creek ponds, 2016.

Water Quality Date	Water Quality Site	Time	Water Temperature (° C)	Conductivity (uS/cm)	Dissolved Oxygen (mg/l)
January 12	Jacoby Creek	1015	10.0	101.2	8.87
	Jacoby Low Pond	1135	11.8	114.4	8.47
	Jacoby Up Pond	1050	11.1	92.2	9.14
February 11	Jacoby Creek	0905	10.2	110.5	9.46
	Jacoby Low Pond	1020	12.2	131.9	8.52
	Jacoby Up Pond	0930	10.8	97.3	7.90
March 8&9	Jacoby Creek	1025	10.3	90.8	9.10
	Jacoby Low Pond	1055	11.5	105.3	6.06
	Jacoby Up Pond	0940	9.7	80.3	8.14
April 5&7	Jacoby Creek	0920	9.4	110.1	9.85
	Jacoby Low Pond	1035	13.7	122.4	3.87
	Jacoby Up Pond	0925	14.6	112.6	7.06
May 6&9	Jacoby Creek	0915	11.4	121.3	8.70
	Jacoby Low Pond	0945	14.1	111.6	2.62
	Jacoby Up Pond	0905	15.3	143.6	7.21
June 7&9	Jacoby Creek	1030	12.9	146.2	8.97
	Jacoby Low Pond	1110	16.4	119.5	2.10
	Jacoby Up Pond	0945	18.5	200.7	5.32
July 7	Jacoby Creek	1120	14.6	-	7.00
	Jacoby Low Pond	1145	15.8	-	1.44
	Jacoby Up Pond	0955	19.3	-	5.40
August 3	Jacoby Creek	0925	14.3	185.5	6.70
	Jacoby Low Pond	Dry	-	-	-
	Jacoby Up Pond	1050	15.4	316.3	8.14
September 8	Jacoby Creek	1055	14.7	201.4	5.68
	Jacoby Low Pond	Dry	-	-	-
	Jacoby Up Pond	Dry	-	-	-
October 6	Jacoby Creek	1300	13.3	194.5	6.56
	Jacoby Low Pond	Dry	-	-	-
	Jacoby Up Pond	Dry	-	-	-
November 9&15	Jacoby Creek	0910	12.3	145.5	8.75
	Jacoby Low Pond	0930	14.2	145.3	0.90
	Jacoby Up Pond	0950	13.1	111.1	7.98
December 7&8	Jacoby Creek	1045	9.0	93.0	10.37
	Jacoby Low Pond	1105	7.5	102.9	3.10
	Jacoby Up Pond	0905	7.0	91.0	8.63

Table 43. Water quality measurements collected at the surface in Jacoby Creek and at the surface of the downstream end of lower and upper Jacoby Creek ponds, 2017.

Water Quality Date	Water Quality Site	Time	Water Temperature (° C)	Conductivity (uS/cm)	Dissolved Oxygen (mg/l)
-	Jacoby Creek	-	-	-	
January 11	Jacoby Low Pond	1000	9.5	62.5	5.52
January 12	Jacoby Up Pond	0955	8.4	71.1	9.16
February 17	Jacoby Creek	0900	9.2	67.1	10.30
February 17	Jacoby Low Pond	1015	9.8	102.9	2.04
February 15	Jacoby Up Pond	0930	10.9	83.8	8.45
March 13	Jacoby Creek	0920	9.2	89.0	9.74
March 13	Jacoby Low Pond	0940	12.3	118.3	3.86
March 14	Jacoby Up Pond	0935	11.1	85.0	8.12
April 12	Jacoby Creek	1105	10.3	92.7	5.98
April 12	Jacoby Low Pond	0945	12.9	109.3	3.32
April 13	Jacoby Up Pond	0925	10.6	84.2	8.14
May 18	Jacoby Creek	1015	9.7	91.1	10.64
May 18	Jacoby Low Pond	1040	11.6	80.0	3.06
May 17	Jacoby Up Pond	0940	11.9	94.6	7.11
June 15	Jacoby Creek	0950	12.0	133.0	9.18
June 15	Jacoby Low Pond	1025	13.4	88.2	1.99
June 14	Jacoby Up Pond	1010	17.3	150.0	6.30
July 12	Jacoby Creek	0950	13.6	155.6	7.91
July 12	Jacoby Low Pond	1020	14.2	102.6	0.37
July 11	Jacoby Up Pond	0935	19.4	174.9	5.83
August 9	Jacoby Creek	1105	15.2	176.1	6.82
August 9	Jacoby Low Pond	Dry	-	-	-
August 9	Jacoby Up Pond	0945	17.7	202.7	5.24

MARTIN SLOUGH

In 2016, we captured we captured 263 yearling-plus Coho Salmon, 64 sub-yearling Coho Salmon, two juvenile steelhead trout, and 14 cutthroat trout by seine in Martin Slough. We captured an additional 18 yearling-plus and 72 sub-yearling Coho Salmon in minnow traps. About half (n=242) of the Coho Salmon and all of the steelhead and cutthroat trout were captured by seining the 17th hole pond. We captured yearling-plus Coho Salmon January to July and again in December and their peak monthly catch of 27.70 fish/set occurred in April (Table 44). Their monthly mean FL's by seine increased

Table 44. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Martin Slough, 2016.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	5	2.60	0	0	0	0
February	5	19.60	0	0	0.40	0
March	5	1.40	0	0	0	0
April	3	27.70	0	0	0	0
May	5	10.40	0	0	0.20	0
June	5	1.40	0	0	0.60	0
July	5	0.40	0.20	0.20	0.60	0
August	5	0	0	0	1.00	0
September*	3	0	0	0	0	0
October*	3	0	0	0	0	0
November	5	0	1.40	0	0	0
December	5	0.20	11.20	0.20	0	0

*Pond not sampled

from 90 mm in January to 139 mm in June (Table 45) and their individual FL's ranged from 71 to 155 mm. Seine caught Coho Salmon were larger than those captured in minnow traps (Table 45). The juvenile Coho Salmon in Martin Slough were larger than the ones we captured in other Humboldt Bay tributaries. In addition, the yearling-plus Coho Salmon we seined from the pond were larger (118 $\pm$ 14.7 mm; n=190) than those seined from other locations of Martin Slough (104 $\pm$ 15.2; n=73). We captured sub-yearling Coho Salmon in July, November, and December and their peak catch of 11.20 fish/set occurred in December (Table 44). Their FL's ranged from 64 to 119 mm and their monthly mean FL increased 15 to 20 mm from November to December by both capture methods (Table 45). We captured juvenile steelhead trout in July and December (Table 44) and their FL's were 131 and 202 mm (Table 45). We captured cutthroat trout in February and then May to August (Table 44) and their FL's ranged from 177 to 290 mm.

In 2017, we captured we captured 394 yearling-plus Coho Salmon, 27 sub-yearling Coho Salmon, three sub-yearling Chinook Salmon, and 11 cutthroat trout by seine in Martin Slough. We captured an additional 24 yearling-plus Coho Salmon in minnow traps. About a third (n=151) of the Coho Salmon and most of the cutthroat trout were captured by seining the 17th hole pond. We captured yearling-plus Coho Salmon by seine from January to July and their peak monthly catch of 40.67 fish/set occurred in April (Table 46). Their monthly mean FL's by seine increased from 92 mm in January to 141 mm in June (Table 47) and their individual FL's ranged from 81 to 168 mm. Seine

Table 45. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and steelhead trout (SH) captured by seine (S) and minnow trap (MT) in Martin Slough, 2016.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. SH Trout	Mean FL SH Trout	SD SH Trout
January									
S	13	90	12.1	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
February									
S	98	103	13.5	0	-	-	0	-	-
MT	15	90	9.6	0	-	-	0	-	-
March									
S	7	111	4.9	0	-	-	0	-	-
MT	3	104	8.4	0	-	-	0	-	-
April									
S	83	120	9.4	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
May									
S	52	127	8.7	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
June									
S	7	139	5.5	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
July									
S	2	132	33.2	1	74	-	1	131	-
MT	0	-	-	0	-	-	0	-	-
August									
S	0	-	-	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
September	0	-	-	0	-	-	0	-	-
October	0	-	-	0	-	-	0	-	-
November									
S	0	-	-	7	70	4.7	0	-	-
MT	0	-	-	7	62	6.3	0	-	-
December									
S	1	130	-	56	89	12.9	1	202	-
MT	0	-	-	65	77	8.6	0	-	-

Table 46. Monthly effort (number of seine hauls) and catch-per-unit-effort (CPUE; number of fish per seine haul) of juvenile salmonids captured by seine nets in Martin Slough, 2017.

Month	Effort	Yearling Coho Salmon	Sub-yearling Coho Salmon	Steelhead Trout	Cutthroat Trout	Sub-yearling Chinook Salmon
January	5	1.40	0	0	0	0
February	5	18.00	0	0	0	0
March	5	21.00	0	0	0	0
April	3	40.67	0	0	0.33	0
May	5	12.00	0	0	0.20	0.60
June	5	1.60	0.60	0	1.20	0
July	5	0.40	2.40	0	0.40	0
August	5	0	2.40	0	0.20	0

caught Coho Salmon were larger than those captured in minnow traps (Table 47). The juvenile Coho Salmon in Martin Slough were larger than the ones we captured in other Humboldt Bay tributaries. We captured sub-yearling Coho Salmon in June to August and their peak catch of 2.40 fish/set occurred in July and August (Table 44). Their FL's ranged from 57 to 114 mm and their monthly mean FL increased from 59 mm in June to 92 mm in August (Table 47). We captured sub-yearling Chinook Salmon in May (Table 46), all adjacent to the tide gate, and their FL's ranged from 54 to 73 mm. We captured cutthroat trout April to August (Table 44) and their FL's ranged from 167 to 315 mm.

<u>Recaptured PIT Tagged Fish 2016</u>

In 2016, we applied PIT tags to 272 yearling-plus Coho Salmon and recaptured eight (2.9%). We also recaptured one fish that our project tagged in December 2015. They were at-large 23 to 86 days and grew 8-39 mm (0.29-0.77 mm/day). We tagged 133 sub-yearling Coho Salmon (118 in December) and did not recapture any of them. We did recapture some in 2017 (see below). We also tagged one juvenile steelhead trout in July and recaptured it 145 days later (12/6/16). We tagged and recaptured it in the 17^{th} hole pond and while at large it grew 71 mm (0.49 mm/day). We tagged 11 cutthroat trout and recaptured three (27.3%). We tagged and recaptured all of them in the 17^{th} hole pond, and they were at large 28 to 30 days and grew 17 to 21 mm (0.61-0.70 mm/day).

In 2017, we applied PIT tags to 363 yearling-plus Coho Salmon and recaptured 18 (5.0%). We also recaptured 23 yearling-plus Coho Salmon we marked in Martin Slough in November and December 2016. The 18 fish tagged and recaptured in 2017 were at large an average of 51 days (range 17-87 days). They grew 7-35 mm while at large for a mean growth rate of 0.36 mm/day (range 0.16 to 0.53 mm/day). The yearling plus

Table 47. Number measured, mean fork-length (FL), and standard deviation (SD) of yearling Coho Salmon (1+ Coho), sub-yearling Coho Salmon (yoy Coho), and sub-yearling Chinook Salmon (CH) captured by seine (S) and minnow trap (MT) in Martin Slough, 2017.

Month	No. 1+ Coho	Mean FL 1+ Coho	SD 1+ Coho	No. yoy Coho	Mean FL yoy Coho	SD yoy Coho	No. CH Trout	Mean FL CH Trout	SD CH Trout
January									
S	7	92	11.0	0	-	-	0	-	-
MT	0	-	-	0	-	-	0	-	-
February									
S	90	106	8.6	0	-	-	0	-	-
MT	16	102	5.7	0	-	-	0	-	-
March									
S	104	114	9.3	0	-	-	0	-	-
MT	4	112	4.2	0	-	-	0	-	-
April									
S	122	128	9.4	0	-	-	0	-	-
MT	3	114	3.5	0	-	-	0	-	-
May									
S	60	135	9.8	0	-	-	3	63	9.5
MT	0	-	-	0	-	-	0	-	-
June									
S	8	141	8.4	3	59	1.7	0	-	-
MT	0	-	-	0	-	-	0	-	-
July									
S	2	139	4.2	12	75	9.9	0	-	-
MT	0	-	-	0	-	-	0	-	-
August									
S	0	-	-	12	92	16.0	0	-	-
MT	0	-	-	0	-	-	0	-	-

Coho Salmon we tagged in 2016 and recaptured in 2017 were at large an average of 84 days (range 69-118 days). They grew 14-47 mm while at large for a mean growth rate of 0.35 mm/day (range 0.20 to 0.47 mm/day). The 41 yearling-plus Coho Salmon we recaptured during the 2016/17 sampling season in Martin Slough had a mean residency time of 70 days (range 17-118 days). They grew 7-47 mm while at large for a mean growth rate of 0.35 mm/day (range 0.16-0.53 mm/day). We PIT tagged 19 sub-yearling Coho Salmon in 2017 and recaptured five (29.4%). All the recaptured fish were tagged and recaptured at the Fairway Drive site on July 3 and August 3, respectively. They were at large 31 days and grew 3-7 mm (0.10-0.23 mm/day). We PIT tagged two sub-yearling Chinook Salmon and nine cutthroat trout in 2017 and did not recapture any of them. We did recapture two cutthroat trout tagged by our project in Martin Slough in

June and July of 2016. They were at large 263 and 359 days and one grew 68 mm while at large for a growth rate of 0.19 mm/day.

WOOD CREEK AND SALMON CREEK OFF CHANNEL POND WATER QUALITY 2013 TO 2016

We found similar water quality patterns in the off-channel ponds on Wood Creek (Table 48) and Salmon Creek (Table 49) in that water temperature, salinity, and dissolved oxygen (DO) varied with season. During 2013 to 2016, annual summer water temperatures ranged from 25 to 33°C in Wood Creek pond (Table 48) and 20 to 26°C in Salmon Creek ponds (Table 49). Winter water temperatures in the ponds were much cooler, ranging from 11 to 18°C in Wood Creek pond (Table 48) during March (usually 6-10°C December to February) and 7 to 14°C in Salmon Creek ponds during February (Table 49). Water salinity levels also varied seasonally in the ponds with mostly freshwater conditions occurring during the winter and early spring during high stream flows and then becoming more brackish during the summer and early fall during low stream flows. During the summer, the off-channel ponds had water salinities ranging from 11 to 26 ppt in Wood Creek (Table 48) and 31-37 ppt in Salmon Creek (Table 49). DO varied seasonally but also with depth in the off-channel ponds. In Wood Creek pond during March, surface and mid-level DO ranged from 6 to 11 mg/l while near the bottom of the pond it ranged from 0 to 5 mg/l (Table 48). In the Salmon Creek ponds during February, surface and mid-level DO ranged from 6 to 10 mg/l while near the bottom it ranged from 1 to 9 mg/l (Table 49). DO during the summer months was highly variable in both Wood and Salmon Creek ponds. DO ranged from 12 to 23 mg/l at the surface and mid-level and 2 to 17 mg/l near the bottom of Wood Creek pond (Table 48) and 4 to 17 mg/l near the surface and 3 to 14 mg/l near the bottom of the Salmon Creek ponds (Table 49). Generally, the ponds provided adequate rearing conditions for juvenile salmonids in the winter and early spring but were not suitable for them in the summer and early fall.

Meromixis, the warming and depletion of oxygen in the brackish layer of the water column, is often seen in lagoons along the California coast (Zedonis et al. 2007; Atkinson 2010). It also occurred in the off-channel ponds of Wood and Salmon creeks during the summer and fall and during low stream flow periods in the winter and spring. Saltwater is more dense than freshwater and will settle to the bottom of unmixed stream channels and ponds. Saltwater enters the ponds during high tide and becomes trapped in pools after the tide drops. With the lack of water circulation, the salt water begins to warm from solar radiation and the DO drops within the lens of salt water creating conditions too warm, salty, and un-oxygenated for juvenile salmonids.

Past studies in the SEE of Humboldt Bay found that juvenile coho salmon preferred freshwater habitat with water temperatures ≤17°C (Wallace 2006; Wallace and Allen 2007, 2009, 2012). Bjornn and Reiser (1991) reported that preferred water temperatures were 12-14°C for Chinook and Coho Salmon and 10-13°C for steelhead trout and that conditions become life threatening when temperatures exceeded 23-25°C. They also reported that salmonids function without impairment at DO levels near 8mg/l and were probably limited by levels <5mg/l. In the SEE of Humboldt Bay, juvenile

Table 48. Annual typical differences in water temperature in degrees Celsius (°C) , salinity in parts per thousand (ppt), and dissolved oxygen in milligrams per liter (mg/l) in Wood Creek pond at winter (March) and summer (July/August) stream flows, 2013-2017.

Date and Water Quality Site	Depth (feet)	Water Temperature (° C)	Salinity (ppt)	Dissolved Oxygen (mg/l)
March 4, 2013				
surface	0.5	11.0	0.8	10.94
middle	1.5	13.7	2.6	6.14
bottom	3.0	13.1	3.2	0.07
August 1, 2013				
surface	0.5	24.9	15.4	18.00
middle	1.5	28.0	22.3	15.14
bottom	3.0	27.5	24.4	2.20
March 27, 2014				
surface	0.5	11.6	0.3	7.38
middle	1.5	12.5	1.5	11.32
bottom	3.0	18.1	9.5	4.69
July 31, 2014				
surface	0.5	30.1	15.9	14.01
middle	1.3	31.1	22.6	15.45
bottom	2.5	29.3	24.9	9.46
March 19, 2015				
surface	0.5	15.7	2.1	9.11
middle	2.0	16.0	6.1	8.49
bottom	4.0	15.7	7.3	4.99
July 24, 2015				
surface	0.5	26.6	12.7	15.55
middle	1.8	33.0	22.3	23.25
bottom	3.5	32.4	25.5	16.64
March 7, 2016				
surface	0.5	11.9	0.2	6.64
middle	2.0	11.4	0.2	6.60
bottom	4.0	16.0	9.8	5.08
July 26, 2016				
surface	0.5	25.1	10.7	12.20
middle	2.3	27.2	17.9	12.68
bottom	4.5	28.8	18.3	15.18
Wood Creek 2017 Pond isolated, not comparable to past years				

Table 49. Annual typical differences in water temperature in degrees Celsius (°C) , salinity in parts per thousand (ppt), and dissolved oxygen in milligrams per liter (mg/l) in Salmon Creek at winter (February) and summer (July) stream flows, 2013-2017.

Date and Water Quality Site	Depth (feet)	Water Temperature (° C)	Salinity (ppt)	Dissolved Oxygen (mg/l)
February 20, 2013				
Pond 0 (time 1140 hrs)				
West Transect				
surface	0.5	8.3	0.3	9.04
bottom	2.0	10.7	1.1	8.60
Pond 1 (time 1045 hrs)				
West Transect				
surface	0.5	6.6	0.3	7.97
middle	2.0	6.5	0.4	7.98
bottom	4.0	10.8	15.9	5.71
Pond 2 (time 1030 hrs)				
West Transect				
surface	0.5	6.9	0.3	7.75
middle	1.5	6.9	0.3	8.28
bottom	3.0	6.8	0.3	8.63
July 24, 2013				
Pond 0 (time 1315 hrs)				
West Transect				
surface	0.5	24.1	23.2	7.01
middle	-	-	-	-
bottom	2.0	22.3	24.6	9.84
Pond 1 (time 1150 hrs)				
West Transect				
surface	0.5	20.0	29.3	6.92
middle	-	-	-	-
bottom	2.0	20.2	31.1	5.26
Pond 2 (time 1130 hrs)				
West Transect				
surface	0.5	20.0	27.9	17.14
middle	-	-		-
bottom	1.5	21.1	30.8	13.36
February 12, 2014				
Pond 0 (time 1015 hrs)				
West Transect				
surface	0.5	10.2	0.8	9.11
middle	1.5	10.6	1.5	8.09
bottom	3.0	11.9	27.1	1.10
Pond 1 (time 1130 hrs)				
West Transect				
surface	0.5	10.9	2.2	9.39
middle	2.3	11.7	20.7	5.65
bottom	4.5	11.7	24.7	4.54
Pond 2 (time 0920 hrs)				
West Transect				
surface	0.5	10.1	1.7	9.57
middle	1.5	10.3	3.7	7.99
bottom	3.0	11.5	18.0	5.74

July 23, 2014				
Pond 0 (time 1000 hrs)				
West Transect				
surface	0.5	21.1	35.4	3.56
middle	-	-	-	-
bottom	2.0	21.1	35.6	3.68
Pond 1 (time 1200 hrs)				
West Transect				
surface	0.5	21.2	36.5	4.22
middle	2.0	21.1	36.6	4.27
bottom	4.0	20.9	37.1	5.58
Pond 2 (time 1100 hrs)				
West Transect				
surface	0.5	20.9	36.6	3.99
middle	1.5	20.7	36.9	4.71
bottom	3.0	20.7	37.0	5.71
February 19, 2015				
Pond 0 (time 1005 hrs)				
West Transect				
surface	0.5	12.1	1.1	9.23
middle	-	-	-	-
bottom	2.0	13.9	3.7	7.43
Pond 1 (time 1050 hrs)				
West Transect				
surface	0.5	11.5	0.2	9.27
middle	1.5	11.4	0.3	9.10
bottom	3.0	11.5	0.4	7.71
Pond 2 (time 1130 hrs)				
West Transect				
surface	0.5	11.6	0.2	9.77
middle	-	-	-	-
bottom	2.5	11.5	0.3	8.88
July 29, 2015				
Pond 0 (time 0930 hrs)				
West Transect				
surface	0.5	24.9	31.2	4.98
middle	-	-	-	-
bottom	1.5	25.5	34.9	13.55
Pond 1 (time 1045 hrs)				
West Transect				
surface	0.5	22.2	35.6	4.97
middle	1.5	22.4	35.4	7.92
bottom	3.0	22.0	36.6	4.62
Pond 2 (time 0950 hrs)				
West Transect				
surface	0.5	21.4	35.7	3.77
middle	-	-	-	-
bottom	1.5	21.7	36.1	6.04
February 18, 2016				
Pond 0 (time 0945 hrs)				
West Transect				
surface	0.5	10.1	0.2	8.21
middle	1.5	10.6	0.3	8.17
bottom	3.0	12.8	1.0	8.66
Pond 1 (time 1035 hrs)				

West Transect				
surface	0.5	9.9	0.6	8.10
middle	2.0	9.9	0.7	8.02
bottom	4.0	13.2	19.5	5.90
Pond 2 (time 1145 hrs)				
West Transect				
surface	0.5	10.1	0.4	7.50
middle	1.8	10.0	0.5	7.26
bottom	3.5	12.5	8.5	5.86
July 13, 2016				
Pond 0 (time 0920 hrs)				
West Transect				
surface	0.5	19.8	7.44	5.72
middle	-	-	-	-
bottom	2.0	24.0	20.0	3.71
Pond 1 (time 1035 hrs)				
West Transect				
surface	0.5	21.0	23.6	5.88
middle	1.5	22.1	26.2	4.08
bottom	3.0	24.2	32.8	5.91
Pond 2 (time 0935 hrs)				
West Transect				
surface	0.5	20.6	23.5	5.66
middle	-	-	-	-
bottom	2.0	22.5	29.3	3.32
Salmon Creek 2017				
Not Sampled				

Coho Salmon do not appear to rear in water >17°C while juvenile steelhead and cutthroat trout are often captured in areas as warm as 21°C (Wallace 2006; Wallace and Allen 2007, 2009, 2012). These same studies also typically captured juvenile salmonids in areas where DO levels were 5-7mg/l and often captured juvenile Coho Salmon in areas as low as 3.5 to 5mg/l. Ruggerone (2000) reported that juvenile Coho Salmon tolerated lower DO levels than other salmonids, often as low as 4mg/l.

Discussion

This paper presents the final two years of data from a 14-year study of juvenile salmonid use of the SEE of Humboldt Bay. In Freshwater Creek Slough, where we have our longest continuous juvenile salmon data set in Humboldt Bay, we captured relatively large numbers of sub-yearling Coho Salmon in 2016 and 2017 compared to past years (Table 50). The CPUE of sub-yearling coho salmon in 2016 and 2017 were the third and second highest, respectively recorded by our project (Table 50). However, the mean monthly FL in 2017 was smaller compared to most other years and monthly FL increase in 2016 was “flat” compared to the other years (Figure 8). In 2012, we observed the highest sub-yearling Coho Salmon CPUE of our study (Table 50) coupled with the smallest monthly mean FL of our study (Figure 8). These findings suggests high sub-yearling Coho Salmon density inhibits their growth in the SEE. Also, from

Table 50. Annual effort, number captured, and catch-per-unit-effort of sub-yearling Coho Salmon captured by seine net in Freshwater Creek Slough during June-September, 2006-2017.

Year	Effort (No. Seine Hauls)	No. Fish Captured	Catch-per-unit-effort (No. fish/haul)
2006	204	420	2.06
2007	168	101	0.60
2008	188	11	0.06
2009	104	247	2.38
2010	87	73	0.84
2011	108	264	2.44
2012	101	1,340	13.27
2013	108	274	2.54
2014	108	89	0.82
2015	107	486	4.54
2016	96	556	5.79
2017*	84	493	5.87

*Sampled only from June to August so CPUE is likely biased high compared to other years

2006 to 2010 and from 2015-2017, June and July were the months of peak CPUE for sub-yearling Coho Salmon; however, from 2011 to 2014 the monthly CPUE peaked in August to December possibly the result of low stream flows during the drought forcing fish to move downstream. In 2016, PIT tagged sub-yearling Coho Salmon mean residence times of 67 days in the SEE of Freshwater Creek Slough was above average compared to past years and their growth rate of 0.10 mm/day was the second lowest recorded during our study (Appendix 1). In 2017, their mean residence time was 30 days, which was the shortest recorded during our study, and their mean growth rate was 0.19 mm/day, which is intermediate to past years (Appendix 1). The 2017 estimated residence time is likely biased low since we ended sampling in August and therefore did not include recaptured fish rearing in the SEE from September to December.

In both years of this study, we found that juvenile salmonids were also rearing in the SEE of Wood and Ryan creeks and that fish would move throughout the entire Freshwater-Wood-Ryan SEE. Residence times of PIT tagged juvenile Coho Salmon ranged from 1 to 308 days in Freshwater Creek Slough, 4 to 167 days in Wood Creek, and 13 to 273 days in Ryan Creek (Appendix 1). Residence times of PIT tagged juvenile steelhead trout ranged from 13 to 238 days in Freshwater Creek and 14 to 378 days in Ryan Creek and PIT tagged cutthroat trout were at-large for 13 to 716 days in Freshwater Creek Slough and 13 to 350 days in Ryan Creek (Allen et al. 2016). We detected tagged juvenile salmonids from throughout the Freshwater and Ryan Creek basins at our PIT tag antennas on Wood Creek (Tables 21 & 22) and Ryan Creek Slough (Table 32). These observations demonstrate that juvenile salmonids rear and

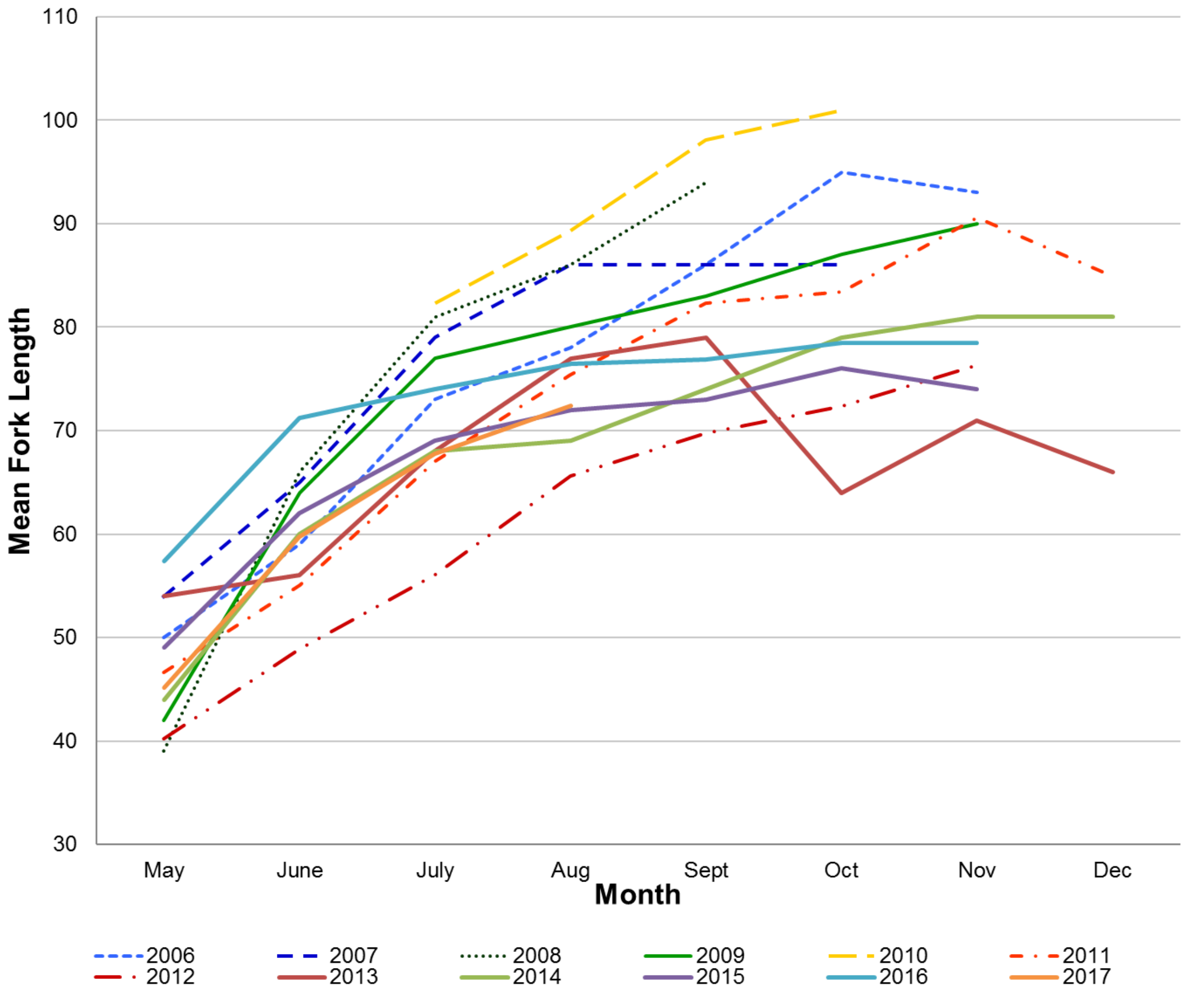


Figure 8. Mean monthly fork lengths of sub-yearling Coho Salmon captured in Freshwater Creek Slough, 2006-2017.

move throughout the entire Freshwater-Wood-Ryan SEE. Therefore, it is important to maintain and enhance connectivity between the streams entering the SEE.

This and earlier studies by PSMFC and CDFW (Wallace 2006; Wallace and Allen 2007, 2009, 2012, 2015; Wallace et al. 2015; Allen et al. 2016) showed that sub-yearling and yearling-plus Coho Salmon, as well as a wide size range of juvenile steelhead trout routinely reared in the SEE for months. There appears to be at least three basic life history strategies exhibited by juvenile Coho Salmon in Humboldt Bay tributaries (Wallace 2006; Wallace and Allen 2007, 2009, 2012, 2015; Wallace et al. 2015; Allen et al. 2016). One strategy is sub-yearling Coho Salmon move to the SEE during spring and reside there throughout the summer and fall with at least some continuing to rear in the SEE throughout the winter and into the spring. The second strategy is as stream flow increase in the fall or winter, there is a large-scale redistribution of Coho Salmon from stream habitat downstream to the SEE of Humboldt Bay tributaries. The third strategy is stream-reared Coho Salmon smolt and emigrate quickly through the SEE in the spring. There is also evidence that some Freshwater Creek Coho Salmon emigrate to the ocean as sub-yearlings (Seth Ricker, CDFW personal communication). This alternate life history strategy has also been documented in other watersheds (Bennett 2015).

The "fall redistribution" of Coho Salmon into winter habitat has been observed by other researchers throughout the Pacific Northwest (Koski 2009). Wallace et al. 2015 cited studies showing it occurs in California rivers such as the Smith River, Klamath River, Redwood Creek, Eel River, and Russian River. Also, the SEE provides rearing habitat for a large portion of juvenile salmonids in Humboldt Bay tributaries. CDFW estimated that about 40% of coho salmon smolts and 80-90% of large steelhead trout smolts originated from the SEE of Freshwater Creek in 2007 and 2008 (Ricker and Anderson 2011). Our studies also showed that juvenile salmonids using this habitat experienced faster growth, obtained a larger size, and therefore likely were larger when entering the marine environment (Wallace 2006; Wallace and Allen 2007, 2009, 2012; CDFG 2006, 2007, 2008, 2009, 2010).

However, there does appear to be density dependent effect on growth for at least sub-yearling Coho Salmon in Freshwater Creek Slough. This study found that monthly mean FL of sub-yearling Coho Salmon was negatively correlated to their June-September CPUE (Table 51 and Figure 8). This suggests that in summers of high sub-yearling Coho Salmon abundance in the SEE, growth rate is muted compared to lower abundance years. Restoring and increasing SEE habitat could result in more habitat for juvenile Coho Salmon rearing in the SEE and lowering their density resulting in larger sized fish entering the winter season. Or, it could support higher numbers of rearing Coho Salmon at the same densities occurring presently.

Poor over-winter survival has been suggested as limiting production of juvenile salmonids in Freshwater Creek (Ricker and Anderson 2011) and Coho Salmon in other watersheds throughout the Pacific Coast of North America (Nickelson et al. 1992; Quinn and Petersen 1996; Ebersole et al. 2006). Ricker and Anderson (2011) speculated that many fish moved downstream to the SEE in the fall and winter prior to installation of smolt traps in March. Numerous studies have concluded that low gradient habitats such as the SEE, as well as marshes, wetlands, off-channel pools, and beaver ponds provide favorable over-winter habitat resulting in faster fish growth in Coho Salmon, higher over-winter survival rates, and larger sized smolts than other stream habitats (Quinn and Petersen 1996; Miller and Sadro 2003; Ebersole et al. 2006; Ricker and Anderson 2011). Ricker and Anderson (2011) found over-winter survival of Coho Salmon in low-gradient reaches 2-6 times higher than the other sampled reaches. In addition, increasing aquatic habitat connectivity between rearing habitats can increase survival and the resiliency of populations (Bisson et al. 2009). In tributaries entering Humboldt Bay, most of the low-gradient over-winter habitat appears to occur in the SEE (Wallace 2006; Wallace and Allen 2007, 2009, 2012; Ricker and Anderson 2011), with the best examples being non-natal tidal tributaries that are connected to streams containing “source” populations of salmonids (e.g. non-natal Wood Creek connected to source population in Freshwater Creek).

Generally, SEE habitat restoration projects appear to be successful at providing over-winter habitat for juvenile salmonids. During this study, we assessed off channel habitat construction, and tide gate replacement/modification completed in Wood and Salmon creeks, pre and post project sampling of tide gate replacement in Martin Slough, and pre and project sampling of off channel pond construction in Jacoby Creek. Most years the off channel ponds in Wood and Salmon creeks were occupied by juvenile salmonids from around December to May, but due to high water temperature and salinities and often low DO they were unsuitable for salmonids June to November. More recent off channel habitat projects in Wood and Jacoby creeks supported large numbers of juvenile Coho Salmon and some juvenile steelhead during the winter and spring.

Relatively large numbers of juvenile salmonids, especially Coho Salmon, were captured in the restored habitat. In Salmon Creek, off-channel ponds were constructed in 2011, and we captured more juvenile Coho Salmon in the ponds the first year after they were constructed than the previous seven pre-project years combined. We have annually captured hundreds of juvenile Coho Salmon in Wood Creek, Martin Slough, and Jacoby Creek project sites.

Fish growth could be quite high in the ponds, especially in the spring. In Wood Creek from February to April 2013 we found yearling-plus Coho Salmon that were tagged and recaptured in the pond had a mean growth rate of 0.40 mm/day (range 0-0.85 mm/day; n=11) while those tagged and recaptured in the main channel of Wood Creek had a mean growth rate of 0.22 mm/day (range 0.03-0.42 mm/day; n=7). In the Salmon Creek ponds, we recaptured one yearling-plus Coho Salmon tagged in the ponds during the four years of our study and their growth rates were 0.79 to 1.00 mm/day (Appendix 1). In Martin Slough during 2015 we found yearling-plus Coho Salmon tagged and recaptured in the off channel pond had a mean growth rate of 0.48 mm/day (range 0.33-0.72; n=5) while the single yearling coho tagged and recaptured in the main channel of Martin Slough grew 0.21 mm/day. Finally, data from the newly constructed upper Jacoby Creek pond showed that yearling-plus Coho Salmon had annual mean growth rates of 0.30 and 0.32 mm/day (range 0-0.73 mm/day) in 2016 and 2017, respectively, while growth rates of PIT tagged yearling-plus Coho Salmon from the mainstem Jacoby Creek prior to construction in 2014 and 2015 ranged from 0.03 to 0.25 mm/day (Appendix 1).

Recent reports have documented a coast-wide pattern of juvenile Coho Salmon utilizing estuaries (Miller and Sadro 2003; Koski 2009; Jones et al. 2014) and have determined that movement to the estuary or other off-channel habitats increases their life history diversity and population resilience increasing the chance to recover these species (Koski 2009). Since the ability to restore complex estuarine ecosystem functions is contingent upon a landscape perspective to restoration planning (Simenstad et al. 2000) and will likely not be achieved through isolated manipulation of individual elements (National Research Council 1992), fishery managers and restoration scientists will need to take several actions. The actions include gauging the relative success of these restoration projects, developing appropriate habitat criteria targets, determining which restoration techniques work best, and determining how these restoration projects ties into the greater ecosystem functions. By first recognizing, and then understanding the role of the entire estuarine rearing stage in juvenile salmonid life history, we will be better able to form effective restoration and management practices to help recover anadromous salmonids.

The SEE surrounding Humboldt Bay is important to juvenile salmonids, especially Coho Salmon, because 1) it supports multiple life stages; 2) juvenile salmonids rear in the ecotone for significant periods of time; 3) a significant portion of the populations utilizes the ecotone; and 4) salmonids rearing in the ecotone grow faster and larger than their cohorts rearing upstream in stream habitat.

MANAGEMENT RECOMMENDATIONS

Consider how the proposed SEE habitat restoration project fits into known salmonid life history strategies. Is lack of over-winter rearing habitat upstream of the SEE limiting salmonid production in your watershed? Are there too few adult fish to seed the watershed, or ample rearing habitat upstream of the SEE that will limit movement of juvenile fish to the SEE? The answer to these questions will determine the potential value of SEE habitat restoration projects in specific watersheds.

SEE habitat restoration projects should be located in areas connected to “source” populations of salmonids so fish are available to occupy restored habitat.

When designing SEE habitat restoration projects proponents should not only consider their target species but also specific life stages.

SEE habitat restoration projects that increase connectivity between watersheds or adjacent habitat units should be the highest priority. Think laterally instead of linearly.

SEE habitat restoration projects targeting juvenile Coho Salmon should be located in areas of primarily freshwater habitat. This includes seasonal (over-winter) freshwater habitat.

SEE off channel habitat creation/restoration does not need to be limited to tidally influenced areas. Restoring off channel low gradient habitat can be sited in any appropriate location in the basin.

Off channel habitat does not need to support salmonids year-round or be used by salmonids every year to be a success. Providing seasonal habitat to be used by specific life stages of salmonids is important.

Much of the historic SEE habitat was ephemeral so plan for periodic maintenance to keep restored off channel habitat in fixed locations from filling with sediment or otherwise destroyed.

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Appendix 1- Summary of residence time and growth rates of PIT tagged sub-yearling (SY) Coho Salmon, yearling-plus (1+) Coho Salmon from Freshwater Creek Slough (FW), Wood Creek, Ryan Creek Slough, Salmon Creek, Jacoby Creek, and Martin Slough, 2013-2017.

	Year	No. Tagged	No. Recap	Percent Recap	Mean DAL	Range DAL	Mean Growth Rate	Range Growth Rate
Coho								
FW	2013	201	99	49.3	45	6-140	0.20	-0.07-0.86
SY	2014	61	27	44.3	62	13-140	0.16	0.00-0.40
	2015	252	120	47.6	71	13-152	0.08	0.00-0.27
	2016	310	161	51.9	67	13-156	0.10	-0.07-0.47
	2017	233	112	48.1	30	13-70	0.19	0.00-0.57
FW	2013	222	49	22.1	32	6-140	0.30	0.00-0.58
1+	2014	395	91	23.0	40	7-224	0.31	-0.08-0.71
	2015	87	13	14.9	47	1-287[a]	0.18	0.00-0.57[a]
	2016	165	12	7.3	24	12-71	0.40	0.00-0.50
	2017	87	10	11.5	25	14-308[a]	0.40	0.00-0.57[a]
Wood	2013	156	22	14.1	27	4-59	0.32	0.00-0.85
1+	2014	184	8	4.3	-	28-121	-	0.03-0.89
	2015	68	7	10.3	-	18-164	-	0.00-0.33
	2016	36	3	8.3	-	35-35	-	0.06-0.23
	2017	153	15	9.8	59[a]	13-167[a]	0.45[a]	0.13-0.93[a]
Ryan	2013	75	21	28.0	24	13-84	0.19	0.00-0.36
SY	2015	27	6	22.2	-	14-98	-	0.06-0.43
	2016	80	13	16.3	44	14-139	0.16	0.00-0.36
	2017	15	2	13.3	-	14-42	-	0.07-0.41
Ryan	2013	439	108	24.6	58	13-252[a]	0.19	-0.08-0.57[a]
1+	2014	254	52	20.5	63	13-266[a]	0.27	0.04-0.79[a]
	2015	72	11	15.3	71	14-273[a]	0.42	0.21-0.62[a]
	2016	86	6	7.0	-	28-237[a]	-	0.15-0.72[a]
	2017	29	3	10.3	-	26-44	-	0.31-0.46
Salmon	2013	12	1	8.3	-	27	-	0.81
1+	2014	17	1	5.9	-	31	-	0.87
	2015	22	1	4.5	-	29	-	0.79
	2016	15	1	6.7	-	14	-	1.00

Appendix 1 (con't)- Summary of residence time and growth rates of PIT tagged sub-yearling (SY) Coho Salmon, yearling-plus (1+) Coho Salmon from Freshwater Creek Slough (FW), Wood Creek, Ryan Creek Slough, Salmon Creek, Jacoby Creek, and Martin Slough, 2013-2017.

	Year	**No. Tagged**	**No. Recap**	**Percent Recap**	**Mean DAL**	**Range DAL**	**Mean Growth Rate**	**Range Growth Rate**
Jacoby	2013	50	6	12.0	-	35-90	-	0.03-0.11
SY	2015	8	3	37.5	-	55-55	-	0.02-0.04
	2016	185	140	75.7	31	13-59	0.07	-0.08-0.47
	2017	76	36	47.3	45	28-55	0.22	0.09-0.32
Jacoby	2014	20	1	5.0	-	64-272[a]	-	0.03-0.25[a]
1+	2015	6	1	16.7	-	56	-	0.09
	2016	285	59	22.4	41	13-132	0.30	0.00-0.53
	2017	188	32	17.0	60[a]	27-155	0.32	0.09-0.73
Martin	2015	6	1	16.7	-	28	-	0.29
SY	2016	0	-	-	-	-	-	-
	2017	19	5	29.4	-	31-31	-	0.10-0.23
Martin	2014[b]	14	4	28.6	-	35-35	-	-0.03-0.03
1+	2015	82	6	7.3	-	30-160	-	0.21-0.72
	2016	272	8	2.9	-	23-86[a]	-	0.29-0.77[a]
	2017	363	18	5.0	70[a]	17-118[a]	0.35[a]	0.16-0.53[a]

[a] *Includes captured fished tagged in previous year*

[b] *Sampling started in August 2014*

Section 2

One of the major challenges of collecting and using PIT tag antennas is finding a way to summarize and analyze the extremely large tag detection data sets generated by the PIT tag antenna stations. A PIT tag within the read range of the antenna station typically generate 5 to 10 records per second. In some cases, our annual data sets from individual stations exceeded one million records. The majority of the records in these data sets are not useful because most represent; 1) long series of records from stationary tagged fish within the read range of the antenna; 2) loose tags from dead fish that have settled near or become impinged on the antenna, and; 3) bad or incomplete tag detections caused by partial detections or malfunctioning tag stations.

In order to develop a way to efficiently deal with these exceeding large data sets PSMFC hired Gabe Scheer. He wrote an automated program to combine individual data sets downloaded from each antenna station into one annual data set and then "filter" out the bad or replicate records to create useful data set of a more manageable size. Typically, the "filtered" data sets were about 10% the size of the unfiltered data sets. Mr. Scheer then wrote a program package using Program-R to perform a variety of data summary and data analysis functions described below. This program prompts users to input information about their specific data sets, so one of the most useful functions of this Program is that it not only worked on our project data sets from Humboldt Bay SEE but was also designed to analyze PIT tag antenna data sets by most other projects collecting this type of data throughout northern California.

Finally, working with CDFW Region 1 Coho Salmon Recovery Coordinator Seth Ricker, Mr. Scheer organized a two-day workshop to train staff of multiple projects from CDFW, NMFS, PSMFC, Smith River Alliance, Sonoma County Water Agency, and the Yurok Tribe working on the Smith River, Klamath River, Redwood Creek, Humboldt Bay, Mendocino County, Russian River, and Scott Creek watersheds. The following is the "user's manual," that Mr. Scheer wrote to assist users in using the programs he developed to summarize and analyze PIT tag antenna data.

Basin Antenna Analysis

General System Requirements:

Software:

R version 3.3.1 (2016-06-21) -- "Bug in Your Hair" or newer

- This is an open source statistical platform that can be freely and easily downloaded at: https://cran.r-project.org/
- For California users: under current State of California IT protocol (Jan 2017) R should be installed on the D drive

Rstudio Version 0.99.903 or newer (Optional)

- Rstudio is a free integrated development environment for R. It makes R easier to use, and keeping track of graphical outputs, scripts, and the R workspace simpler and more intuitive
- RStudio can be freely downloaded from: https://www.rstudio.com/
- Recommended for ease of use, but not required to run these scripts

Packages: R Script will search your package library and download/install any required packages not currently installed on your system. If you are missing packages, an Internet connection is required for the initial run of these R scripts.

General Script Description:

Basin Analysis:
This script runs a series of analyses' based on user specified inputs. The input requires properly formatted csv files containing time gap filtered antenna data, and a data table showing directionality between antenna sites for some analyses. Following data import, the following functions can be performed:

- Elapsed Time For Directional Movement CDF (single array)
    - Counts
    - Density
- Directional Movement Count Graphics (single antenna array)
    - Time
    - Tide Height
    - Tidal Stage
    - User defined environmental covariate
    - Day/Night
- Individual Antenna efficiency
- Site specific residence time
- Movement/residence times between sites (multiple arrays)
- First entry to last observation

Outputs include a series of graphics and tabular summary metrics

Initial Input Requirements:

The raw data input format for this file is consistent with the output of "CDFW Antenna Data FormatQA/QC" script, and will work with any data set containing column headings of: "[date]", "[time2]", "[basin]", "[site]", "[reader]", and "[tagid]". Formatted as a csv file, any input containing those data fields will work for this script.

Antenna Networks and Individual Antenna Read Efficiency

If you are running analyses to evaluate individual antenna efficiency metrics, or movement/residence times between multiple sites, a second input file is required. This file consists of a matrix specifying the directional identifiers between each antenna array site within your study area. This should be formatted as a csv file in which a designation of upstream between one array and another is signified with a "U", and downstream directionality is signified as “D”. Directions should be assigned by row, resulting in a matrix similar to Table 1:

Table 1: Directionality within a watershed between each of eight antenna arrays within Freshwater Creek CA. Table should be organized by rows and read left to right (reading by columns will change the designations)

	WCT	WCP	FWW	HH	MMS	CLO	UMS	SFO
WCT	x	U	U	U	U	U	U	U
WCP	D	x	U	U	U	U	U	U
FWW	D	D	x	U	U	U	U	U
HH	D	D	D	x	U	U	U	U
MMS	D	D	D	D	x	U	U	U
CLO	D	D	D	D	D	x	U	U
UMS	D	D	D	D	D	D	x	U
SFO	D	D	D	D	D	D	D	x

Basin Antenna Analysis Walkthrough:

A flowchart depicting the following steps can be found in appendix I

Run the Script:

- Select the “Basin Antenna Analysis” file and open it with R or RStudio.
- Click the “Source” button at top right of script window (RStudio)
- Alternative to sourcing code: Select all (Cntrl+A or on Mac Cmnd+A), run code (Cntrl+Enter or on Mac Cmnd+Enter)
- Upon sourcing, the script will search your package library and download/install any required packages or package dependents that are not currently installed on your system (Broadband connection required for initial run of this program).

Initial Prompt Setup

Initial GUI prompt asks user to identify which data type you wish to import.

- **Antenna data only:** This is defined as only filtered antenna data
- **Antenna data + user defined environmental covariates:** This is defined as the standard filtered antenna data, but with additional column(s) of environmental data that is not defined by subsequent GUI’s in this script (e.g. flow, temperature, rainfall, etc.)

- **Subset of antenna data:** This is the same as filtered antenna data, but with a user defined subset group on which analysis will be performed.
- **Subset of antenna data and user defined environmental covariates**: This is the same as the filtered antenna data + environmental covariate, but with a user defined subset group on which analysis will be performed.

Import dataset and subset tags

- Select a csv file of previously formatted antenna data
- The raw data input format for this file is consistent with the output of "CDFW Antenna Data FormatQA/QC" script, and will work with any data set containing column headings of: "[date]", "[time2]", "[basin]", "[site]", "[reader]", "[ANT]", and "[tagid]". Formatted as a csv file, any input containing those data fields will work for this script. "[ANT]" field is the upstream or downstream ("U" or "D") antenna designation for each individual site.
- Select csv file containing tags that are to be subset from raw data input file. These should be only PIT Tag numbers that are preselected by the user and saved as a csv file.

<u>Define Your Analysis:</u>

GUI prompt will ask you to select any number of analyses that you wish to perform on the imported dataset:

- **Elapsed Time For Directional Movement CDF (single array)(Pg 5):**
    - Calculate the directional movement metrics for antenna array
    - Outputs distribution of times for upstream, downstream and unknown direction movements in table, and CDF graphics
- **Directional Movement Count Graphics (single antenna array)(Pg 6):**
    - Creates graphics and tabular metrics summarizing directional movement in relation to time, as well as a number of environmental covariates
- **Individual Antenna efficiency(Pg 10):**
    - Calculates the rough antenna efficiency at each site using detections at upstream and downstream antenna arrays to inform antenna read rates
- **Movement/residence times between sites (multiple arrays)(Pg 11):**
    - Calculates the residence/movement times between different antenna arrays
    - Outputs include reach specific plots, and tabular data describing each reaches distribution of resident/movement timing
- **Site specific residence time(Pg 12):**
    - Calculates the minimum residence time for individual fish at each antenna array site
- **First entry to last observation(Pg 13):**
    - Calculates the minimum residence time for a specific site, or specific group of sites.

- This function was developed to look at early emigrant Coho in off channel habitats, but can easily be used to look at other environments within a watershed.

Elapsed Time For Directional Movement CDF (single array):

If this analysis is chosen, no more prompts will be required. The algorithm will calculate the delta time distribution of upstream, downstream and unknown directional movements. The distribution of this metric is useful when determining a number of fish behaviors, as well as setting up antenna data logging structures. Determining how long a majority of fish take to pass through an antenna array is useful when considering how long to set your the gap time length on both loggers, as well as raw data QA/QC and consolidation. This metric may also be useful in determining fish behavior. By determining the timing by which a majority of directional movements occur within an array, managers can deduce movement or migratory behavior from resident with more certainty.

- Upstream movements are defined at an individual site when a fish is read at the downstream antenna, then the following record is the upstream antenna. The difference in time is recorded for an upstream movement.
- Downstream movements are defined at an individual site when a fish is read at the upstream antenna, then the following record is at the downstream antenna. The difference in time is recorded for a downstream movement.
- Unknown movements are defined as an antenna read that is logged as two consecutive reads on the same antenna; upstream or downstream. The difference in time between the two records is recorded as an unknown movement.

Outputs include:

- CDF graphs: These graphs show the cumulative distribution of delta times for each of the three directional movement categories. Break in slope is identified, as well as the 80% and 90% quantiles.
- Tabular data is stored in tables: **Detections** (# or directional movements, # total detections, % unknown direction) and **Breaks** (50^{th} quantile, 80^{th} quantile, 90^{th} quantile, and quantile at the slope break of each CDF). To review data tables used in this analysis, the following R objects can be queried:
    - **Detections**
    - **Breaks**

Directional Movement Count Graphs (single antenna array):

Initial Inputs:

A series of GUI prompts will define which analysis is performed and how the outputs are binned and displayed.

- **Directional Antenna Count Criteria:** Specify the bins by which directional movements are counted
    - Every Directional Movement: Every directional movement that occurs is counted. Outputs are a representation of your raw antenna movement data
    - Daily: Directional movements are binned by day. Starting at 12:01 AM, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
    - Weekly: Directional movements are binned by week. Starting at 12:01 AM on Monday, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
    - Monthly: Directional movements are binned by month. Starting at 12:01 AM on the first of every month, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
    - Only the first detection: Only the first directional movement for each individual fish is counted.
- **Define Y-Axis:** Define the units in which you would like the graphical output of this analysis to be displayed
    - Count: Displays graphical outputs as counts vs whichever X-axis criteria you select
    - Density: Displays graphical outputs as density plots against whichever X-axis criteria you select
- **Define X-Axis:** Define which metric you would like to represent your X-axis
    - Time: This will define the x-axis as a time series starting at the first record in your input file, and ending with the last record.
    - Tide Height: Outputs will be graphed and grouped according to tidal height at your specific site.
    - Tide Stage: Outputs will be graphed and grouped according to tidal stage at your specific site. Three stages are possible: Incoming, Outgoing, and Slack tide.
    - Environmental Covariate not listed: Directional movements will be graphed and grouped by a user specified environmental covariate that is not listed in the predefined set of analyses'.
    - Time + Env. Cov. Overlay: Directional movement graphical outputs will be graphed as a time series, with values for the user defined environmental covariate overlayed as per user specifications
    - Day/Night: Directional movements will be graphed and grouped by whether they occurred during the day and night, as determined by the sunrise/sunset times for each specific site.

X-Axis = Time:

If you defined your x-axis as Time, additional GUI inputs will be required to further define your analysis

- **Graphical Display Output Bins:** Choose how you would like the graphical outputs to be displayed. . (Note: This is different than the "directional movements count criteria". This is simply defining how your graphical outputs are displayed in the resulting analysis, while the former designation defines which directional movements are included in the analysis itself.)
    - **Daily:** This bins directional movement counts by day for graphical display.
    - **Weekly:** This bins directional movement counts by week for graphical display.
    - **Monthly:** This bins directional movement counts by month for graphical display.
- **Was the Antenna Down?** Was there any dates during which the antenna was not functioning?
    - **Yes:** Input start and end dates when antennas were not reading PIT Tags
    - **No:** No further action required

Once user inputs are defined, the script will output a series of graphs and tabular data:

- Three graphs include the upstream detections by time, downstream detections by time, and a single graph with upstream and downstream vs time on the same graph.
- Tabular data is stored as table: **Time**. If user does not save outputs, this table can be viewed by querying the R object of the same name.

<u>X-Axis = Tide Height or Tidal Stage:</u>

If you defined your x-axis as tide height or tidal stage, additional user defined inputs will be required to identify the correct tidal measurements for each specific site.

- **Select Nearest Tide Station:** From dropdown menu you should select the nearest tide station to your sites location. (Note: This program was primarily written for California monitoring efforts, therefore, the default tide station list includes 37 sites specific to California. If you are not in California, remove hashtag from line 1304 in the program script. This will allow you to choose from any of the 637 tide stations located within the United States. Additional documentation for this function can be found at: https://cran.r-project.org/web/packages/rtide/rtide.pdf).
- **Select lag time:** Choose the lag time (in minutes) for your specific sites with respect to the nearest tide station that you have previously chosen.

Once tide station and lag time are entered, outputs include graphs and tabular data relating directional movements to tidal height and stage.

- Graphs: One graph of tidal height vs. directional movement counts.
- Graphs: One graph of tidal stage vs. directional movement counts.
- Tabular data: Tabular data is saved as csv files, and can be queried in the R environment as: **TideHeight** and **TideStage**

X-Axis = Day/Night:

If you defined your x-axis as Day/Night, one additional GUI will be required to identify the exact location of your site.

- **Latitude and Longitude:** Define in decimal degrees the exact latitude and longitude of your specific site. (Note: This program is written to provide times in Pacific Standard Time, if not in this time zone, adjust lines 1458 and 1460 to reflect the proper time zone specification) Default setting is Humboldt Bay, Latitude: 40.786763 Longitude: -124.097261

Outputs include directional movement graph grouped by day and night, and directional movement graph grouped by hour in the day. Tabular data is summarized in the table **DayNight**, and can be queried in the R environment by the same name.

X-Axis = User Defined Environmental Covariate:

If you would like to graph directional movements by an alternative environmental covariate that is not one of the pre-programmed analyses this option will ask you for a number of GUI inputs to define your variables:

- **Which column in your dataset:** If your dataset contains multiple unrecognized column headings, input which column # contains the environmental covariate data that you would like to be used. Select from the dropdown menu.
- **Title of your data:** Confirm the correct title of your environmental covariate

X-Axis = Time + Env. Cov. Overlay:

If you defined your x-axis as Time + Env. Cov. Overlay, additional GUI inputs will be required to define your analysis.

- **Graphical Display Output Bins:** Choose how you would like the graphical outputs to be displayed (Note: This is different than the "directional movements count criteria". This is simply defining how your graphical outputs are displayed in the resulting analysis, while the former designation defines which directional movements are included in the analysis itself.)
    - **Daily:** This bins directional movement counts by day for graphical display.
    - **Weekly:** This bins directional movement counts by week for graphical display.
    - **Monthly:** This bins directional movement counts by month for graphical display.
- **Was the Antenna Down?** Was there any dates during which the antenna was not functioning?
    - **Yes:** Input start and end dates when antennas were not reading PIT Tags
    - **No:** No further action required
- **Which column in your dataset:** If your dataset contains multiple unrecognized column headings, input which column # contains the environmental covariate data that you would like to be used. Select from the dropdown menu.
- **Title of your data:** Confirm the correct title of your environmental covariate

Once user inputs are defined, the script will output a series of graphs and tabular data:

- Three graphs include the upstream detections by time, downstream detections by time, and a single graph with upstream and downstream vs time on the same graph, with the environmental covariate graphed on a second axis overlaying each graph.
- Tabular data is stored as table: **Time.ENV**. If user does not save outputs, this table can be viewed by querying the R object of the same name.

Individual Antenna Efficiency

This analysis is meant to give a quick and rough estimate of the general read efficiency of each antenna within a watershed network. Read efficiencies are calculated by using antenna records from upstream and downstream antennas to deduce if individual fish moved up/downstream, but missed a read by an intermediate antenna. The logic is as follows: Fish detected at an upstream antenna of an array, then subsequently detected at a different antenna array without being detected on the downstream antenna of the initial array can definitively be considered alive, and to have passed the downstream antenna, but not detected by said antenna. By calculating the proportion of individuals that these conditions are true, both upstream, and downstream, a rough estimate of individual antenna efficiency can be deduced.

Initial Inputs:

If individual antenna efficiency is chosen, a second file will be required to define where each antenna is located within the watershed. GUI will prompt user to import the "**Directionality of Antenna Network**" as a csv file. Example of this file can be found in Table 1 on page two of this readme Table should be organized by rows and read from left to right (reading by columns will change the designations).

Outputs:

Outputs include three bar plots: upstream antenna efficiency for each array, downstream antenna efficiency for each array, and a grouped bar plot with upstream and downstream antenna efficiencies for each array. Tabular data can be queried in the R environment under the object: **reads** (case sensitive).

Movement/Residence Times Between Sites (multiple arrays):

This analysis is meant to determine the minimum residence time for individual reaches and between two antenna arrays within a watershed. The multiple antenna arrays within a basin can be used to determine roughly how long individual fish are spending between two arrays.

Initial Inputs:

If Movement/Residence Times Between Sites is chosen, a second file will be required to define where each antenna is located within the watershed. GUI will prompt user to import the “**Directionality of Antenna Network**” as a csv file. Example of this file can be found in Table 1 on page two of this readme Table should be organized by rows and read from left to right (reading by columns will change the designations).

Outputs:

Box plot summarizing the distribution of residence times between each pair of antenna arrays within the basin that both detected at least one fish moving between them. Tabular data is stored in the table: **results2** ("Min","1st Quartile","Median","Mean","3rd Quartile","Max","Standard Deviation","N"). Review data table by querying the R object of the same name.

Site Specific Residence Time:

This section of the script simply calculates the minimum residence time that might be expected from data at single antenna arrays. It calculates the minimum time each fish with more than one detection at a single array spent between its first and last detection.

Outputs:

Data is summarized with a boxplot depicting residence time distributions for each antenna array present in the dataset. Tabular summaries are stored as a data.frame in the R environment and can be queried by entering the name: **results** ("Minimum","1st Quartile","Median","Mean","3rd Quartile","Maximum","SD","N")

First Entry to Last Detection:

This section of the script calculates the minimum residence time for a specific site, or specific group of sites. This function was developed to look at early emigrant Coho in off channel habitats, but can be used to look at other environments within a watershed as well.

Inputs:

A series of GUI’s allow user to define how the detection data will be grouped, and how the output graphics will be binned and displayed:

- **Define Y-Axis:** Define the units in which you would like the graphical output of this analysis to be displayed

    - Count: Displays graphical outputs as counts vs whichever X-axis criteria you select
    - Density: Displays graphical outputs as density plots against whichever X-axis criteria you select
- **Graphical Display Output Bins:** Choose how you would like the graphical outputs to be displayed
    - **Daily:** This bins directional movement counts by day for graphical display.
    - **Weekly:** This bins directional movement counts by week for graphical display.
    - **Monthly:** This bins directional movement counts by month for graphical display.
- **Grouped Sites?**
    - **Yes:** Select which sites you would like to perform this analysis on. Select group named for title of graph
    - **No:** If there are multiple sites in your input file, GUI will ask you to define which site you wish to perform analysis on

Outputs:

Output counts or density plots are graphed against time on the x-axis. Tabular summaries are stored as a data.frame in the R environment and can be queried by entering the name: **firstlast** (tagid, first detection date, last detection date, first detection site, last detection site, elapsed residence time)

Technical Program Outline:

This program was written primarily to assist the organization and standardized analysis of antenna data from CDFW projects in Humboldt Bay. However, it has been generalized to some extent to accommodate multiple programs data processing needs. The following is a step-by-step summary of the various processes each algorithm is using to accomplish this task.

Initial Inputs & Package Loading

Upon sourcing the Basin Analysis script it will search your R package library and download and install any packages that are not currently installed on your system. Initial GUI inputs require you to upload a filtered antenna file in csv format, and then enter a number of user specified inputs to give the program the correct working parameters.

Initial GUI prompt asks user to identify which data type you wish to import.

- **Antenna data only:** This is defined as only filtered antenna data
- **Antenna data + user defined environmental covariates:** This is defined as the standard filtered antenna data, but with additional column(s) of environmental

data that is not defined by subsequent GUI's in this script (e.g. flow, temperature, rainfall, etc.)

- **Subset of antenna data:** This is the same as filtered antenna data, but with a user defined subset group on which analysis will be performed.
- **Subset of antenna data and user defined environmental covariates**: This is the same as the filtered antenna data + environmental covariate, but with a user defined subset group on which analysis will be performed.

Import dataset and subset tags

- Select a csv file of previously formatted antenna data
- The raw data input format for this file is consistent with the output of "CDFW Antenna Data FormatQA/QC" script, and will work with any data set containing column headings of: "[date]", "[time2]", "[basin]", "[site]", "[reader]", "[ANT]", and "[tagid]". Formatted as a csv file, any input containing those data fields will work for this script. "[ANT]" field is the upstream or downstream ("U" or "D") antenna designation for each individual site.
- Select csv file containing tags that are to be subset from raw data input file. These should be only PIT Tag numbers that are preselected by the user and saved as a csv file.

<u>Define Your Analysis:</u>

GUI prompt will ask you to select any number of analyses that you wish to perform on the imported dataset:

- **Elapsed Time For Directional Movement CDF (single array):**
    - Calculate the directional movement metrics for antenna array
    - Outputs distribution of times for upstream, downstream and unknown direction movements in table, and CDF graphics
- **Directional Movement Count Graphics (single antenna array):**
    - Creates graphics and tabular metrics summarizing directional movement in relation to time, as well as a number of environmental covariates
- **Individual Antenna efficiency:**
    - Calculates the rough antenna efficiency at each site using detections at upstream and downstream antenna arrays to inform antenna read rates
- **Movement/residence times between sites (multiple arrays):**
    - Calculates the residence/movement times between different antenna arrays
    - Outputs include reach specific plots, and tabular data describing each reaches distribution of resident/movement timing
- **Site specific residence time:**
    - Calculates the minimum residence time for individual fish at each antenna array site
- **First entry to last observation:**
    - Calculates the minimum residence time for a specific site, or specific group of sites.

- Outputs graphical and table summaries of first and last detections within specified site(s), as well as elapsed residence times
- This function was developed to look at early emigrant Coho in off channel habitats, but can easily be used to look at other environments within a watershed.

Elapsed Time For Directional Movement CDF (single array):

If this analysis is chosen, no more prompts will be required. The algorithm will calculate the delta time distribution of upstream, downstream and unknown directional movements. The following steps will be used to accomplish this task:

1. Import data for each individual site
2. Combine date and time field into POSIXlt object in new field: “date2”
3. Sort by tagid, then by date2
4. Create new field that calculates the difference in times between each antenna read: “diff.time”
5. Create new field that determines if each consecutive row is the same antenna or not: “diff.reader”
6. Add additional fields of lagged criteria containing no real data:
    a. “tagid2” – “diff.time2” – “ANT2”
7. Determine if consecutive records can be characterized as a directional movement, criteria as follows:
    a. Upstream movement – if the same tag is detected at the downstream antenna, then the following record is detected at the upstream antenna. Elapsed time for this movement is saved to a new field “m.up”.
    b. Downstream movement - if the same tag is detected at the upstream antenna, then the following record is detected at the downstream antenna. Elapsed time for this movement is saved to a new field “m.down”.
    c. Unknown Direction – if the same tag is detected on an antenna, then the following record is detected on that same antenna. Elapsed time for this movement is saved to a new field “m.unk”
8. For upstream, downstream, and unknown movements, determine where the break in slope occurs for each movement’s elapsed time distributions.
9. For upstream, downstream, and unknown directional movements, calculate 50th, 80th, and 90th quantiles for elapsed time distributions.
10. Graph elapsed time cumulative distributions
11. Output table of directional detection summaries saved to object assigned: “**Detections**”
12. Output table of directional movement elapsed times saved to object assigned: “**Breaks**”

Directional Movement Count Graphics (single antenna array):

Creates graphics and tabular metrics summarizing directional movement in relation to time, as well as a number of environmental covariates.

Initial Inputs:

A series of GUI's will require user to input a number of criteria to define the correct working parameters for this analysis:

- **Directional Antenna Count Criteria:** Specify the bins by which directional movements are counted
  - Every Directional Movement: Every directional movement that occurs is counted. Outputs are a representation of your raw antenna movement data
  - Daily: Directional movements are binned by day. Starting at 12:01 AM, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
  - Weekly: Directional movements are binned by week. Starting at 12:01 AM on Monday, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
  - Monthly: Directional movements are binned by month. Starting at 12:01 AM on the first of every month, only the first directional movement (upstream/downstream) for each individual fish is recorded for analysis and graphical displays.
  - Only the first detection: Only the first directional movement for each individual fish is counted.
- **Define Y-Axis:** Define the units in which you would like the graphical output of this analysis to be displayed
  - Count: Displays graphical outputs as counts vs whichever X-axis criteria you select
  - Density: Displays graphical outputs as density plots against whichever X-axis criteria you select
- **Define X-Axis:** Define which metric you would like to represent your X-axis
  - Time: This will define the x-axis as a time series starting at the first record in your input file, and ending with the last record.
  - Tide Height: Outputs will be graphed and grouped according to tidal height at your specific site.
  - Tide Stage: Outputs will be graphed and grouped according to tidal stage at your specific site. Three stages are possible: Incoming, Outgoing, and Slack tide.
  - Environmental Covariate not listed: Directional movements will be graphed and grouped by a user specified environmental covariate that is not listed in the predefined set of analyses'.

- Time + Env. Cov. Overlay: Directional movement graphical outputs will be graphed as a time series, with values for the user defined environmental covariate overlayed as per user specifications
- Day/Night: Directional movements will be graphed and grouped by whether they occurred during the day and night, as determined by the sunrise/sunset times for each specific site.

X-Axis = Time:

If you defined your x-axis as Time, additional GUI inputs will be required to further define your analysis

- **Graphical Display Output Bins:** Choose how you would like the graphical outputs to be displayed. . (Note: This is different than the "directional movements count criteria". This is simply defining how your graphical outputs are displayed in the resulting analysis, while the former designation defines which directional movements are included in the analysis itself.)
    - **Daily:** This bins directional movement counts by day for graphical display.
    - **Weekly:** This bins directional movement counts by week for graphical display.
    - **Monthly:** This bins directional movement counts by month for graphical display.
- **Was the Antenna Down?** Was there any dates during which the antenna was not functioning?
    - **Yes:** Input start and end dates when antennas were not reading PIT Tags
    - **No:** No further action required

Once all user inputs are defined, the following steps will be taken to perform this analysis:

1. Import data for each individual site
2. Combine date and time field into POSIXlt object in new field: "date2"
3. Sort by tagid, then by date2
4. Create new field that calculates the difference in times between each antenna read: "diff.time"
5. Create new field that determines if each consecutive row is the same antenna or not: "diff.reader"
6. Add additional fields of lagged criteria containing no real data:
    a. "tagid2" – "diff.time2" – "ANT2"
7. Determine if consecutive records can be characterized as a directional movement. Criteria as follows:
    a. Upstream movement – if the same tag is detected at the downstream antenna, then the following record is detected at the upstream antenna. Elapsed time for this movement is saved to a new field "m.up".
    b. Downstream movement - if the same tag is detected at the upstream antenna, then the following record is detected at the downstream antenna. Elapsed time for this movement is saved to a new field "m.down".

8. Filters out all records that the directional movement elapsed time is equal to zero (simultaneous read by both antennas? Software glitch?)
9. Define new field that indicates the direction of movement: "mvmt.direction"
10. Separate upstream and downstream fish into two different objects: "dy.u" and "dy.d"
11. Define new field that adds an identifier to each record indicating the "Directional Count Criteria" bin (every, daily, weekly, monthly, first) that was previously selected: "div"
12. If div=every: Nothing further is done to this field
13. If div=daily/weekly/monthly/first: Removes all duplicate records that share the same "div" designation, keeping only the first.
14. Recombine upstream and downstream records to object: "data.y2"

<u>If x-axis = Time:</u>

15. Convert all records to frequency table: "mvmt" with elements ["Date","Direction","Freq"]
16. Add new fields containing weekly, and monthly markers to identify the display bin criteria: "Week", "Month"
17. Graph upstream/downstream movements
18. Multiply downstream Freq by negative one for graphing purposes
19. Graph upstream/downstream movements on the same axis
20. Save count data as new R object: "**Movement**"

<u>If x-axis = Tide Height or Tidal Stage:</u>

If you defined your x-axis as tide height or tidal stage, additional user defined inputs will be required to identify the correct tidal measurements for each specific site.

- **Select Nearest Tide Station:** From dropdown menu you should select the nearest tide station to your sites location. (Note: This program was primarily written for California monitoring efforts, therefore, the default tide station list includes 37 sites specific to California. If you are not in California, remove hashtag from line 1304 in the program script. This will allow you to choose from any of the 637 tide stations located within the United States. Additional documentation for this function can be found at: https://cran.r-project.org/web/packages/rtide/rtide.pdf).
- **Select lag time:** Choose the lag time (in minutes) for your specific sites with respect to the nearest tide station that you have previously chosen.

Once all user inputs are defined, the following steps will be taken to perform this analysis:

<u>Tide Height:</u>

15. Add new field defining the selected tide station: "Station"
16. Subset the "station" and "date2" fields, rename "Station" and "DateTime"
17. Add user defined lag time to ["DateTime"] field

18. Calculate tide height at each movement record time, add this to new field: “tide.h”
19. Group tidal heights into 10 evenly spaced bins
21. Convert all records to frequency table: “mvmt” with elements [“tide.h”,”mvmt.direction”,”Freq”,”bins”]
22. Multiply downstream Freq by negative one for graphing purposes
23. Graph upstream/downstream movements on the same axis
24. Save count data as new R object: “**TideHeight**”

Tide Stage:

15. Order by date and time
16. Convert “date2” field to POSIXct object
17. Remove any NA values from “date2” field
18. Create new data.frame “dat” containing tidal heights in 15 minute intervals for the duration of the data set date range
19. Calculate the difference in consecutive tide heights and save to new field “chg”
20. Create new field “tide.stage” defining tidal stage as Incoming (I): tidal change is positive, Outgoing (O): tidal stage is negative, or Slack (S): tidal change is less than 1cm over a 15 minute interval.
21. Convert all records to frequency table: “mvmt” with elements [“tide.stage”,”mvmt.direction”,”Freq”]
22. Graph upstream/downstream movements on the same axis
23. Save count data as new R object: “**TideStage**”

If x-axis = Day/Night:

If you defined your x-axis as Day/Night, one additional GUI will be required to identify the exact location of your site.

- **Latitude and Longitude:** Define in decimal degrees the exact latitude and longitude of your specific site. (Note: This program is written to provide times in Pacific Standard Time, if not in this time zone, adjust lines 1458 and 1460 to reflect the proper time zone specification) Default setting is Humboldt Bay, Latitude: 40.786763 Longitude: -124.097261

15. Order by “date2” field
16. Convert “date2” to Date object in new field: “date3”
17. Calculate sunrise and sunset times for each data record and store in new fields: “s.rise” and “s.set”
18. Convert “s.rise” and “s.set” to POSIXct objects
19. Create new field “daynight” to assign each record to either a day or night group
20. Add new field “counter” for use in summing day/night counts
21. Convert records to frequency tables “dy.u” and “dy.d”
22. Create barplot of upstream and downstream movements grouped by day and night

23. Create new objects “hcu” and “hcd” that groups upstream/downstream movements by the hour
24. Fill any hours in the day in which no detections occurred with zeros
25. Graph upstream/downstream movements on the same axis
26. Save count data as new R object: “**DayNight**”

Individual Antenna Efficiency:

This analysis is meant to give a quick and rough estimate of the general read efficiency of each antenna within a watershed network. Read efficiencies are calculated by using antenna records from upstream and downstream antennas to deduce if individual fish moved up/downstream, but missed a read by an intermediate antenna. The logic is as follows: Fish detected at an upstream antenna of an array, then subsequently detected at a different antenna array without being detected on the downstream antenna of the initial array can definitively be considered alive, and to have passed the downstream antenna, but not detected by said antenna. By calculating the proportion of individuals that these conditions are true, both upstream, and downstream, a rough estimate of individual antenna efficiency can be deduced.

Initial Inputs:

If individual antenna efficiency is chosen, a second file will be required to define where each antenna is located within the watershed. GUI will prompt user to import the “**Directionality of Antenna Network**” as a csv file. Example of this file can be found in Table 1 on page two of this readme. Table should be organized by rows and read from left to right (reading by columns will change the designations). The following steps are used to perform this analysis:

1. Import data for each individual site
2. Combine date and time field into POSIXct object in new field: “date2”
3. Order by “tagid” then by “date2”
4. Create new field that calculates the difference in times between each antenna read: “diff.time”
5. Create new field that determines if each consecutive row is the same antenna or not: “diff.reader”
6. Add additional fields of lagged criteria containing no real data:
    a. “tagid2” – “diff.time2” – “ANT2” – “diff.site”
7. Creates new R object “da” with elements: “site” and “diff.site”
8. Queries “Directionality of Antenna Network” file to assign direction of movement between consecutive records with the same “tagid”. Creates new field to store this information: “movement”
9. Create new fields to identify missed/confirmed directional movements:
    a. “capd.up” when an individual is read on a downstream antenna, and the next record is on the upstream antenna of that same array

    b. “capd.dn” when an individual is read on a upstream antenna, and the next record is on the downstream antenna of that same array
    c. “miss.up” when an individual is read on a downstream antenna, then the next record is at a different site, upstream of the original antenna location
    d. “miss.dn” when an individual is read on a upstream antenna, then the next record is at a different site, downstream of the original antenna location
10. Create new date.frame to store summary metrics: “**reads**”
11. Store results for antenna efficiency for each site present in the original data file. Elements include: [“"Missed Up","Missed Down","Confirmed Up","Confirmed Down","Upstream Efficiency","Downstream Efficiency"]
    a. Upstream efficiency = confirmed upstream double antenna reads divided by total amount of fish confirmed to have moved upstream: [“Confirmed Up” / (“Confirmed Up” +”Missed Up”)]
    b. Downstream efficiency = confirmed downstream double antenna reads divided by total amount of fish confirmed to have moved downstream: [“Confirmed Down” / (“Confirmed Down” +”Missed Down”)]
12. Create bar plot of upstream/downstream antenna read efficiencies grouped by site
13. Save count data as R object: “**reads**”

Site Specific Residence Time:

This section of the script simply calculates the minimum residence time that might be expected from data at single antenna arrays. It calculates the minimum time each fish with more than one detection at a single array spent between its first and last detection. The following steps were taken to determine this:

1. Filter detection records to keep only the first and last detection for each individual fish at each site
2. Combine date and time field to one POSIX object – “date2”
3. Order records by “tagid”, then date and time “date2”, and finally by “site”
4. Create new fields that contain no real information, but for use in filtering data records by conditional criteria: “diff.time” – “diff.time2” – “tagid2” – “diff.tag” - “diff.site”
5. Subset time between first and last detection (“diff.tag2”) and site.
6. Graph distributions by site name
7. Output table saved to object assigned: “**results**”

Movement/Residence Times Between Sites (multiple arrays):

This analysis is meant to determine the minimum residence time for individual reaches and between two antenna arrays within a watershed. The multiple antenna arrays within a basin can be used to determine minimum times individual fish are spending between two arrays.

Initial Inputs:

If Movement/Residence Times Between Sites is chosen, a second file will be required to define where each antenna is located within the watershed. GUI will prompt user to import the "**Directionality of Antenna Network**" as a csv file. Example of this file can be found in Table 1 on page two of this readme Table should be organized by rows and read from left to right (reading by columns will change the designations).

To determine minimum residence time for individual reaches, the multiple antenna arrays within a basin can be used to determine roughly how long individual fish are spending between two arrays. The following steps are used to determine the residence times between each set of antenna detections that were associated with a change in site location. The following steps were used to determine this:

1. Import data for each individual site
2. Convert date fields to POSIXct objects in new field: "date2"
3. Sort by tagid, then by date2
4. Insert new field that calculates the difference in times between each antenna read: "diff.time"
5. Create multiple new fields containing no real information, for use in sorting data and defining directional movement: "diff.time2" – "tagid2" – "diff.reader" – "diff.site" – "ANT2"
6. Add additional fields of lagged criteria containing no real data:
    a. "site (1-3)" – "tagid (1-3)" – "time (1-3)"
7. Filter records to keep the time difference between the last antenna detection at site A, and the first detection at site B.
8. Make boxplots of residency time distributions for each combination of antenna site locations
9. Output table saved to R object assigned: "**results2**"

First Entry to Last Detection:

This section of the script calculates the minimum residence time for a specific site, or specific group of sites. This function was developed to look at early emigrant Coho in off channel habitats, but can be used to look at other environments within a watershed as well.

Inputs:

A series of GUI's allow user to define how the detection data will be grouped, and how the output graphics will be binned and displayed:

- **Define Y-Axis:** Define the units in which you would like the graphical output of this analysis to be displayed

    - <u>Count:</u> Displays graphical outputs as counts vs whichever X-axis criteria you select
    - <u>Density:</u> Displays graphical outputs as density plots against whichever X-axis criteria you select
- **Graphical Display Output Bins:** Choose how you would like the graphical outputs to be displayed
    - **Daily:** This bins directional movement counts by day for graphical display.
    - **Weekly:** This bins directional movement counts by week for graphical display.
    - **Monthly:** This bins directional movement counts by month for graphical display.
- **Grouped Sites?**
    - **Yes:** Select which sites you would like to perform this analysis on. Select group named for title of graph
    - **No:** If there are multiple sites in your input file, GUI will ask you to define which site you wish to perform analysis on

Once user inputs are defined, the following steps are used to determine first and last detections, and residence times:

1. Import data for each individual site
2. Order by “tagid” then “date2”
3. Filter detection records to keep only the first and last detection for each individual fish at each site
4. Remove any records in which the first and last detection are the same
5. Convert “date2” field to POSIXlt object
6. Create new field for lagged “tagid” assigned: “diff.tag”
7. Create new field for order of records (“First”,”Last”) assigned: “det”
8. Create frequency table “d” containing the elements: ["date","Detection","Freq"]
9. Create multiple fields new fields containing no real information to identify daily, weekly, or monthly bins: “date2”,”Week”,”Month”.
10. Graph First detections and Last detections as a histogram
11. Save output table as R object assigned: “**FirstLast**”

<u>Save Results:</u>

Once all analyses have been completed, a GUI will prompt you to save your results or not.

- **If Yes:** Results will be saved in a folder in the file directory which your input file was imported from. Tabular data will be saved as csv files, graphical outputs will be saved as jpeg files
- **If No:** No results will be saved to your hard drive. Tabular data can be queried by executing the following commands in the R workspace:

- **Detections:** Summary of directional detections at each antenna array
- **Breaks:** Summary of elapsed times of directional movements at each antenna array
- **Movement:** Count data for directional movement vs. time
- **TideHeight:** Count data for directional movement vs. tidal height
- **Tide Stage:** Count data for directional movement vs. tidal stage
- **DayNight:** Count data for directional movement grouped by day and night, as well as hour in the day
- **reads:** Individual antenna read efficiency metrics
- **results:** Site specific minimum residence time metrics
- **results2:** Reach specific residence/movement time distribution metrics between two arrays
- **FirstLast:** Count data for first and last detections at a site or group of sites.

Appendix I: Flowchart for Basin analysis script