JUVENILE SALMONID SURVIVAL IN SPECIFIC AREAS OF THE NEHALEM WATERSHED

ANNUAL REPORT

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EXECUTIVE SUMMARY

Mortality of wild steelhead in Nehalem Bay was estimated to be 54%, as assessed by acoustic telemetry throughout the outmigration season on five separate dates. The majority of this loss occurs in the very short (~2 km) region between the lower part of the estuary and the ocean. Likely predators included double-crested cormorants, and harbor seals, other cormorants, great blue herons, and Caspian terns. Movement between individual fish was variable in the river and appears to be related to river flow and precipitation. Significant changes in the behavior of fish were observed over time. The majority of fish migrated to the estuary during the first part of the season (April to early May). However, fish that were captured in the smolt trap in the latter part of the run (late May to June) tended to remain in the river even though they may have been moving on a more limited basis. Residence times of fish in the estuary tended to be less than a day. No differences in length, condition factor, stress, or disease, which can affect migration and saltwater entry, were evident between releases of smolts. No trends existed between mortality and migration behavior for the releases. Double-crested cormorants were the most abundant avian predator. No relationship between cormorant numbers and smolt mortality or total smolt numbers in Nehalem existed, though they overlapped with smolts spatially. Because the present study represents only the initial field season, this work needs to be finalized to better understand the relationship between smolt behavior, predation, and management measures.

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INTRODUCTION

Mitigation of the loss of salmonids has been mandated by the Oregon Plan. In several Oregon coast estuaries, including Nehalem Bay, efforts towards this goal have been ongoing via watershed council activity (specifically, the Lower Nehalem Watershed Council), private management efforts (e.g., the Smolt Protection Program, funded by ODFW), and scientific assessment (Oregon Cooperative Fish and Wildlife Research Unit, OCFWRU). In order to restore to safe numbers and keep the salmonid population in the Nehalem watershed healthy, it is imperative that the factors causing mortality of smolts be identified such that they can be managed in this watershed, as well as others.

Jack return rates are highly correlated with subsequent adult coho salmon returns (Oregon Production Index - OPI), therefore, a significant proportion of mortality for coho salmon (*Oncorhynchus kisutch*) must occur between the time when outmigrating smolts are last counted and jacks return in the fall of the same year. Based on this it is also reasonable to assume that similar losses are experienced by other salmonid species, including steelhead (*Oncorhynchus mykiss*). This suggests that prior to reaching the oceanic rearing grounds juvenile salmonids pass through areas that are critical to determining adult abundance. Conceptually these areas include: 1) the lower river, downstream of the point where the smolts are last counted; 2) the estuary; 3) the nearshore ocean when fish are adjusting to saltwater; and 4) the open ocean. The open ocean has traditionally been the area where most of this mortality has been *assumed* to occur. However, the only data available on mortality is referenced from the upstream point in the watershed where fish are counted. We know very little about the relative losses of salmon in the different areas listed above. Our recent research indicates that a high degree of mortality, especially due to avian predators, may occur before outmigrating salmon reach the open ocean (Schreck *et al.* 1993, 1996, 1997; Schreck and Stahl, 1998). Specifically, in the Nehalem watershed, we have preliminary evidence indicating that ~47% of outmigrating *hatchery* coho salmon (*Oncorhynchus kisutch*) smolts may perish in the lower river and estuary alone (Schreck and Stahl, unpublished data). If this percentage is consistent throughout the entire outmigrating smolt population and other Oregon coastal estuaries, then the total number of juvenile salmonids taken by predators, or otherwise lost in estuaries, may be sufficiently large to negatively influence adult returns.

Mortality occurs for a variety of reasons, but a large proportion of it can be directly related to predation on outmigrating smolts and possibly to the smolts' physiological condition, which would affect the ability of the fish to successfully enter the ocean and perhaps even (contribute substantially to) their vulnerability to predators. Predators of smolts in Nehalem include harbor seals (*Phoca vitulina*), cormorants (*Phalacrocorax* spp.), Caspian terns (*Sterna caspia*), and various other avian predators (Schreck and Stahl, unpublished data and personal observation). Physiological condition of smolts is affected by upstream habitat (including temperature, riparian zone, substrate, contaminants, and flow) but will be manifested through disease, stress, smoltification abnormalities, and other indicators of general health. If negative habitat conditions in the upper watershed adversely affect the physiological condition of smolts, this may affect their ability to avoid predation, feed, enter saltwater, and survive in saltwater (Schreck and Stahl, 1998). Our prior research suggests that variation in fish quality is reflected in the ability of juvenile salmonids to perform various tasks, such as migration through a river and successful entry into the ocean.

The goal of this study is to obtain information that will allow us to make recommendations concerning areas of the Nehalem watershed (lower river, estuary, and/or nearshore ocean) where management efforts would have the greatest impact in minimizing the loss of outmigrating salmonid smolts. Through cooperation with the Lower Nehalem Watershed Council and other researchers, we conducted an assessment of the condition and survival of wild steelhead salmon in the Nehalem watershed (Fig 1) in order to understand spatially-explicit sources of mortality. Given this goal, we have set forth two objectives.

Objectives

1. Determine spatially-explicit mortality factors of steelhead smolts in the lower river, estuary, and nearshore ocean of the Nehalem watershed.

2. Assess the physiological condition of wild juvenile steelhead salmon from the North Fork of the Nehalem River prior to and during migration, and in relation to subsequent lower river, estuary, and nearshore ocean behavior, survival, salinity levels, and food availability.

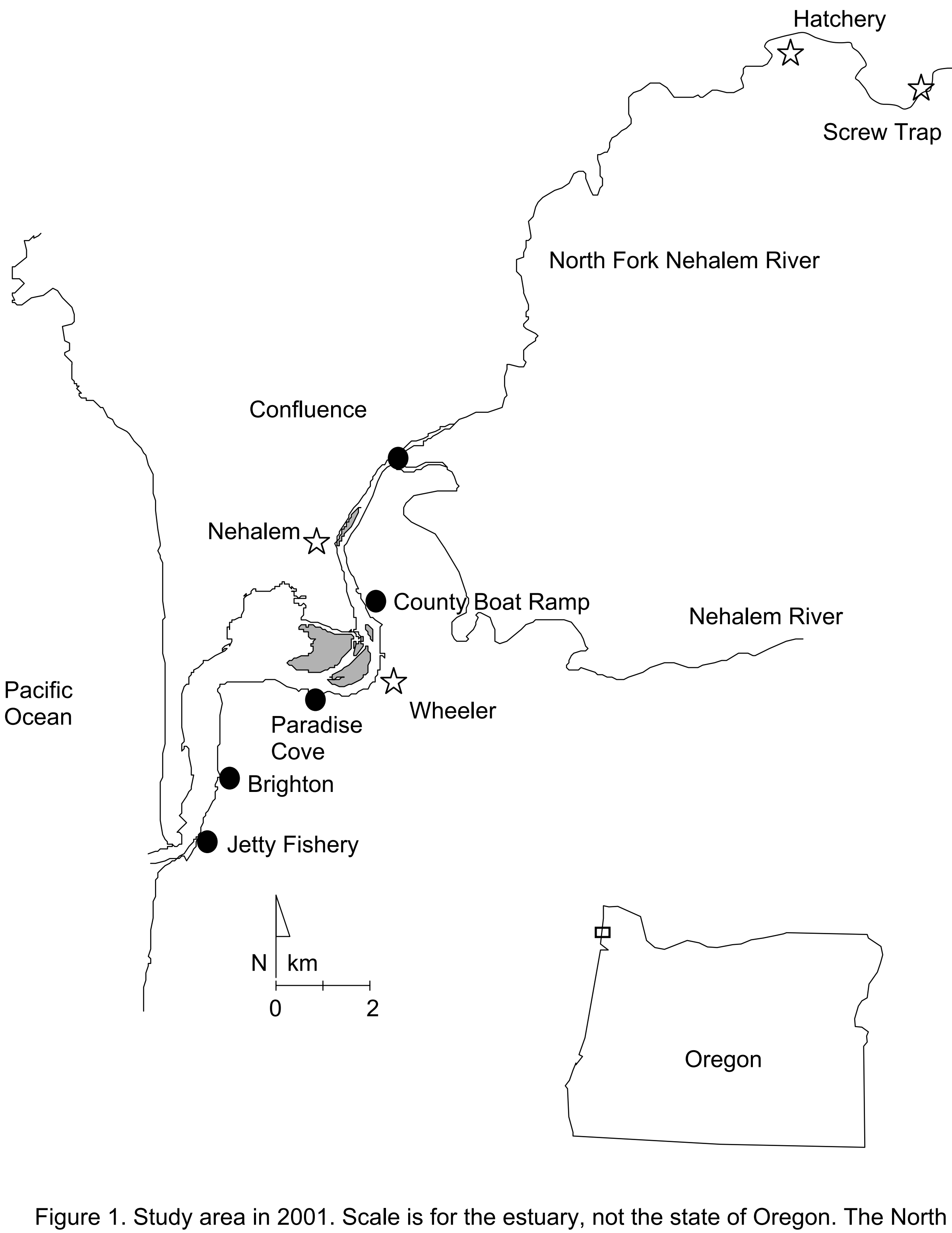

Figure 1. Study area in 2001. Scale is for the estuary, not the state of Oregon. The North Fork of the Nehalem Fish Hatchery, the ODFW Screw Trap and the towns of Wheeler and Nehalem (stars), the confluence, Paradise Cove, and the Jetty Fishery (Solid circles).

METHODS

Objective 1 Determine spatially-explicit mortality factors of steelhead smolts in the lower river, estuary, and nearshore ocean of the Nehalem watershed.

BIOTELEMETRY.

Based on analysis of data for steelhead smolts captured in smolt migrant traps on the North Fork of the Nehalem River in 2000 it was decided to have four releases of 15 fish to cover the main peak during the outmigration (late April early May). The remaining tags were then divided up to cover the remainder of the run and monitor behavior of fish during a second smaller peak in late May early June. Because the outmigration is often patchy and unpredictable in the later part of the season it was not always possible to obtain the desired number of fish on any given day. Therefore, the tagging was done over several days.

Collection and surgical procedure.

Wild steelhead smolts were collected over a 24 h period using an 8 foot screw trap on the north fork of the Nehalem River operated by ODFW. The trap was cleared between 8 and 9 each morning by ODFW staff. On days when OCFWRU was present wild steelhead smolts were transferred to separate holding tanks. Fish were transferred individually into anaesthetic (10 L) (MS-222 50 mg/L buffered with $NaHCO_3$ 125 mg/L) to prepare them for tagging. Once anaesthetized the fish were measured and any external abnormalities noted. The fish were then placed ventral side up in a plastic covered foam wedge to hold them securely. Commercially available “stress coat” was applied to the wedge to minimize scale loss. Anaesthetic was perfused over the gills using a squeeze bottle to maintain oxygen to the gills while keeping the fish sedate. A 1-1.5 cm incision was made into the ventral body wall just anterior of the pelvic girdle. The hydroacoustic transmitter was then inserted. The procedure was essentially the same for radio transmitters, however a smaller incision was made (< 1 cm). In addition, a 20 G stainless steel hypodermic needle was used to run the antennae along the inside of the body cavity before exiting just anterior and above the anal vent. Once the transmitter was inserted the incision was closed using nylon sutures (simple interrupted knot). The fish were then transferred to a recovery area. The recovery area consisted of a 2.5 cm tubular PVC frame encased with black fabric mesh (type) designed to minimize scale loss if the fish came into contact with the walls. The enclosure measured 2.5 m long x 1.2 m wide x 1 m deep, and was placed in the river downstream of the trap. Fish were held in the enclosure for 3-5 hours after surgery at which time they were liberated. Survival during this period was 100%. It is not possible to determine whether any of these fish suffered mortality due to the surgery following release, however previous research suggests that mortality from this procedure is relatively low. Welch et al (2002) reported between 6-10% mortality after 12 weeks for salmonids of a similar size following implantation with acoustic transmitters. Our own research suggests that 0-5 % of fish suffer mortality within 1 month following implantation in the laboratory environment.

Radiotelemetry research

To determine the holding locations of smolts and to assess predation by avian, piscine, and mammalian predators, wild steelhead smolts were implanted with radiotransmitters. Nine releases were conducted in total with the number of fish in each release varying (table 1). Radio transmitters were purchased from Advanced Telemetry Systems (ATS-Isanti, Minnesota). Each transmitter operated on the 149 MHz bandwidth. Tags weighed approximately 1.2 g in air and were powered by two 1.5 volt batteries. The transmitters were designed to operate continuously for a minimum of 9-10 days. Each transmitter operated on a separate frequency to allow us to identify individual fish. Prior to implantation all tags were tested for proper function following a 12 h immersion in water.

Table 1. Release dates and the number of radio and/or acoustic transmitters that were implanted on each date.

date	10 April	17 April	26 April	6 may	20 may	22 may	25 may	12 June	13 June	14 June	15 June	27 June	total
hydroacoustic	9*	10	9*	10	7	0	2	2	0	3	1	3*	56
radio	5	5	5	5	0	3	3	1	1	1	0	1	30
total	13	15	14	15	7	3	5	3	1	3	1	4	85

*on these dates we were unable to implant the intended number of hydroacoustic tags due to failure of the tags to activate.

Tracking.

The migration behavior of the radiotagged yearling steelhead as they moved downstream from the ODFW screw trap was documented using radio and hydro acoustic telemetry. Following release, the locations of radiotagged individuals were monitored primarily by a boat equipped with one 4-element Yagi antenna and an ATS Challenger 2000 radio receiver. The boat was a 19' Alumaweld Formula Vee Jet Boat with an inboard Ford 302 V8 engine and a 770 series Hamilton Jet. Location data were collected daily for eight days after each release and then approximately every other day until fish were out of the system or tag-life ended. Typical boat sampling/tracking protocol consisted tracking upriver from the point where saltwater attenuated radiotag transmissions (generally at Fishery Point – hydrochemistry site 3, Fig. 5; see *Estuary Hydrochemistry* below). Upriver tracking was generally terminated approx 1 mile above the confluence on the mainstem of the Nehalem and approx 3 miles upriver of the confluence on the North Fork of the Nehalem. During each tracking event the seal colony at the mouth of the estuary was checked for radio tags. In addition, hydrochemistry readings were taken at fixed points throughout the system (see *Estuary Hydrochemistry* below). If a transmitter was heard, every effort was made to locate the exact position of the fish by modifying the gain and direction of the antennae. Fish locations were recorded by GPS equipment (Garmin GPSMAP 230), and were later imported into GIS software (ArcView 3.0) to determine exact distances traveled by the fish. At each fish acquisition, we also recorded water depth, time, and notes about the location and avian predators present in the area. While tracking, boat speed was fixed at 1500-1900 engine rpm (roughly 5 km/h) to allow the distance traveled by the boat within a full radio receiver scan-cycling time not to be greater than the range of the radiotransmitters (i.e., we would not miss any tags because we were going too fast). Tracking typically occurred after the peak of a high tide to maximize the chance of obtaining data on fish movements through the estuary.

In addition to the boat tracking described above, a significant proportion of time was spent tracking the fish from land. In 1999 it was found that some hatchery coho salmon implanted with radiotransmitters were transported by avian predators to the cliffs below Neah-Ka-Nie mountain. To monitor possible predation on wild steelhead smolts OCFWRU personnel conducted daily checks of the bird colonies in this area at times when fish with functioning radiotransmitters were present in the estuary. After the 3rd release it was noted that fish were often spending a significant portion of time in the upper river. To obtain data on this, fish movements in the upper river from the screw trap to a point approx 1 km downriver of the North-Fork Nehalem Fish Hatchery were also monitored by OCFWRU personnel from the land. In cases when fish with functioning radiotransmitters were present, this region was monitored 1-2 times each day.

Hydroacoustic research.

To determine the proportion of smolts surviving to different areas of the lower Nehalem watershed wild steelhead smolts were surgically implanted with hydroacoustic transmitters throughout the outmigration season. Ten releases were conducted in total with the number of fish in each release varying (Table 1).

Testing of the acoustic telemetry gear was conducted in summer 2000 in the Columbia River estuary and nearshore ocean (see Table 2 for a summary of the acoustic tag and receiver specifications that were used in 2001).

Table 2. Summary of acoustic tag and receiver characteristics.

Company	Type	Model	L x Diam. (mm)	Weight (g, in air)	Life (d)	#/Freq	Freq. (KHz)	Cost/ Unit	Notes
VEMCO	Tag	V8SC-6L-R256	24 x 8.5	3.3	53	256	69	$305	a,b
VEMCO	Receiver	VR2	340 x 60	1100	180	na	69	$1000	b

[a] turned on by soldering two external wires which must then be sealed
[b] life for the tag is based on a pulse interval of 15 seconds; for the receiver, a special single cell, replaceable lithium thiochloride "C" battery (by Tadiran) is used

Gear selection and deployment was based on prior research for other projects (Schreck and Stahl, 2000). Range results from that study were used to determine how far apart acoustic receivers would be placed. Further testing was conducted on mooring systems, to determine the specific and optimal design of acoustic receiver anchoring systems. Test moorings at the Columbia River bar were conducted in winter 2001 prior to release of fish to ensure that the mooring systems stayed in place and were recoverable in the often turbulent nearshore ocean. Based on these tests the final mooring system consisted of an 18 Kg Kedge anchor, connected to 3.2 m of 9.5 mm galvanized chain. The rope connecting the buoys to the chain was 13 mm crabline. Lead weights were used on the crabline to help maintain an upright attitude in the water. Above the water 2 styrofoam buoys painted in fluorescent yellow to ensure high visibility were used to ensure the system was not lost due to sinking of the buoys during high flows (Fig. 2).

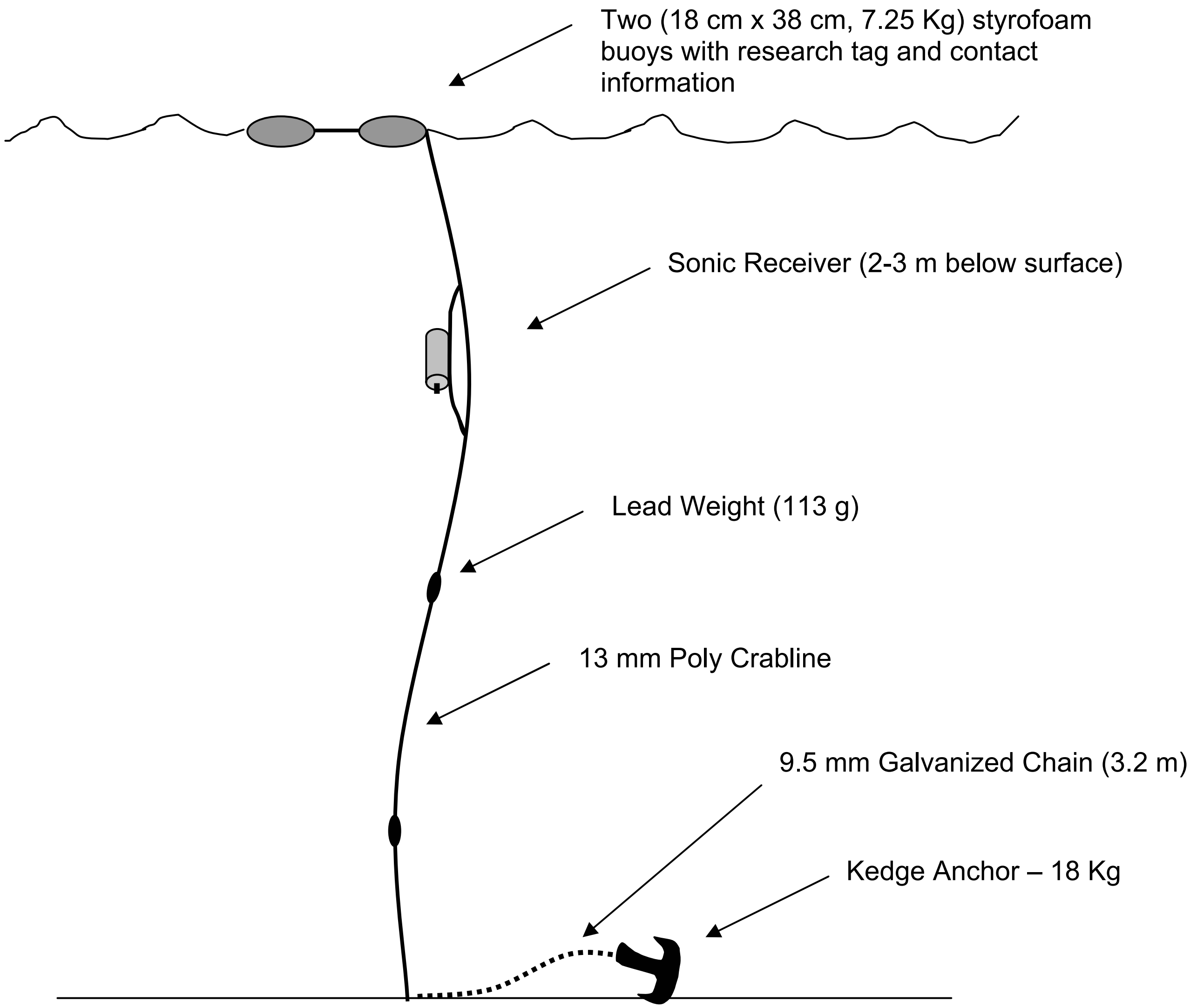

Figure 2. Acoustic Receiver Buoy/Anchor System

Automated hydroacoustic telemetry receivers were deployed throughout the estuary prior to the first release of fish on April 10. Each receiver was mounted on the anchor system approx 2-3 m below the surface with the hydrophone positioned to face vertically down. The receivers were positioned to ensure that the fish could not pass a particular site without being recorded. This entailed positioning the receivers so that the maximum distance between 2 receivers or between a receiver and the land was less than the minimum predicted range of the hydroacoustic transmitters. Based on preliminary trials in the Columbia River the minimum expected range for the transmitters was 200 m. Therefore, the receivers were placed a maximum of 400 m apart. One receiver was deployed on the North-Fork of the Nehalem approx 500 m upriver of the confluence with the mainstem Nehalem River in order to provide information on the travel times and survival of fish in the river proper (Fig. 3). This receiver also provided information on the arrival of fish into the estuary. A second receiver was placed downriver of Wheeler opposite Kahrs dock. Two more receivers were positioned approx 400m upriver of the seal colony near the mouth of the estuary. The final receiver was positioned between the jetties on the ocean side. On April 19th the bar conditions were sufficiently calm to allow the placement of 6 further hydroacoustic receivers in the ocean. This final line was placed up to 1 km out in a ring that circled the mouth of the estuary and was inplace approximately 30 h before the first fish from the 2nd release was recorded at the confluence. All receivers were left in place until the batteries of all acoustic tags would have failed.

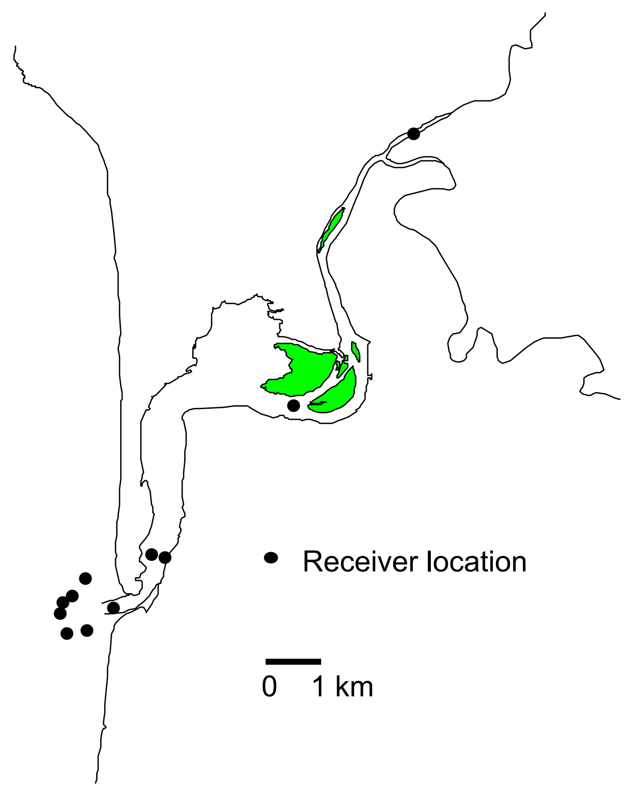

Fig. 3 Location of the hydroacoustic telemetry receivers in the Nehalem Estuary in 2001.

Predator Sampling

In order to understand the dynamics and predation rates of piscine predators, specifically double-crested cormorants and harbor seals, we conducted surveys of predators in Nehalem estuary. We also gathered data on smolt numbers in the Nehalem system, monitored nesting sites near the Nehalem estuary, and attempted to capture double-crested cormorants in order to estimate smolt consumption.

Predator Surveys.

Predator surveys were conducted in Nehalem estuary. Surveys consisted of timed periods of observation at different sites throughout the estuary, the location of which covered the entire surface area of each estuary (Fig. 4). Generally, The estuary was surveyed once daily throughout the entire season. In addition, on several occasions throughout the season two surveys per day were performed to determine daily variance due to time of day and tide. Surveys were typically conducted in the morning (0900-1000). On days when 2 surveys were conducted the afternoon survey was performed between 1500-1700.

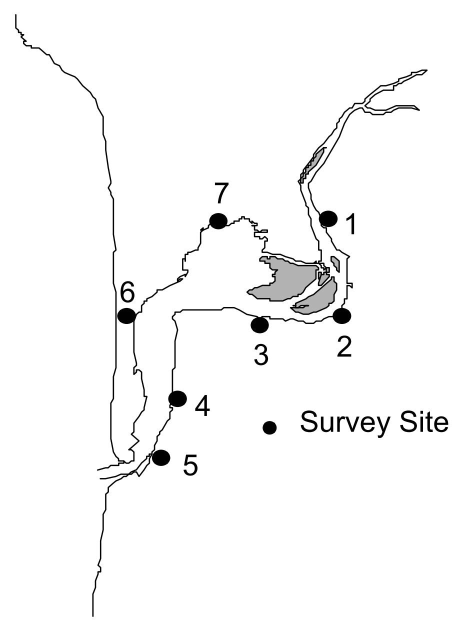

Fig. 4. Map of Nehalem Bay indicating predator survey sites (•)

For individual surveys, at most 10 minutes were spent at each site. This was done to standardize sampling and limit the total survey time to lower the chance of recounting birds at two sites. If all birds at the site were enumerated prior to 10 minutes elapsing, then the site was considered completed. Numbers of birds and their activity were recorded. Birds were spotted using both 10x50 binoculars and a tripod-mounted, variable-magnification (15-45x) spotting scope. Only birds that might possibly prey upon smolts were identified and recorded (number and activity). These birds, at the taxonomic level to which they were identified, were (possible species included in the group are indicated in parentheses) (see Appendix II E for a sample survey form):

- double-crested cormorants, *Phalacrocorax auritus*
- Brandt's cormorants, *P. penicillatus*
- pelagic cormorants, *P. pelagicus*
- western/glaucous-winged/hybrid gulls, *Larus occidentalis* and *L. glaucescens*
- other gulls, *L.* spp
- Caspian terns, *Sterna caspia*
- western/Clark's grebes, *Aechmophorus occidentalis* and *A. clarkii*
- other grebes (horned, eared, red-necked), *Podiceps* spp
- common murres, *Uria aalge*
- pigeon guillemots, *Cepphus columba*
- great blue herons, *Ardea herodias*
- mergansers (common, red-breasted, hooded), *Mergus* spp and *Lophodytes cucullatus*
- loons (common, pacific, red-throated), *Gavia* spp
- kingfishers, *Ceryle alcyon*
- brown pelicans, *Pelecanus occidentalis*
- bald eagles and other raptors, *Heliaeetus leucocephalus* and others

In addition to noting the numbers and activity of these birds, at each site the following information was also recorded:

- time
- tide
- precipitation (at a gross level; e.g. light rain)
- cloud cover (estimate of % of sky)

- sun (whether it is reflected off the water within the site)
- temperature
- Beaufort Factor (wind speed on a scale from 0-7)
- wind direction
- boat numbers
- seal numbers (primarily harbor seals, *Phoca vitulina*)
- notes on general observations and presence of other water birds (e.g., ducks, scoters, etc.)

No other census techniques besides these surveys were conducted by us on this system in 2001. However, numbers of several of these animals were recorded by the contractor performing the Smolt Protection Program (SPP) also recorded avian predator numbers while hazing. The SPP data were contained in reports submitted to ODFW and obtained by us.

Total Smolts in Estuaries

In order to determine whether smolts present in a system were influencing the number of predators (double-crested cormorants and harbor seals, specifically) in the system, we obtained data from ODFW on hatchery salmonid releases and numbers of wild salmonids captured in smolt on the North Fork of the Nehalem River [data courtesy Tim Dalton (Tillamook ODFW) and Joe Watkins (N Fork Nehalem Hatchery)]. Weekly totals of all salmonid smolts in the estuary were summed and calculated by assuming a constant migration rate from either the smolt trap for wild fish or the release point for hatchery fish (generally less than one day). Migration rate was determined from radiotagged coho salmon in 1999 and acoustic tagged steelhead in 2001. Fish that were estimated by hatchery managers to have left hatcheries volitionally were apportioned across the volitional release period. Weekly estimates were used because this was the finest scale at which the smolt traps and estimates of hatchery releases were considered accurate for numbers in the estuary. In order to obtain comparable bird estimates on a weekly basis, the maximum number of double-crested cormorants was taken from all surveys done in the week under consideration to obtain a value. This was done because summing the values from surveys would probably yield an overestimate, given that the same birds may have been counted on separate days.

Note that these estimates of the number of smolts in the estuary, where the avian predators were observed, are based on numbers of smolts upstream of the estuary (from smolt traps or hatchery release points) and are our best estimate as to the number of smolts in each system through time. However, given the nature of the data, these estimates do not take into account numbers of wild smolts from non-sampled streams (there were only a total of 2 smolt traps on the system in 2001) and residency time of all smolts in the estuary is unkown (though our biotelemetry data gives an estimate of this for hatchery coho salmon and wild steelhead smolts). Thus, our estimate should be considered an underestimate.

Objective 2. Assess the physiological condition of wild juvenile steelhead salmon from the North Fork of the Nehalem River prior to and during migration, and in relation to subsequent lower river, estuary, and nearshore ocean behavior, survival, salinity levels, and food availability.

Physiological Condition.

To determine physiological status relative to sea water readiness, wild steelhead smolts were sampled in the upper river three times during the outmigration (April – June 2000). Sampling was done in conjunction with the telemetry work. At each of these sampling times, 10 steelhead smolts were removed from the ODFW smolt-trap in the North Fork of the Nehalem River. For comparison 10 fish were also collected from the river above the trap by angling. Fish were killed with a lethal dose of anaesthetic (MS-222 200 mg/L buffered with $NaHCO_3$ 500 mg/L). Blood, was taken by severing the caudle peduncle and collecting the blood into heparinised capillary tubes. Plasma was separated following centrifugation and stored on dry ice until samples could be transferred to a –80^{0}C freezer for storage and later analysis of plasma cortisol concentrations. Stomachs were removed and stored in glass vials containing 70% ethanol.

Saltwater Entry.

Hydrochemistry data was collected in all instances when radiotagged fish were present in the estuary. Data were collected from fixed points established in 1999 to characterize the freshwater to saltwater transition zone of the estuary. Four standard sites for hydrochemistry measurement within the estuary were used based on sites selected in 1999. These ranged from the mouth to approximately 10 km upstream (Figure 5). The sites were located off the Jetty Fishery (site #4), Fishery Point (site #3), Wheeler (site #2), and the County Boat Ramp near the town of Nehalem (site #1). Water temperature and salinity were measured at these sites with a YSI model 85 DO/Salinity meter. For each site, measurements were taken at the surface, mid-point, and bottom of the water column. Depth was determined with a depth finder and was recorded. Measurements were taken during fish tracking, and thus mostly occurred around high tide, though throughout the season we obtained measurements at different tidal stages.

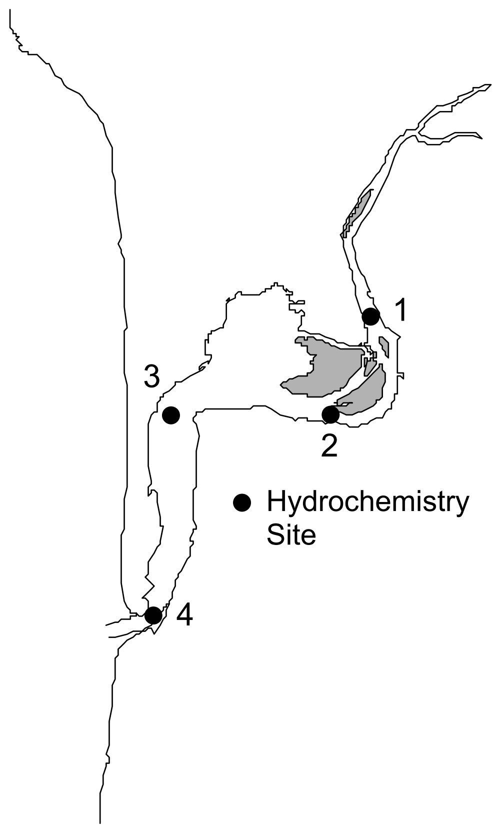

Figure 5. Map of Nehalem Bay indicating hydrochemistry survey sites (•)

Smolt Feeding.

Attempts to collect steelhead smolts in the estuary using a beach seine were unsuccessful, however large numbers of juvenile chinook salmon were captured. In order to obtain some information on food availability, a permit was obtained to lethally sample 20 juvenile fall chinook. These were captured by seining and killed in a lethal dose of MS-222. Stomachs were removed and stored in glass vials containing 70% ethanol.

RESULTS

Objective 1 Determine spatially-explicit mortality factors of steelhead smolts in the lower river, estuary, and nearshore ocean of the Nehalem watershed.

HYDROACOUSTIC RESEARCH.

Mortality Estimates.

During the first release 7 of 9 fish migrated to the estuary (Fig 6). Two fish were heard approximately 100 m below the release point over 1 month after the release; however, it was not possible to determine if these fish were alive. Of the fish that migrated to the estuary: 1 fish was not detected below the confluence; 1 fish migrated to paradise cove but was not heard downriver of this point; 1 fish migrated to the area above the Jetty Fishery but was not heard below this point; and 4 fish migrated successfully to the ocean (Fig 7). During the second release 8 of 10 fish migrated to the estuary. Of the fish that migrated to the estuary: 1 fish was not detected below the confluence; 1 fish migrated to paradise cove but was not heard downriver of this point; 4 fish migrated to the area above the Jetty Fishery but were not heard below this point; and 2 fish migrated successfully to the ocean. During the third release 9 of 9 fish migrated to the estuary. Of the fish that migrated to the estuary: 1 fish migrated to paradise cove but was not heard downriver of this point; 4 fish migrated to the area above the Jetty Fishery but were not heard below this point; and 4 fish migrated successfully to the ocean. During the fourth release 6 of 10 fish migrated to the estuary. Of the fish that migrated to the estuary: 2 fish migrated to paradise cove but were not heard downriver of this point; 1 fish migrated to the area above the Jetty Fishery but were not heard below this point; and 3 fish migrated successfully to the ocean. During the fifth release 9 fish were released and 5 were detected in the estuary. Of the fish that migrated to the estuary: 2 fish migrated to the area above the Jetty Fishery but were not heard below this point; and 3 fish migrated successfully to the ocean.

During the sixth release 6 fish were tagged, however none were detected in the estuary. These fish spent anywhere from 4 days to 1 month in the pool below the trap. Similarly, none of the 3 fish tagged during the seventh release were detected in the estuary. However, two fish did remain by the trap for over 40 days at which time the receivers were removed. Analysis of the receiver data suggests that these fish were moving within the river although we could not determine if these fish left the pool to swim up or downriver before returning.

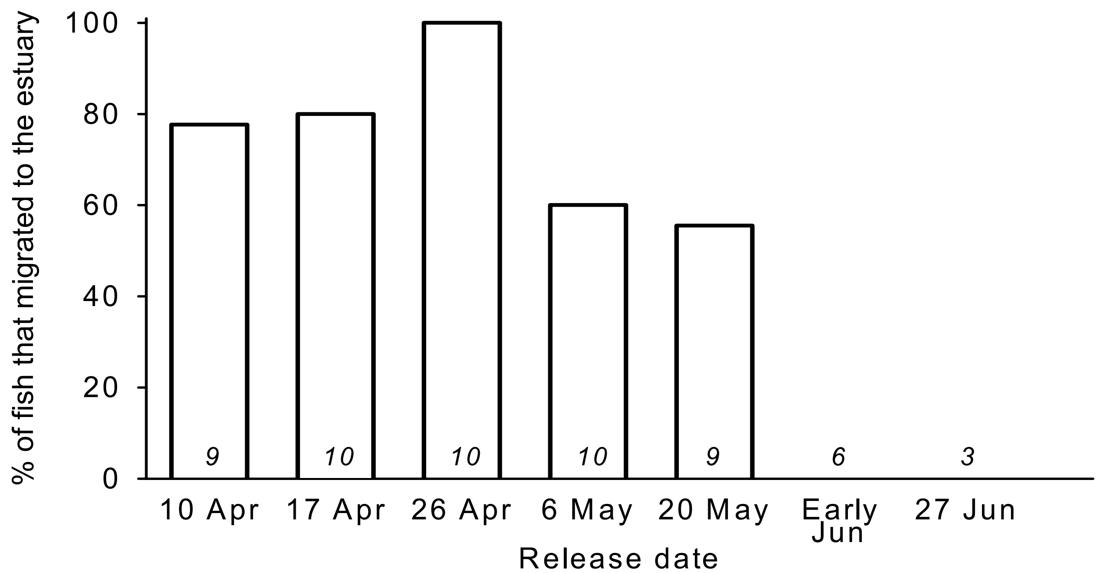

Fig 6 Percentage of fish (*N*) that successfully migrated from the lower screw trap on the north fork of the Nehalem River to the confluence with the mainstem Nehalem River.

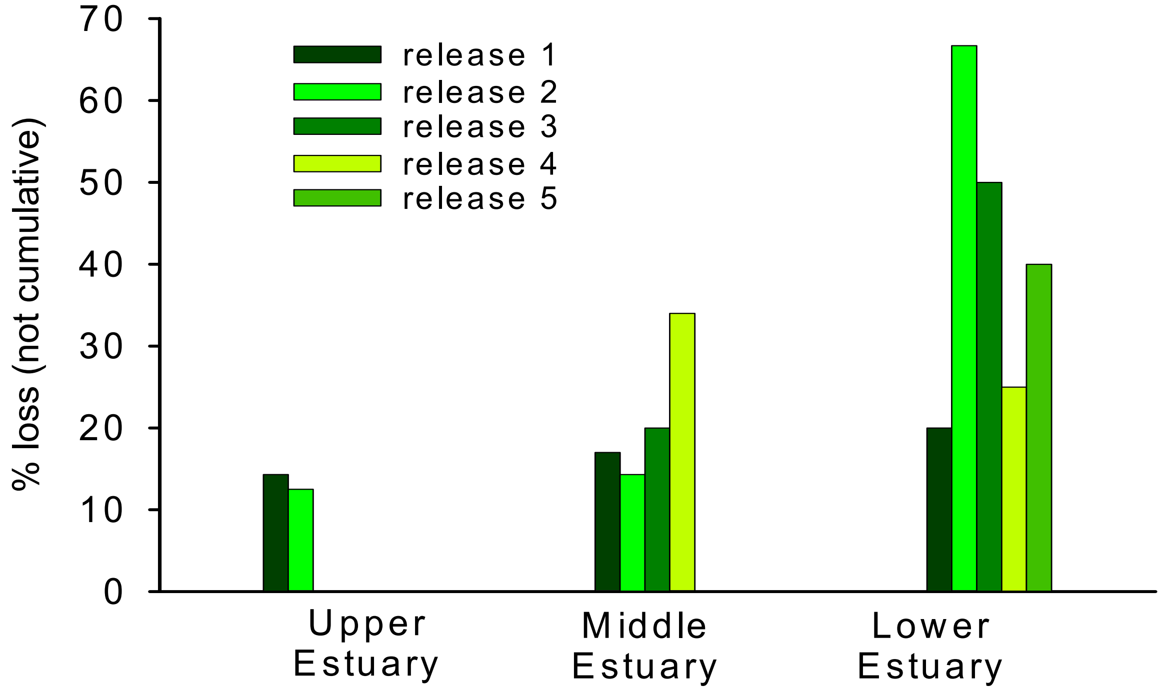

Fig. 7 Percentage of fish that were lost in each zone of the estuary by release date. Percentages were calculated by setting the number that passed each line of receivers to equal 100% then calculating the percentage of this number that were lost in the zone downriver.

Spatial estimates of mortality across the entire outmigration were calculated by setting the number of fish that were detected at the beginning of the zone to 100% and subtracting the number of fish that were not heard again downriver from this. Thus the numbers from this represent the % loss in each zone that is not cumulative. The majority of fish were lost in the relatively small area between the Jetty Fishery and the ocean (Fig 8)

The overall loss of fish in each zone of the estuary is calculated by setting the number of fish that migrate to the confluence as 100% and then subtracting the number of fish that were lost in each zone from this figure. In the area between the confluence and Paradise Cove only 5.7 % of fish went missing (2 of 35). In the area between Paradise Cove and the Jetty Fishery 14.3 % of fish were lost (5 of 35). The greatest loss occurred in the area between the Jetty Fishery and the Ocean. Thirty four percent of all fish making it to the estuary were lost in this area (12 of 35). During the first release when the line of receivers was not present in the ocean 5 fish were recorded by the 2 receivers at the Jetty Fishery and 4 of these were later heard by the receiver placed at the outermost end of the jetty. If one assumes that the missing fish also passed into the ocean successfully but was missed by the last receiver our estimates of loss in this zone change very little (from 34% to 31%).

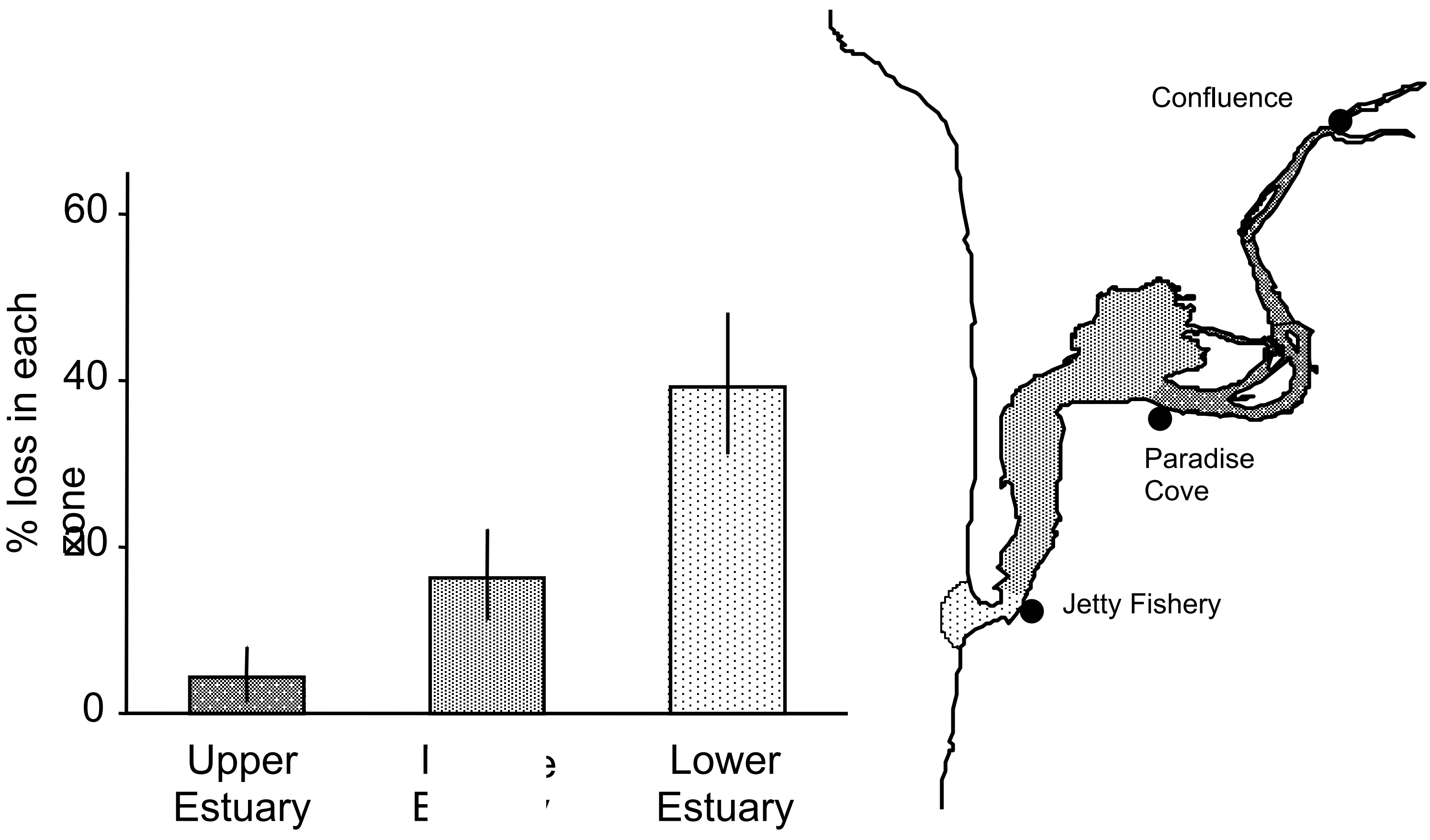

Fig 8 Percentage loss (not cumulative) of fish in three zones of the Nehalem Estuary (average loss from 5 releases of steelhead smolts). Each column corresponds to a zone on the map, identified by the fill pattern.

Efficiency of the receivers

In order to determine the efficiency of the acoustic receivers at detecting fish, the number of known missed detections was calculated for each site. That is, if a fish was not detected at an up river site but was subsequently detected lower in the system then it must have been missed.

The receiver at the confluence detected 100% of the fish that were heard passed that point. The receiver at Paradise Cove detected 100% of the fish that were heard passed that point. The two receivers above the Jetty Fishery detected 96.4 % of the fish that were heard past this point (27 of 28). The receiver at the mouth of the jetties heard 62.5 % of the fish that were heard past this point (10 of 16). The receivers in the ocean detected 87.5 % of the fish that were assumed to have reached this point (10 of 12). Ocean receivers were not deployed during the first release so it was not possible to include these numbers in calculating the efficiency of detection of the ocean receivers. In the remaining 4 releases the line of ocean receivers missed only 2 fish that were detected by the receiver at the mouth of the jetties.

To determine whether wave noise was a factor in the ability of the ocean receivers to detect fish we obtained wave height data from the NOAA website for the Columbia River (buoy number 46029). When this was plotted on the graphs of fish passage through this area (Appendix I Figs.) there was no apparent correlation between the ability of the receivers to hear fish and the wave height. During the first release several fish were detected in the nearshore ocean when the significant wave height was between 4-5 m, which was the highest recorded during this period. During the second release the ocean was relatively calm with the wave height ranging from 0.5 –3 m. The highest wave heights were recorded during the third release; however, again there was no correlation between this and the ability of the receivers to detect fish. Three fish were heard at the jetty fishery but were not heard in the ocean, however, at the same time 2 fish were detected at both lines of receivers. Ocean conditions in releases 4 and 5 were relatively benign so it is unlikely that the efficiency of the receivers was compromised by wave noise in these instances. A number of conditions change the efficiency of the receivers even on an hourly basis. Given this, and the fact that it is unpractical to monitor and test the efficiency on an hourly or daily basis we deployed the receivers in a way that would cover as much of the estuary for the majority of the time. Following the deployment of the receivers we tested each one to ensure it would cover the width of the estuary. Also during analysis of the data one can obtain some indication of the effectiveness of the receiver by checking the detection time for each fish (i.e. how long each fish is in range). In contrast to the Columbia system where fish were often detected only 1-5 times the Nehalem receivers logged fish for between 5 min and 10 hours depending on the tidal stage, suggesting that the range of the receivers was more than adequate to cover the estuary. In order to maintain the optimum function the estuarine receivers were regularly cleaned to remove algae and debris. The ocean receivers were only checked once during the 2 months that fish were present in the estuary, during the last 3 weeks the receivers accumulated a significant amount of fouling including sponges, barnacles and algae. In order to determine whether this had any effect on the detection range of the receiver we conducted a test comparing the performance of fouled vs non fouled receivers. We did not find any decrease in performance of the receiver when tags were within the 250 m detection radius that formed the basis of our receiver placement, it is still possible that tags outside this range would be less likely to be heard, or that during periods of high noise the receivers would work less effectively with the fouling. Our data suggest also that there was no effect as survival to the ocean was similar for all releases including the early ones when receivers were clean.

During 2002 we were able to test the receivers for their reception efficiency (Appendix II Fig F). Our results indicated that calculating the efficiency using known passage of fish (as above) was very similar to the results obtained using drogue tags. Furthermore, the efficiency of the ocean array was between 80-100 % even with the missing receivers in 2002.

Migration Behavior.

In River.

The majority of fish migrated to the estuary during the first 5 releases (Fig 6). In general fish took 125.5 ± 9.8 h to migrate the 20.2 Km down the north fork of the Nehalem River from the lower screw trap to the confluence with the mainstem. However, there was considerable variability both within and between releases with the exception of the 26 Apr release.

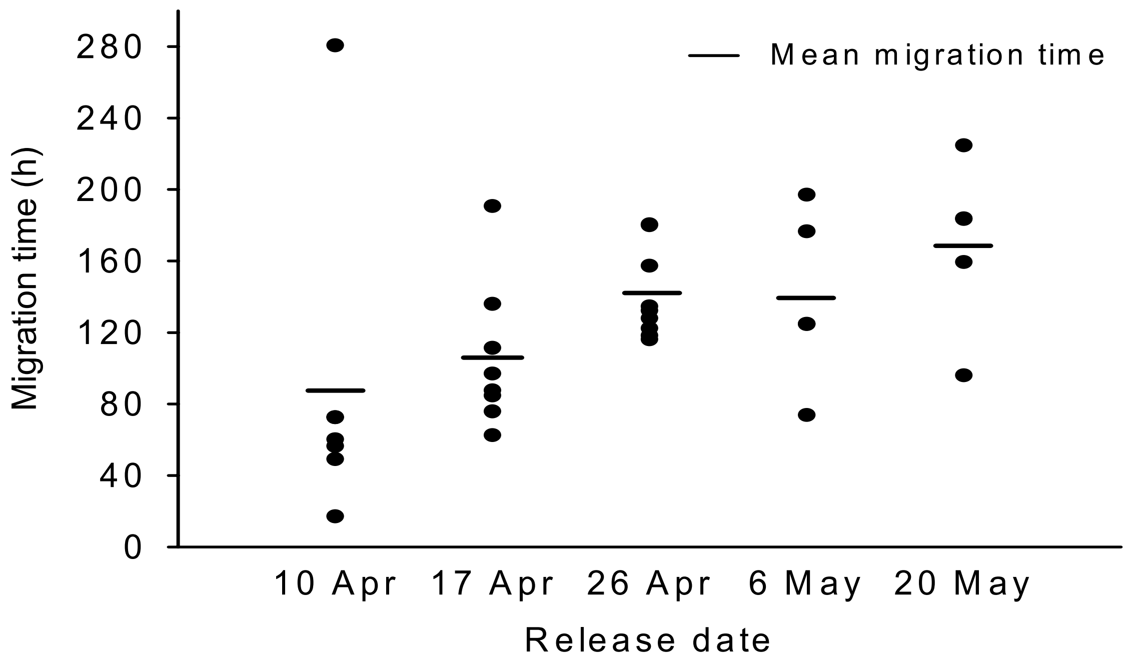

Fig 9 Scatter plot of the time taken for individual fish to migrate from the lower ODFW screw trap on the north fork of the Nehalem River to the confluence with the mainstem.

The variation between releases could be explained by the flow (Appendix II Fig A). As the mean flow (7 day average) decreased during the season, the mean travel time increased (P = 0.036; ANOVA; 1,4 df; $r^2 = 0.81$) (Fig 10). The change in migration rate is given by the simple linear regression model;

Migration time (h) = 92.58 h – (0.398*7 day mean flow)

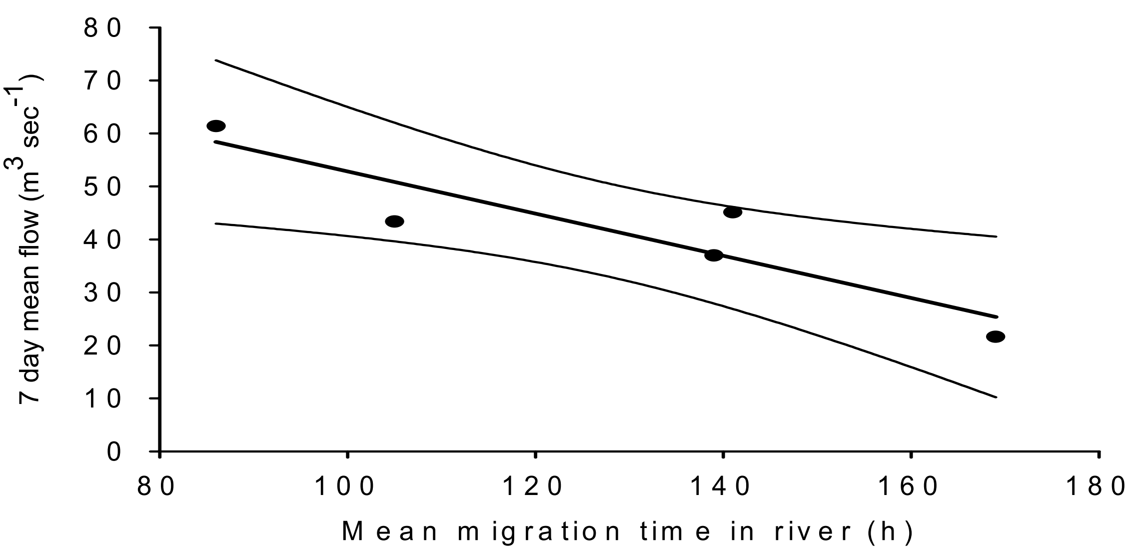

Fig 10 Plot of the Mean migration time for each release vs. the 7 day average flow. The simple linear regression model indicates a negative correlation. Bounded by 95 % confidence limits.

Migration speed varied significantly between releases (P = 0.229; ANOVA, 4,33 df). The fish in release 3 moved significantly faster than the fish in release 1, most likely due to heavy rainfall during this period, however there were no differences between the other release dates (Fig 11).

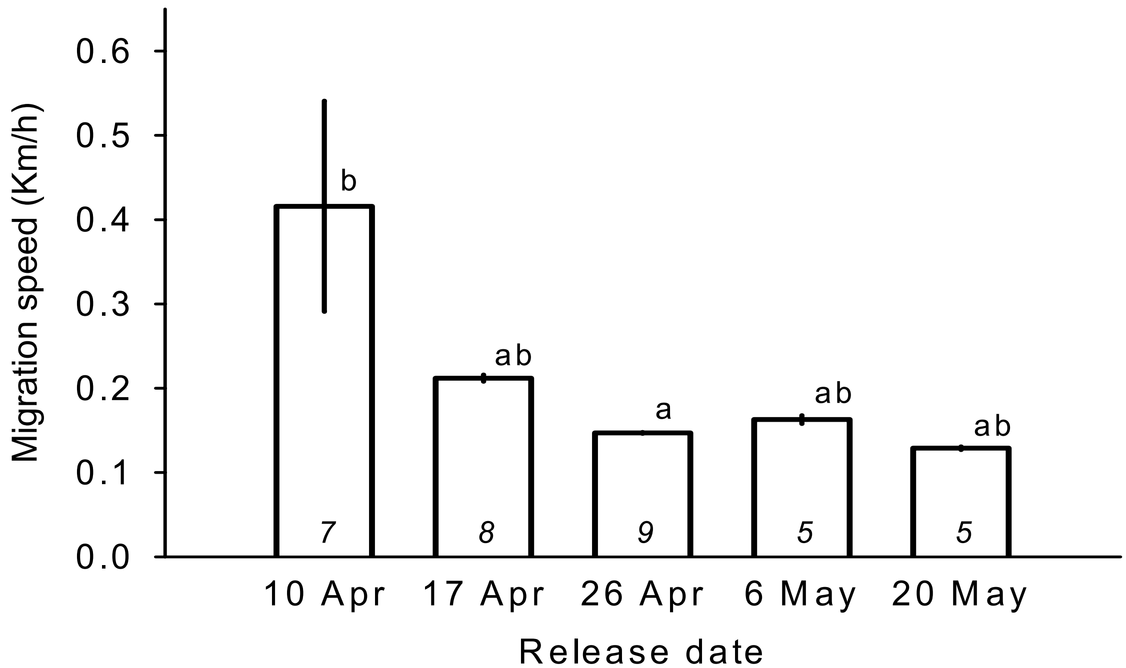

Fig 11. Mean migration speed (± SE, *N*) of fish in the north fork of the Nehalem River between the ODFW lower screw trap and the confluence with the mainstem. Columns that are not significantly different share a common superscript (P > 0.05)

Estuarine

Residence time in the estuary was calculated by subtracting the time fish were last heard on the receiver at the confluence from the time the fish was last heard on the receivers at the jetty fishery. In general fish took 14.5 ± 1.7 h to migrate a total distance of 11.2 Km. (Fig. 12). However, there was considerable variability both within and between releases that relates to the influence of the tidal cycle on each fish. (see Appendix I Figs.). In general fish move through the estuary on an outgoing tide and tend to be stationary on a slack or incoming tide.

Migration speed did not vary significantly between releases. The average speed through the estuary taken across all releases was 1.19 ± .15 Km/h (Fig 13)

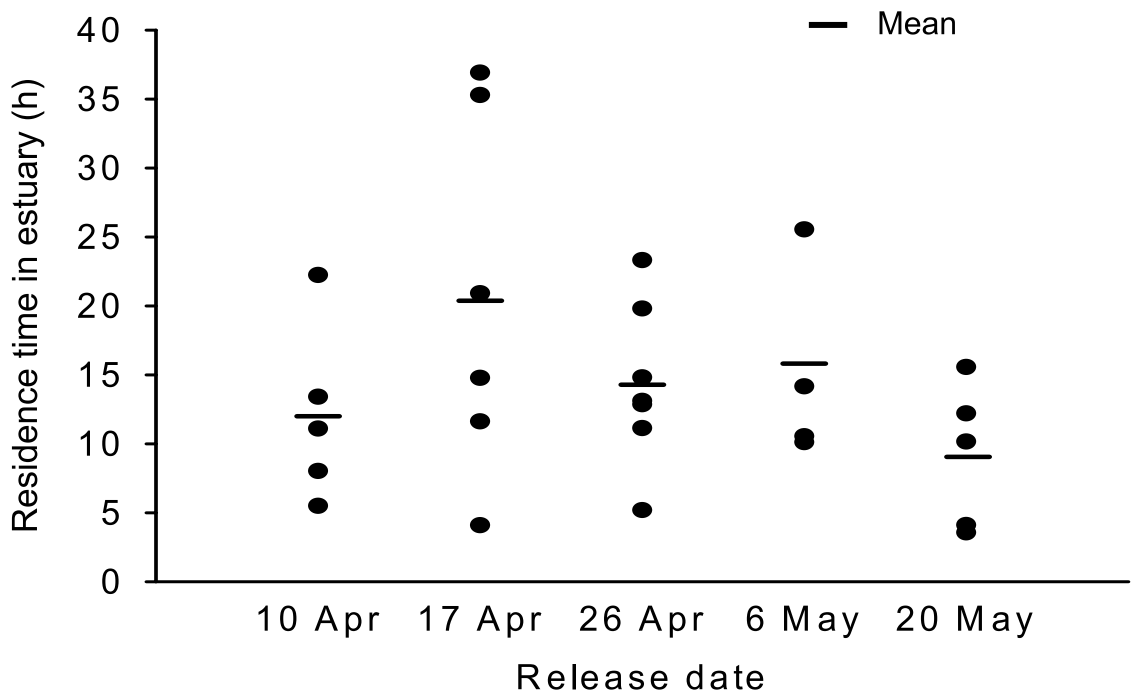

Fig 12 Scatter plot of the time taken for individual fish to migrate from the confluence of the north fork with the mainstem to the Jetty Fishery.

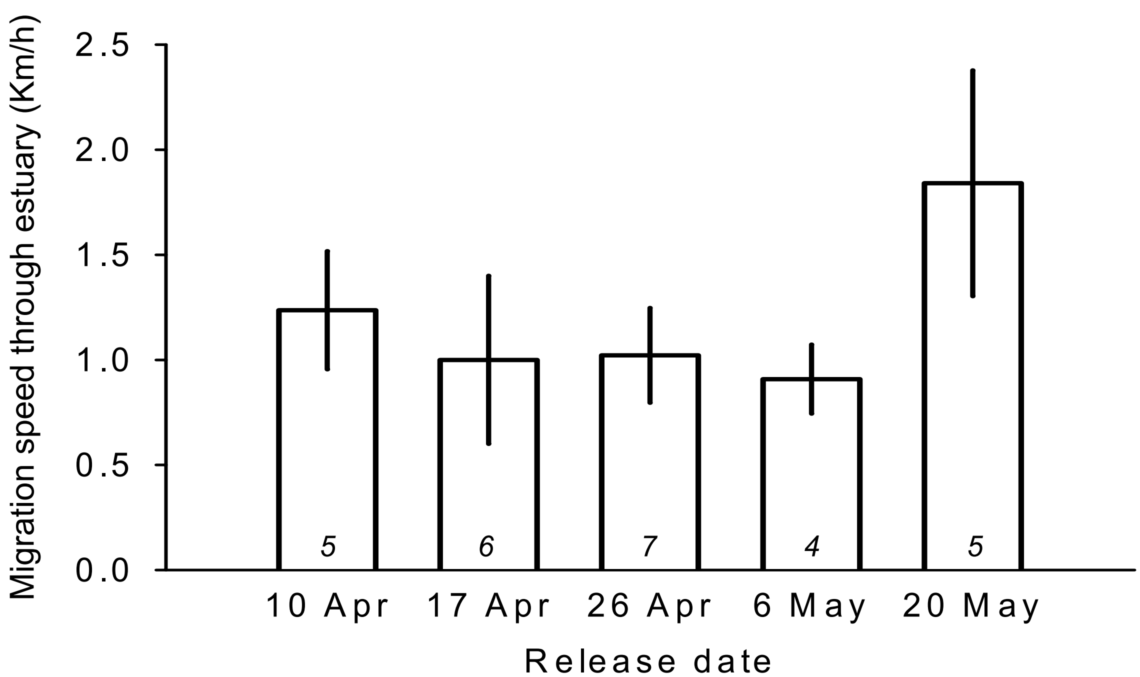

Fig 13. Mean migration speed (± SE, *N*) of fish in the estuary of the Nehalem River between the confluence with the mainstem and the Jetty Fishery. Columns that are not significantly different share a common superscript (P > 0.05).

We compared the residence times of the wild steelhead in 2001 to those of the hatchery coho salmon in 1999 (Fig 14). For hatchery coho the predicted residency is based on the speed of fish to the point that they were last heard in the estuary. The minimum observed residency times represent the average period of time that the fish in a release were heard in the estuary. The maximum residence time assumes that fish remained in the estuary for 1 day longer than they were detected. For wild steelhead the predicted residence time is based on the migration rate through the estuary on each release. Minimum and maximum values represent the observed values during a particular release. Our data suggest that wild steelhead move more rapidly through the system than did the hatchery coho salmon in 1999.

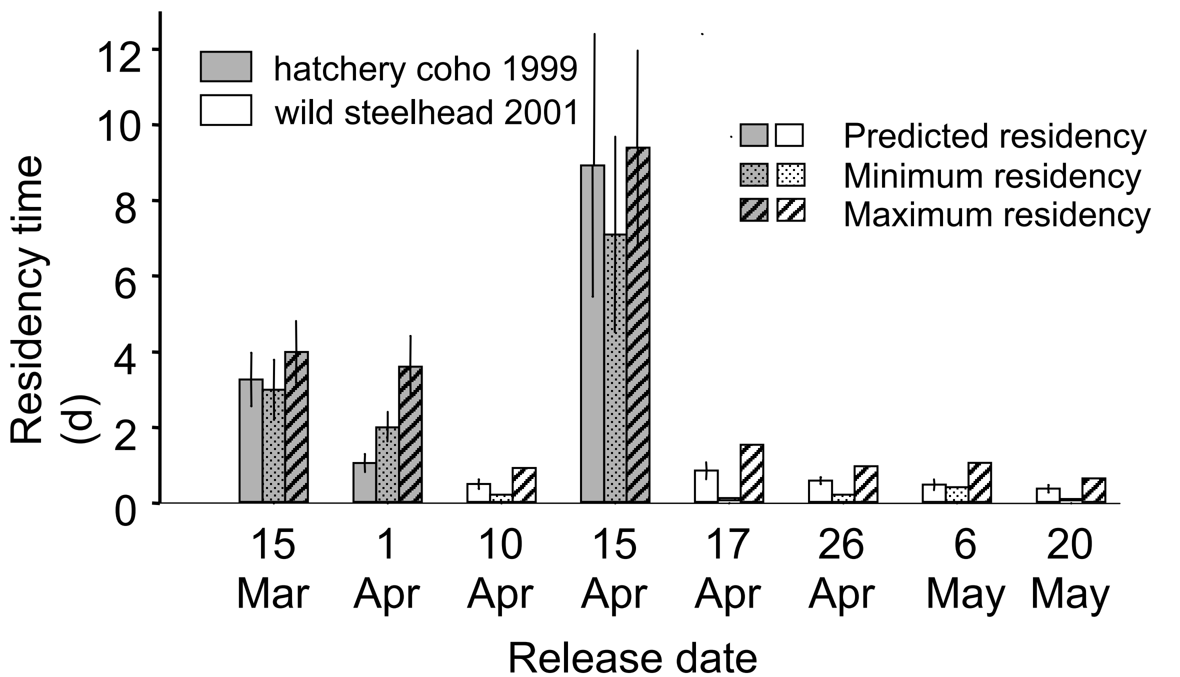

Fig. 14. Residency time of radio and acoustic tagged smolts in Nehalem in 1999 and 2001 for each of our releases (+1 se). Predicted (based on migration rate and distance alone), and observed (early and late) residency estimates are given.

We were able to gain some insight into the direction that fish are moving when they first enter the ocean (Fig. 15). The direction of movement was extrapolated by accounting for the time fish were heard on a particular receiver, and whether they were also heard on more than one receiver. All the fish tended to head west, most likely following the main flow of the river. We never observed any fish turning south. Our ability to detect fish moving north was compromised due to the loss of the receiver that was placed to the north of the jetties.

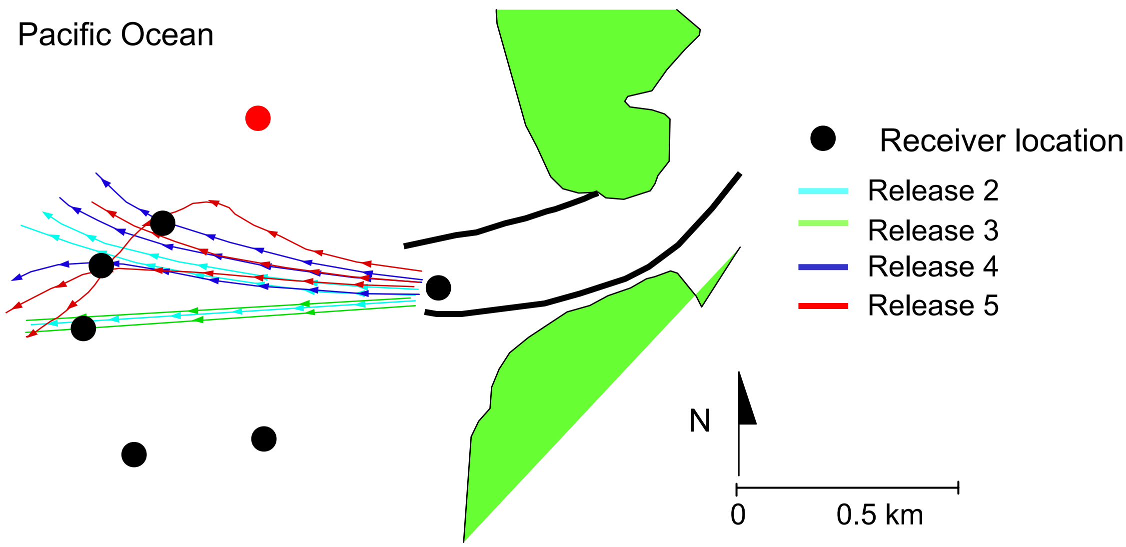

Fig. 15. Plot of the estimated direction of fish exiting from the mouth of the Nehalem River Estuary. Direction is estimated based on the detection times and the pattern of detections at the line of ocean receivers. The receiver at the location in red was missing prior to retrieval of the data.

RADIOTELEMETRY RESEARCH

Mortality Estimates.

We did not observe any mortality of radiotagged smolts in the Nehalem estuary in 2001.

Migration Behavior

Movement of radio-tagged fish appears to be linked to periods of rainfall, and most likely, the associated increase in river flows (Fig 16). Early in the season fish moved down to the estuary relatively quickly. During the first, second and third releases the range was between 3 and 7 days before fish were detected in the estuary. For the 4th release both fish that were detected in the estuary took 9 days to migrate from the Screw trap. In all cases these times were similar to those of the fish that were implanted with acoustic tags. Later in the season (after ~ 6 May) when river flows were decreasing, movement in the river decreased significantly with a number of fish remaining stationary at the screw trap on the North Fork. On several occasions we observed fish holding here for a number of days, only migrating downriver during periods of rainfall. During the last three releases fish remained in the river sufficiently long so that the batteries in the tag died before the fish reached the estuary.

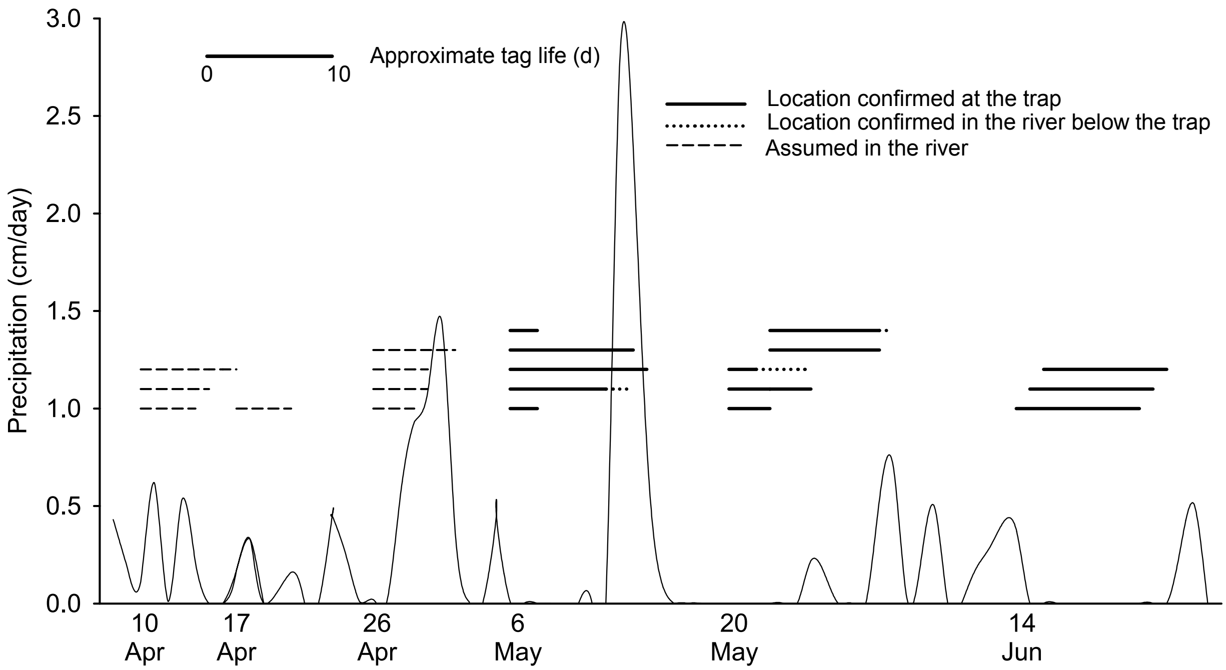

Fig 16. Plot of the residence time of individual fish in relation to precipitation. Each bar represents a single fish released on one of the 6 release dates. The length of each bar denotes the number of days that the fish remained by the trap, in the river below the trap, or was assumed to be in the river. Precipitation data were obtained from the North Fork Nehalem Fish Hatchery.

PREDATOR SURVEYS.

Double-crested cormorants were the most abundant avian predator in the Nehalem Estuary (Table 3). In contrast, the data from 1999 suggest that harbor seals were the dominant predator.

Table 3. Relative abundance of predators in the Nehalem estuary in 2001 and 1999. Data were calculated as average percents of total number of predators over the season. The most abundant predators are in bold.

	Predators							
System	Double Crested Cormorant	Other Corm.	Caspian Tern	Grebe	Great Blue Heron	Merganser	Loon	Seal
Nehalem (2001)	**37.6**	7.1	6.3	0.7	7.9	0.4	0.2	**30.1**
Nehalem (1999)	**19.30**	3.44	10.28	3.17	3.17	8.57	5.7	**46.38**

Large numbers of double crested cormorants were present in the estuary at the beginning of the study (Figure 17). Numbers ranged from 0 to 152, with an average of 48 $\pm$ 4 birds in the estuary per day.

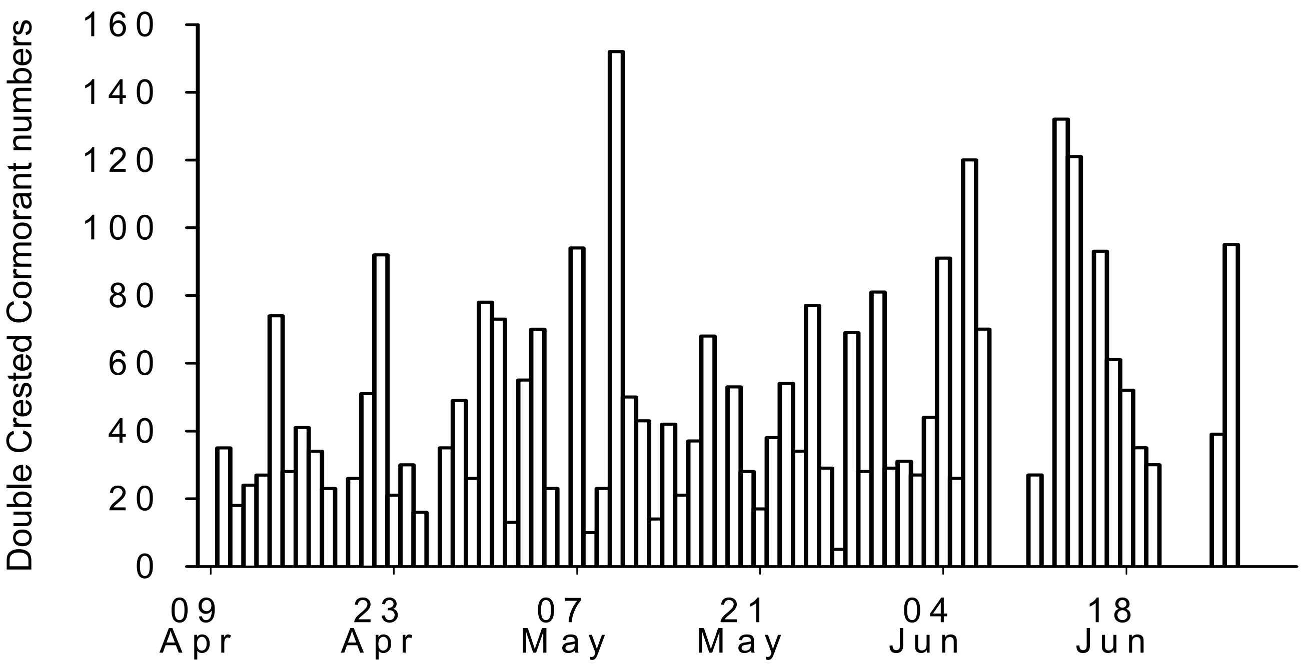

Fig. 17 Total number of Double Crested Cormorants present in the Nehalem estuary during each survey (2001).

Caspian terns were also present in the system at the beginning of the study, However, by the end of April the numbers were negligible (Fig 18). We speculate that these birds were moving north to the Columbia River estuary for the breeding season.

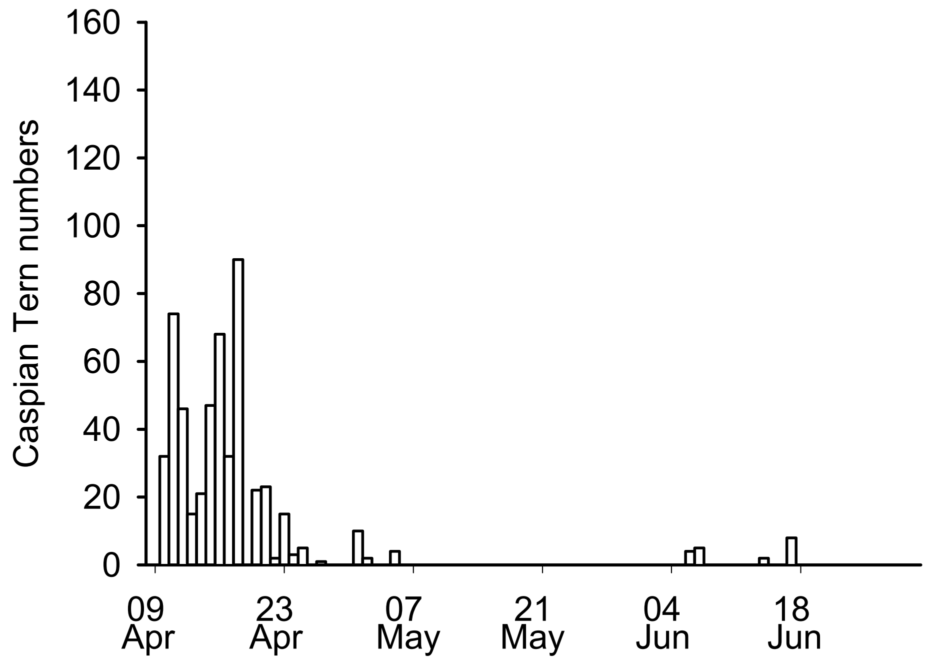

Fig. 18 Total number of Caspian Terns present in the Nehalem estuary during each survey (2001).

Location of Avian Predators

Our data indicates that double-crested cormorants were most often observed near the middle of the estuary (Fig 19). This may be due to the presence of desirable roosting habitat such as pilings. Similarly, it is possible that juvenile salmonids were present in larger numbers in this area if they were holding to avoid saltwater, or they preferred foraging in fresh/brackish water rather than saltwater. We often observed cormorants roosting on the mudflats in Nehalem Bay at low tide and on the pilings between Paradise Cove and Fishery point. Furthermore, this area appeared to be the most common foraging site. The distribution of cormorants in the estuary in 1999 was similar, although more birds were observed further up the estuary around the towns of Wheeler and Nehalem than in 2001.

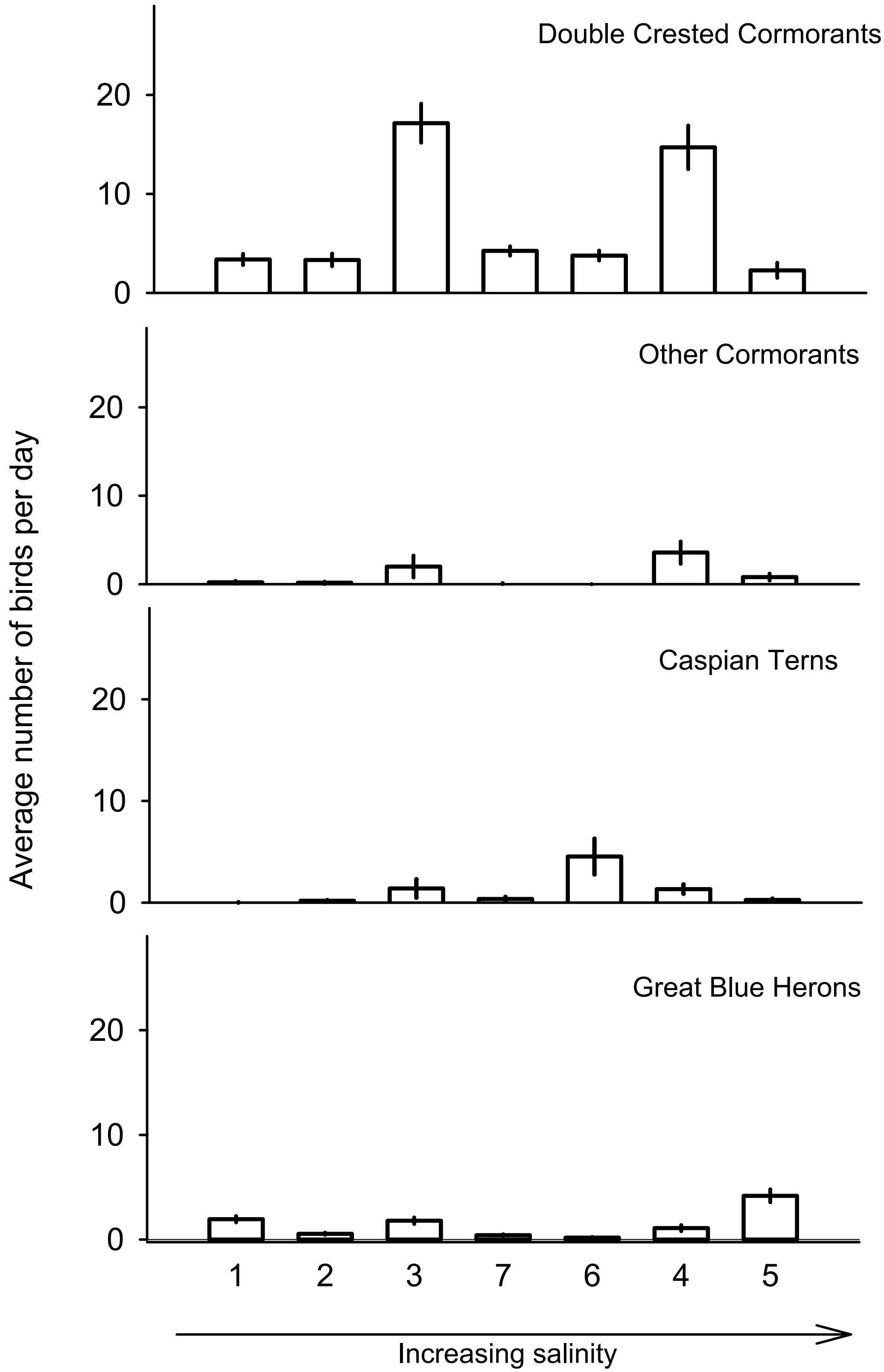

Fig. 19 Average number of avian predators (per day) present at each location in the Nehalem estuary during the season (2001).

We investigated the possibility that the observed differences in the locations of cormorants between the two years was due to changes over time in 2001. Early in the season it appears that some cormorants were foraging further up in the estuary near the town of Nehalem. This may have been a response to the release of hatchery fish at this time of the year. This time period also overlaps with the study done in 1999. This suggests that the distribution of cormorants in this part of the smolt outmigration was, in fact, very similar between years. In 2001 double crested cormorant numbers were relatively constant near the town of Wheeler and closer to the ocean at Brighton and the Jetty Fishery. In contrast, the number of cormorants tended to increase over time between Paradise Cove and Fishery Point. Most likely the result of movement of birds from further up in the estuary (Fig 20).

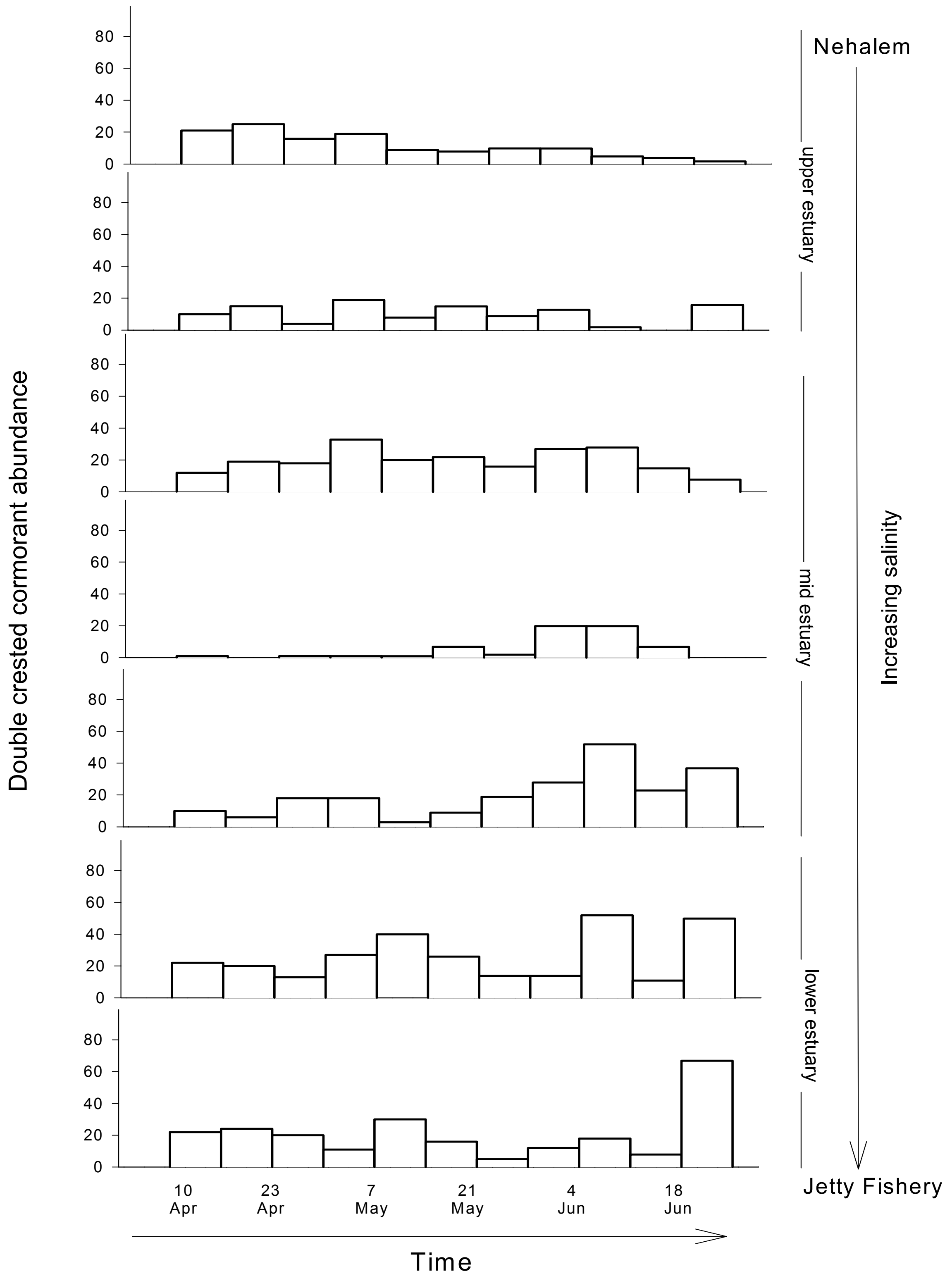

Fig. 20 Proportion of double crested cormorants present over time at each site. Data were normalized by converting the total number at each site on each day to a proportion of the maximum number observed at that site. These values were then averaged over a 7 day period.

Total numbers of double crested cormorants were similar to those in 1999 during the same period of the year, however, we did not observe the same peak number of birds in 2001 (Fig 21).

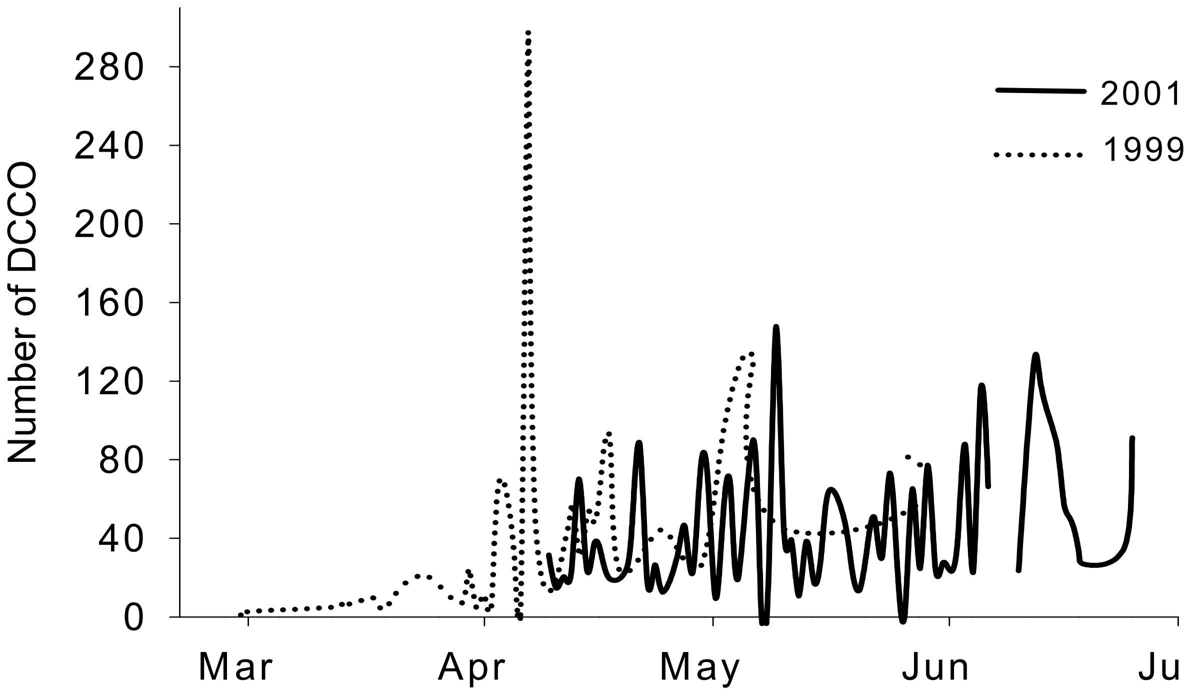

Fig. 21. A comparison of the total number of Double Crested Cormorants present in the Nehalem estuary during each survey in 1999 and 2001.

Seals,

Harbor seals were present in large numbers in Nehalem. Numbers approached and surpassed 100 on several occasions (Fig. 22). Most seals were observed at resting, or pullout, sites on the beach near the mouth of the rivers (Fig. 23). However, they were also observed foraging upstream as far as the confluence of the north fork and mainstem Nehalem river, approximately 13 km upstream from the mouth of the river.

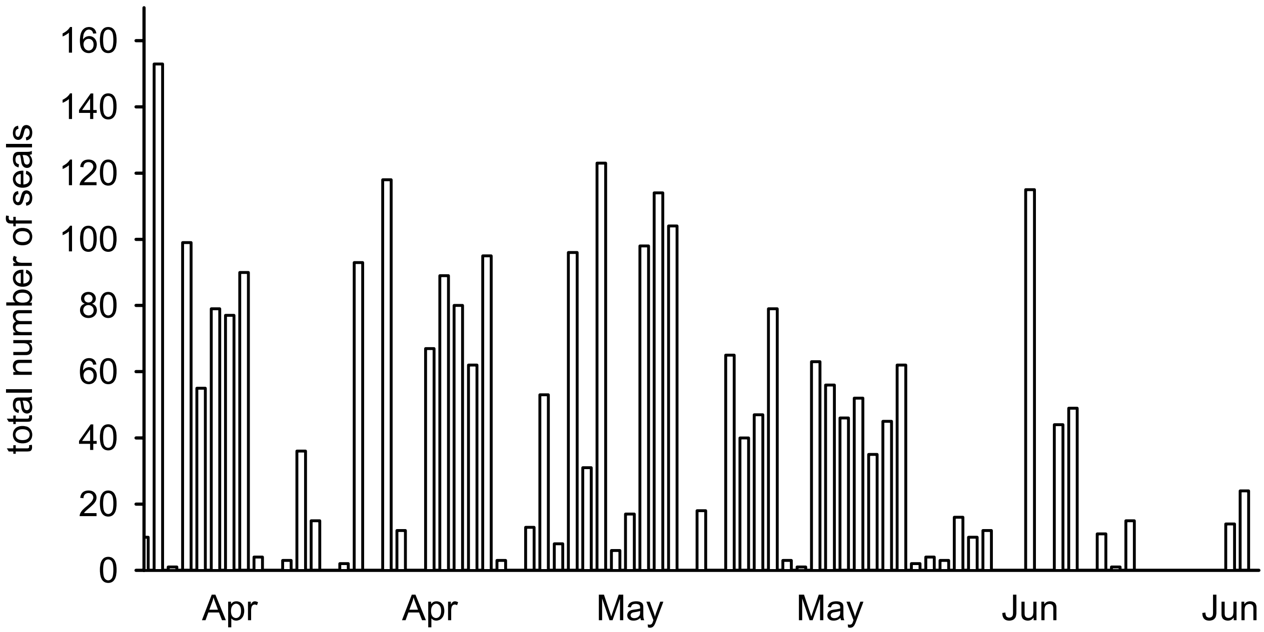

Fig. 22 Total number of harbor seals present in the Nehalem estuary during each survey.

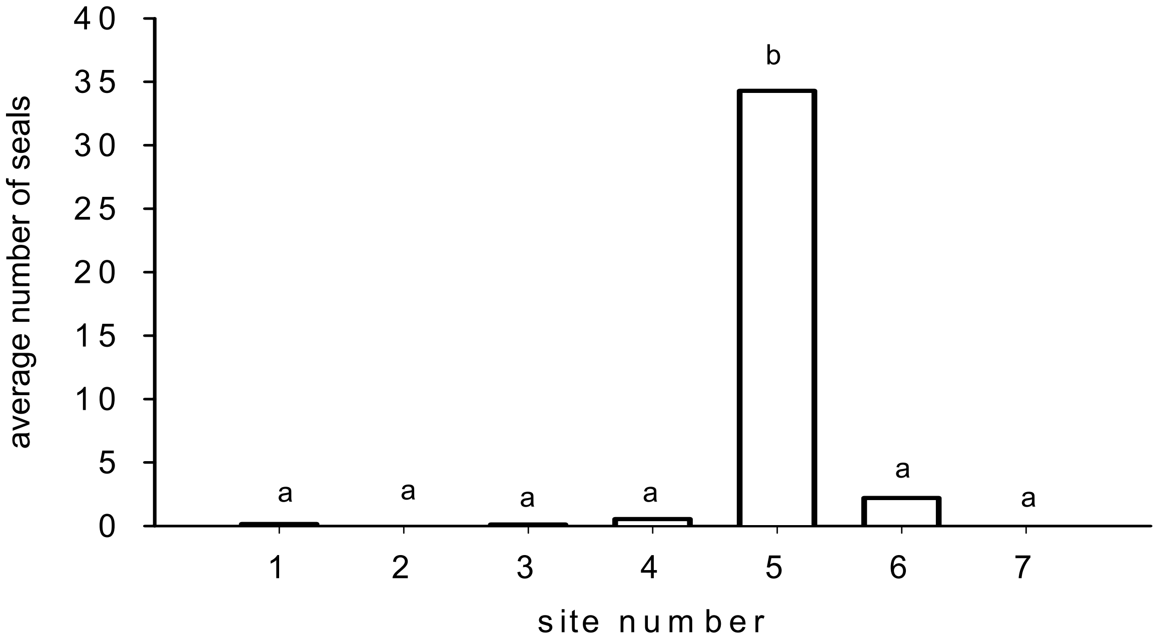

Fig. 23 Average number of harbor seals (per day) present at each location (see Fig. 4) in the Nehalem estuary during the season. Columns that are not significantly different share a common superscript (P > 0.05)

As for the cormorants, the overall seal numbers were comparable to those in 1999, however we did not observe the same peak numbers in 2001 (cf >300 in 1999) (Fig 24)

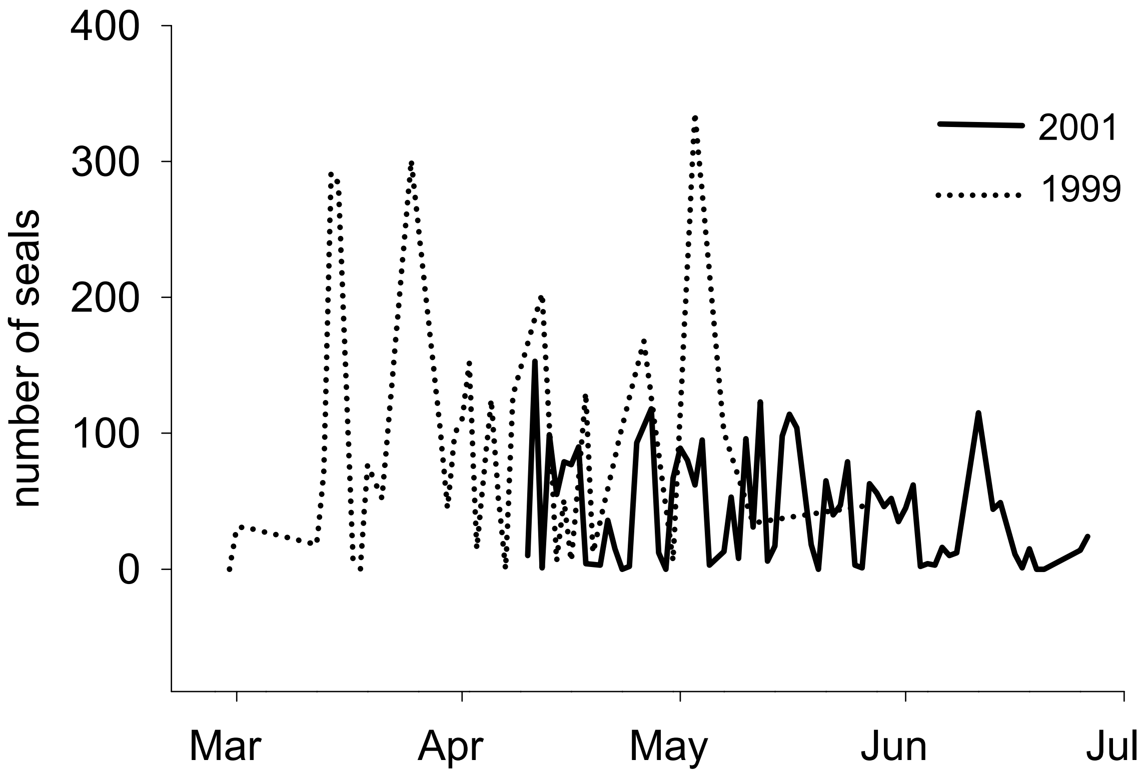

Fig. 24 A comparison of the total number of harbor seals present in the Nehalem estuary during each survey in 1999 and 2001.

Double-Crested Cormorant-Specific Research.

We gained experience in the live-capture of double-crested cormorants. Based on the daily predator surveys we set leg hold traps on several pilings that were used by cormorants between Paradise Cove and Fishery Point, opposite mile post 49 on Highway 101. Attempts to capture cormorants began in early June and continued throughout the month. After the traps were set we observed the behavior of the birds from a distance for several hours. However, for several weeks after the traps were deployed the cormorants avoided landing on these pilings. The traps were left closed when OCFWRU personnel were not present in an attempt to habituate the birds to their presence. Observations at the end of the study suggest that some birds were using these pilings. We also attempted to camouflage the traps using black cloth and built a small platform to encourage roosting. Based on these efforts we suggest that future attempts to live capture these birds allow for a period of acclimation to the presence of the traps.

Total Smolts in Estuaries

Based on our estimates of the total number of smolts in each estuary, peak numbers were driven by hatchery releases (Figure 25). We examined the relationship between smolts and cormorants and smolts and seals on a weekly time scale. There was no relationship between cormorant numbers and smolt numbers for our study period (10 April to 26 Jun). In the latter part of the study, cormorants and seals may have remained in the system due to the presence of fish we do not know were there (i.e., not released from the hatchery or sampled in the smolt traps; smolt data was taken from upstream sites and all wild fish or marine fish were not accounted for). It is also possible that the number of smolts needed to maintain this population level of predators is considerably lower than the peak numbers estimated following the hatchery releases. Also, these data are based on a weekly scale, which may be inadequate to see a relationship because cormorant and smolt numbers may be mismatched. This could arise from lags in response of cormorants to smolt influxes or not knowing the true number of smolts in the estuary at a finer time scale coincident with that used for cormorant sampling. In addition, double-crested cormorant numbers may be driven by other factors than smolts.

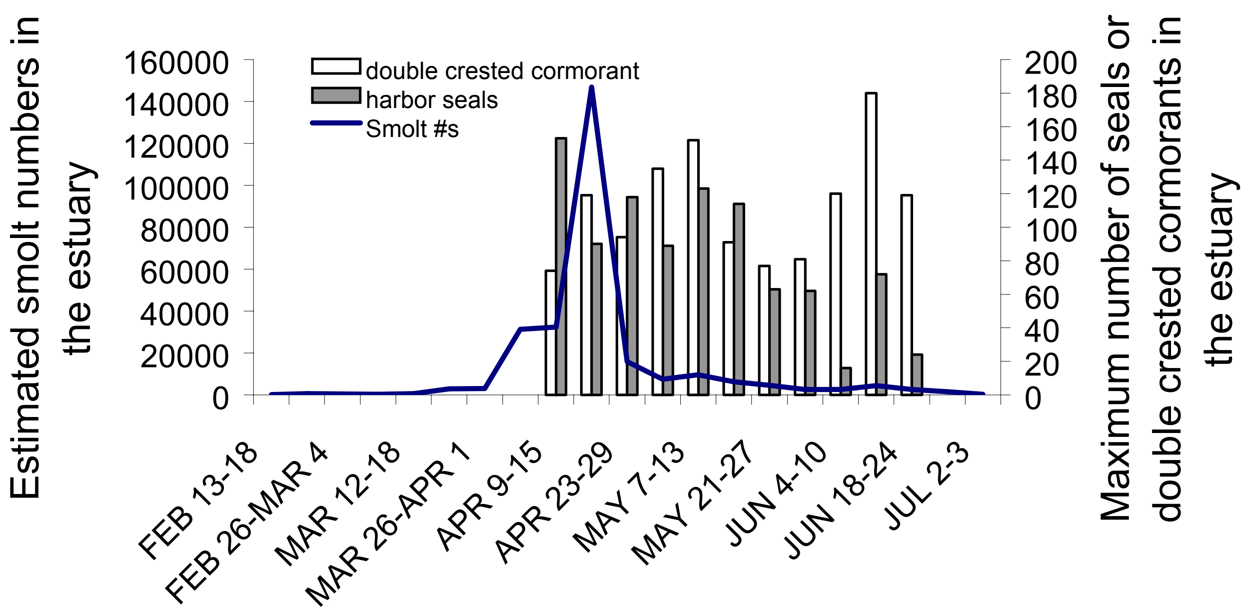

Fig. 25. Plot of the relationship between estimated smolt numbers and predators (double crested cormorants and harbor seals) in the Nehalem estuary. Predator numbers were not collected prior to April 10.

Historical fish trends.

Attempts were made to acquire data about the historical abundance of alternate prey species and predators. However, these were largely unsuccessful. In conversations with agency staff and the public it appears that there may have been some seining done in the estuary some time ago but the information has never been complied and organized. Furthermore, the value of this information is questionable given the lack of consistency in data collection and the patchiness of the data in time. Given the large scale fluctuations in marine species numbers over time due to events such as *El Nino* any historical trends would need to take into account these occurrences. In 2001 we observed a large number of anchovies (*Engraulis mordax*) in the system, that were not present in 1999. These fish attracted a large number of avian predators, however, we do not know whether their impact on the smolts was beneficial or not.

Objective 2) Assess the physiological condition of wild juvenile steelhead salmon from the North Fork of the Nehalem River prior to and during migration, and in relation to subsequent lower river, estuary, and nearshore ocean behavior, survival, salinity levels, and food availability.

Smolt Physiology

Fish length varied significantly between the sampling dates (p=0.002, Kruskall-Wallis). Fish size tended to decrease during the season. The length of fish that were released after the 6 May was significantly lower than that of fish released prior to this date (Table 4). In general the fish that were sampled for physiology were not as long as the fish that were tagged, most likely due to the highgrading of fish for the tagging. Condition factor was not different among any of the groups of fish. All but 1 fish that were sampled were infected with BKD, this is in contrast to 1999 when we did not observe any BKD in hatchery coho. Plasma cortisol was not different on any of the 3 dates that fish were sampled for physiology. Cortisol levels were significantly lower in fish that were taken directly from the river upstream of the trap, most likely because the fish from the trap were stressed prior to our sampling by capture and handling. The measures of stress, smoltification, and disease were used to determine if there were any major differences between groups. Our results suggest that all the fish were similar during the early part of the outmigration. However, we were not able to sample fish during the latter part of the migration so it is possible that these fish were physiologically different from those fish sampled earlier.

Table 4. Morphological and physiological measurements of wild steelhead from the North Fork of the Nehalem river. Cells within a row that are not significantly different share a common superscript (P > 0.05)

	Fish sampled for physiology				Fish sampled for telemetry						
	17 Apr	26 Apr	6 May	In river	10 Apr	17 Apr	26 Apr	6 May	20 May	13 Jun	27 Jun
Length cm	16.1^{ab} *0.34*	18.2^{bc} *0.28*	15.9^{ab} *0.32*	14.9^{a} *0.74*	19.15^{cd} *0.43*	20.26^{d} *0.28*	19^{cd} *0.24*	18.6^{c} *0.38*	15.5^{a} *0.18*	15.4^{a} *0.37*	14.9^{a} *0.42*
Weight g	44^{ab} *2.42*	54.9^{b} *2.11*	41.1^{a} *1.88*	41.2^{ab} *3.73*						36.6^{a} *2.88*	31.6^{a} *3.31*
Condition factor $g.mm^3.10^5$	1.1^{a} *0.03*	0.9^{a} *0.04*	1.0^{a} *0.03*	1.2^{a} *0.19*						1.0^{a} *0.03*	1.0^{a} *0.04*
Cortisol ng mL^{-1}	180.1^{b} *4.70*	177.8^{b} *14.69*	161.8^{b} *18.66*	28.5^{a} *10.80*							
BKD	100%	90%	100%								

Estuary Hydrochemistry.

Salinity in Nehalem decreases as one moves upstream from the mouth of the river (Figure 26). At site 3, Fishery Point, where the estuary makes a dogleg south, salinity at low tide (when salinity is lowest; approximately 3-5 ppt), was such that our radiotags no longer transmitted through water to our receivers. At high tide, salinity here often reached full strength saltwater.

Fig. 26 Salinity measurements (ppt) taken at low tide at 4 sites through the Nehalem Estuary. Measurements were made at the surface, near the middle of the water column, and at the bottom.

Salinity at site one near the county boat ramp appeared to be influenced by the river flow (Figure 27), however this relationship did not hold for those sites further downriver.

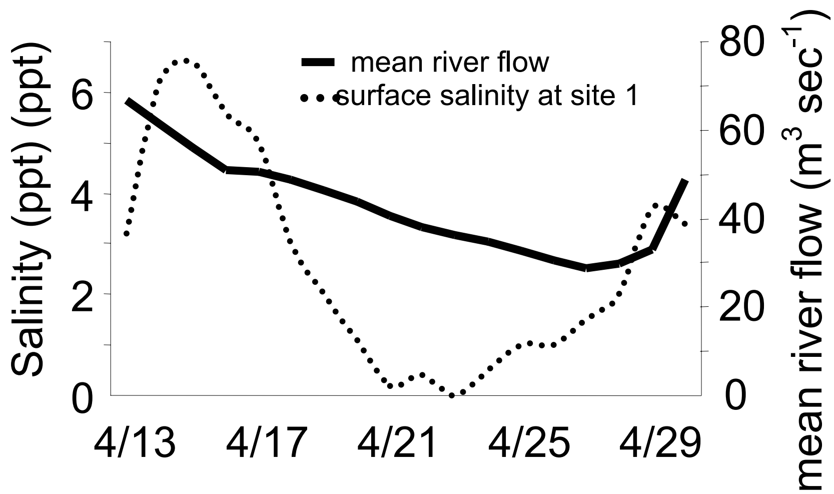

Fig. 27 Salinity measurements (ppt) taken at the surface at site 1 and plotted against the mean river flow in the mainstem of the Nehalem River.

DISCUSSION

This report presents the findings of the first year of a proposed three year study. The study is directed at identifying spatially explicit sources of mortality of juvenile steelhead trout in the Nehalem river system. Our data suggests that a large proportion (~54 %) of the annual outmigration of juvenile steelhead may be lost prior to reaching the oceanic feeding grounds. Our data further suggest that the majority of the loss occurs in a relatively small zone (-2 km) near the mouth of the estuary. Using hydroacoustic telemetry to determine predation rates depends on three basic assumptions: 1) untagged fish will survive at the same rate as tagged fish; 2) all fish that were not detected at an array perished upriver and; 3) that any fish that perished did so because of predation rather than of other factors such as disease. It is possible, though unlikely, that implanting acoustic tags into these fish compromised their ability to avoid predators. A number of studies have examined this and found little or no effect (Adams, et al. 1998; Jepsen et al. 1998; Martinelli, et al. 1998; Moore et al. 1990). Jepsen et al. (1998) found that mortality of radio tagged smolts was not statistically different from untagged smolts (Table 5)

Table 5 Comparison of mortality of tagged vs untagged fish. Source Jepsen et al (1998).

	Number released (untagged / tagged)	Mortality (calculated from trap catch)	Mortality (radiotagged smolts)
Salmon Hatchery	8715 / 50	86.4	87.5
Trout Wild	4560 / 24	81.8	87.5

Our own experience suggests that survival in the laboratory is between 0-5 % within 30 days following surgery. Furthermore, we did not observe any inflammation around the incision wound, which appears to be of more concern with the implantation of radio tags that have an external antennae. Despite these studies it is not clear what effect the surgery has on burst swimming which may be important for predator avoidance. In order to minimize the chances of releasing sick/injured fish we held fish for 3-5 hours following surgery. Our experience suggests that within a relatively short time it is possible to observe whether a fish has been negatively impacted by the surgery to the point that survival is unlikely. Holding fish during their migration for extended periods (i.e. 1-5 days) will activate the stress response, which in itself can affect swimming and survival. We take the view that it is better to release the fish back into the river and allow recovery to occur in a natural environment. Travel time to the estuary was generally over 3 days, which should be ample time for fish to recover from the surgery. Therefore we do not consider the losses in the estuary to be a consequence of the stress induced by the tagging procedure. Other factors that may affect the ability of tagged fish to survive include tag properties. Tag weight was around 6-8% of the fish's body weight during the study, with the exception of the last two releases where fish were slightly smaller. Despite the common assertion that tag weight should not be more than 2% of the fish's body weight there is very little scientific data supporting this idea. Brown et al. (1999) discuss this and provide evidence that transmitters up to 12% body weight have no effect. Our experience also suggests that the effect of the antennae should also be taken into consideration as long antennas often cause more problems for smaller fish that does the tag itself. As the acoustic tags have no antennae this problem is voided. Finally the weight of the tag in air does not provide a good indication of its effect on the fish as buoyancy characteristics can vary widely.

The second assumption could be tested by searching the areas between receivers manually. This was not done during the current study due to lack of equipment, however based on our knowledge of movement patterns of these fish it is highly unlikely that any missing fish would remain outside the range of the upper and lower sets of receivers for over a month. Finally, it is unlikely that other factors such as disease resulted in direct mortality. Bacterial kidney disease is highly prevalent in many northwest populations of salmonids. The ELISA that was used to measure BKD indicates the presence or absence of the antigen. The cutoff point we used for interpreting the optical density readout is fairly conservative and merely shows that at some point in their history these fish were exposed to the antigen. None of the levels we recorded were above the cutoff for assigning a clinical level of infection, nor did we ever observe any signs of the disease. The ODFW pathologists at OSU do not consider our results to be significant given that steelhead and trout are many times more resistant to BKD than other salmonids. Based on their work it is also unlikely that these fish are dying after entering saltwater. The long incubation period of this disease also means that the fish we tagged would not have died from the disease during the period from release to ocean entry. It is also unlikely that, even if the stress of tagging caused an infection, behavior would be altered within this timeframe. Finally, given that no differences in BKD levels were observed across the season we could not make any conclusions about the link between behavior/mortality and BKD levels. Similarly, the plasma cortisol results do not suggest that there were seasonal differences in the stress response. The Cortisol levels are high but this is most likely due to the trapping operation as fish captured directly from the river had relatively low plasma concentrations of cortisol. Based on laboratory experiments the fish that were trapped would most likely have recovered resting levels of plasma cortisol within 1-2 days which would occur prior to entering the estuary. Given that behavior and survival of the steelhead was similar between the first 5 releases when fish reached the estuary it is not surprising that we did not observe any physiological differences between these fish.

During the spring/summer of 2001 we also studied the migration of juvenile steelhead in the Columbia River. In this system we observed a trend for the majority of fish to exit the rivermouth at or near the end of the outgoing tide and have proposed a hypothesis that this leads to the concentration of fish into a relatively small area at a well defined time. By extension predators could take advantage of this by feeding in this area near the end of an outgoing tide. Although many fewer fish were released in the Nehalem during 2001 it appears that such a trend may also exist in this system and further investigation should reveal if this is in fact the case.

Relatively few predators were observed in the upper part of the estuary and our estimate of mortality in this region is correspondingly low. Double crested cormorants were most abundant near the middle of the estuary, coinciding with the interface between fresh and saltwater. Estimated mortality in this region was significantly higher than in the upper estuary. It is at the fresh/salt water interface that fish that are inadequately smolted are likely to delay the downstream movement, thus making them more vulnerable to predation in this region. However, the wild steelhead tended to move very quickly through the estuary. The only holding behavior we observed was due to the influence of the tides rather than any apparent 'decision' by the fish to remain in a particular area. Harbor seals were most abundant in the region just upriver of the estuary mouth, corresponding with the region of greatest estimated mortality. Despite the correlation between mortality and predator abundance we cannot confirm whether the fish were actually taken by either birds or seals. It is also possible that piscine predators are consuming some smolts, and we have yet to confirm that we can detect the tags if the fish is consumed either by a seal or another fish.

High numbers of alternate prey may help alleviate predation pressure on wild smolts however, they might also indirectly, or directly affect survival by competing for food resources. We found no evidence that the release of large numbers of hatchery fish reduced the estimated mortality for wild fish. Similarly we found no evidence that the large numbers of anchovies observed in the estuary during the third release reduced the predation pressure on steelhead smolts. It is possible that the number of predators on the Nehalem estuary is based on the carrying capacity of a system with considerably fewer salmonid smolts than are released from hatcheries. It is also possible that salmonid smolts do not represent a large proportion of the diets of these predators, outside the period of hatchery releases. It is unlikely that fish of the size we were studying reside in the estuary for a long enough period of time that competition for food resources becomes a factor.

The total number of predators observed during 2001 was very similar to 1999. Our estimates of mortality between these years were also similar despite the difference in species (steelhead and coho) and origin (wild vs. hatchery). However, we did document significant differences in the behavior of these fish. The residence time for hatchery coho salmon in the estuary appears to be significantly longer than that for wild steelhead. Furthermore, the coho salmon appear to spend a significant period of time in the upper/middle region of the estuary. This behavior may prolong the period of time that these fish are vulnerable to avian predators. It would be interesting to determine the prey selectivity of a harbor seal. Given that the steelhead smolts are considerably larger it is possible that these fish are preyed upon selectively by these predators. Future work should be conducted to accurately assess hatchery/wild and species differences in behavior that could account for differential mortality in all regions of the estuary. It would also be of interest to consider those fish that migrate to the estuary at an early stage in their life history and use this area to rear. Prolonged residence in the estuary is likely to increase the vulnerability of these fish to predators, and it is possible that these fish contribute to the diet of predators outside the peak period of migration. This would explain in part why predator numbers and smolt numbers were not correlated in the current study.

In order to mitigate for the loss of salmonid smolts options include the management of habitat in the river and estuary or predators. For example, we could manage habitat (physical and biotic components) in the lower river and estuary to increase survival in these areas. Interestingly enough, we also might be able to increase survival in the ocean through upstream management. The "health" of a watershed is generally determined by the quantity of smolts produced. However, enumeration may not be a sufficient index of adult survival because fish quality is not considered. To illustrate this point, hatcheries produce a large number of fish, but it is accepted that survival of these fish is lower than wild fish. The same may hold true for wild smolts; different habitats may produce fish of different quality. Is it possible that seemingly good practices that increase fish abundance upstream could cause inadvertent problems by decreasing the quality of outmigrant smolts, thereby lowering their survival after emigration? Hence, another management option might be to manage upstream habitat for smolts in order to produce healthier fish which survive better in the open ocean. Our data also suggest that the movement of juvenile steelhead is closely linked to periods of rainfall. The effect of releasing hatchery fish during periods of high rainfall should be evaluated with the goal of reducing predation by reducing travel times, and thus exposure to predators. This may also have an added benefit of reducing visibility in the river and estuary, thereby making it more difficult for visual predators.

Also of interest in the current study was the tendency of fish that were tagged later in the season to remain resident in the river. Although these fish did not migrate to the estuary it appears that they were moving within the river. Given that this is the first documentation of this behavior it is not clear whether this is a response to environmental conditions or if this behavior occurs every year. If these fish did not emigrate until the following year they may contribute to increased competition for food resources with the next seasons year class. Therefore it may be important to determine if this is a response to low water or part of the natural variability in life history strategies of these fish. In relation to this, the migration of the tagged fish was closely linked to periods of precipitation and river flow. Most fish migrated from the river as the river flow increased following rainfall. Given the influence of the physical characteristics of the catchment on river flow efforts should continue to understand how such practices as deforestation and the resultant increase in the ‘flashiness’ of the river impact the migratory behavior of these fish.

What leads to "ocean mortality"? Is the significant portion of post-smolt mortality in the lower river, estuary, nearshore area, or high seas? Do upper-watershed effects contribute to downstream or ocean mortality? By understanding these questions, we can then develop prioritized management plans intended to increase the survival of steelhead salmon in the Nehalem watershed, as mandated by the Oregon Plan.

SPECIFIC RECOMMENDATIONS

Given the results obtained in 2001 and the success of the hydroacoustic system, we make the following recommendations:

- continue and build upon work started in these studies in order to understand the interactions between the nature of the upper watershed, predators, smolt physiology, smolt migration, and smolt vulnerability to predators.

- Comparisons between species and between hatchery/wild fish would be most valuable given the differences documented between 1999 and 2001.

- Increase the number of tagged fish in each release in order obtain more reliable estimates of mortality.

- Extend the length of tag life later in the season to follow the movement of fish that remain in the river.

- Conduct further tests to determine the efficiency of the receivers under a variety of conditions.

- Consider the use of manual tracking for hydroacoustic tags in order to search for tags that go missing in some areas. This may give some indication of whether the fish is still in the area or whether it has been transported away, possibly by avian predators.

- Increase the number of radiotags and extend their life so that meaningful estimates of avian predation can be obtained.

- Concentrate efforts during the early part of the run when fish are moving to the estuary.

- Obtain more information on the movement of fish through the area surrounding the seal colony.

- Work with local groups on the coast, including watershed councils and ODFW to conduct research and keep the public informed about what research is being done in the area. Cooperation from these groups and individual citizens in the Nehalem area in 1999 and 2001 helped our research greatly. By keeping the public informed and involved, we hope to continue good relations in the area. .

We gained useful information in 2001 on how birds and wild fish move in the Nehalem estuary. The research was well publicized and many individuals contributed in different ways to the success of our efforts. We thank in particular the Lower Nehalem Watershed Council, North Fork of the Nehalem Fish Hatchery personnel, ODFW-Tillamook personnel, SPP personnel, and the citizens in the area for their help in our data collection. These data are vital for achieving our goals of determining the level of predation on smolts and we must build upon this work by continuing the research and devising further research, as recommended above, in order to achieve our goal of managing the system in order to increase salmonid populations by decreasing avian predation upon outmigrating smolts.

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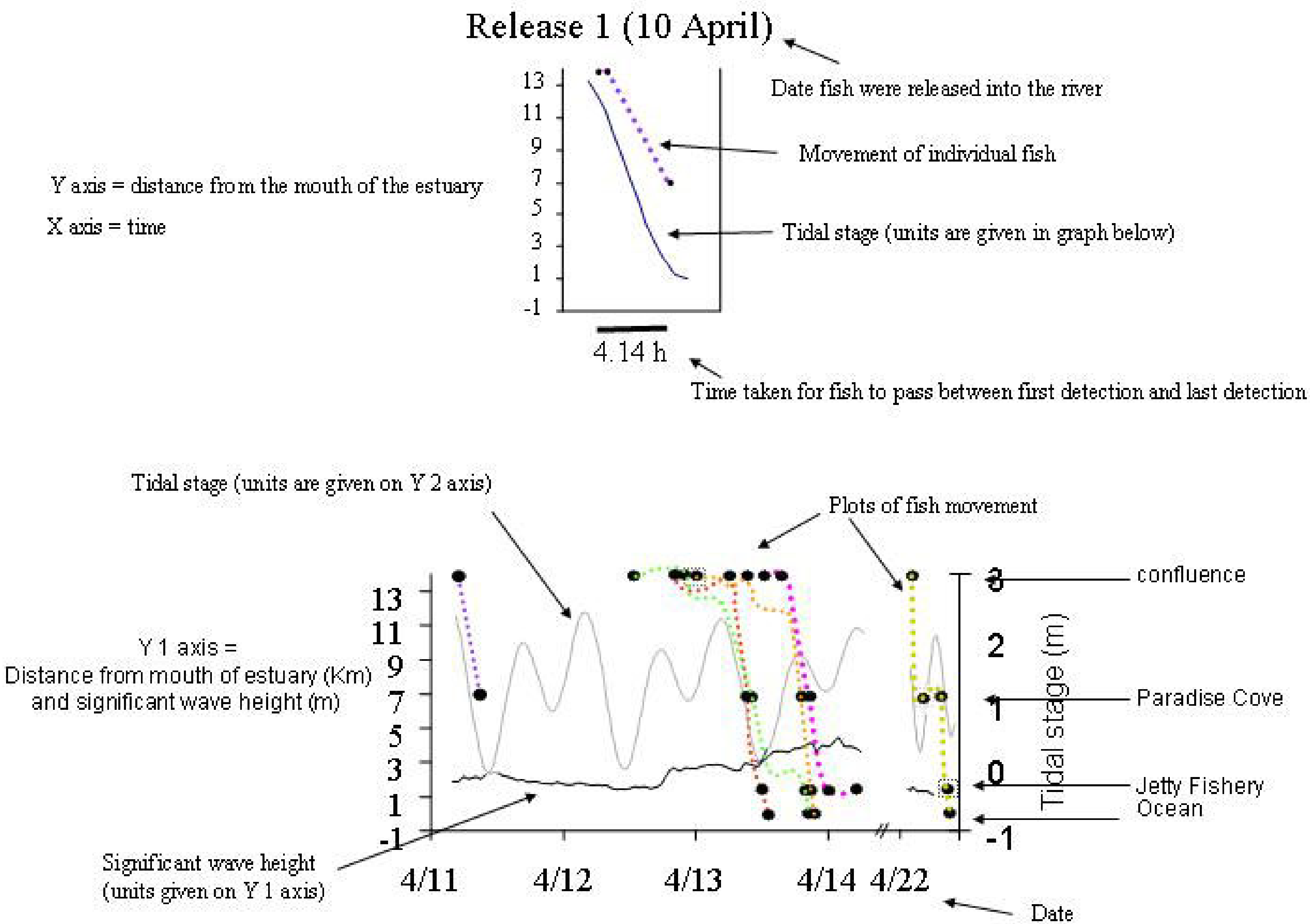
APPENDIX I

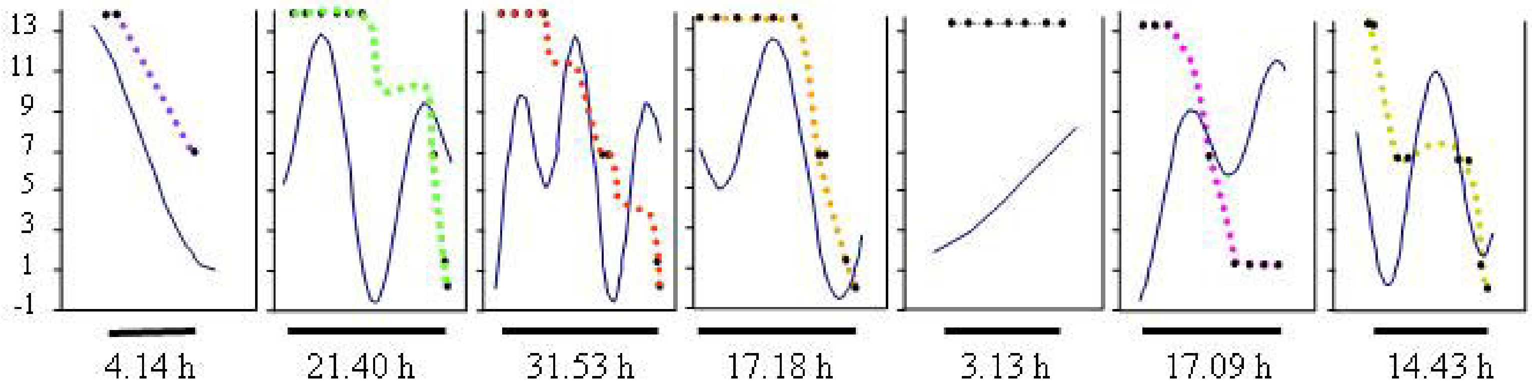
Sonic fish data

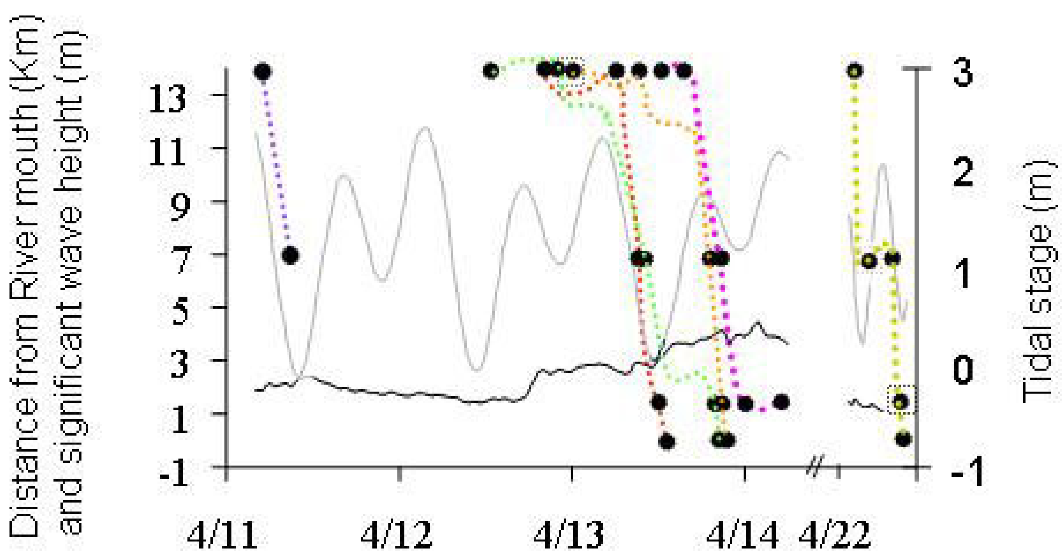
The following graphs represent the individual estimates of fish movement through the Nehalem Estuary. The first page explains what each part of the graphs represent. Each point (dot) on the graph indicates the time at which the fish was detected on a receiver. The lines connecting these points represent our best estimate at the behavior of each fish between these detections. This is based on radio telemetry data where we have followed individual fish at different tidal cycles to observe their behavior and residence times at each receiver. The data are separated by release dates. For each release (a page) we have presented the data separately for each fish and at the bottom of the page on a graph for all fish within the release.



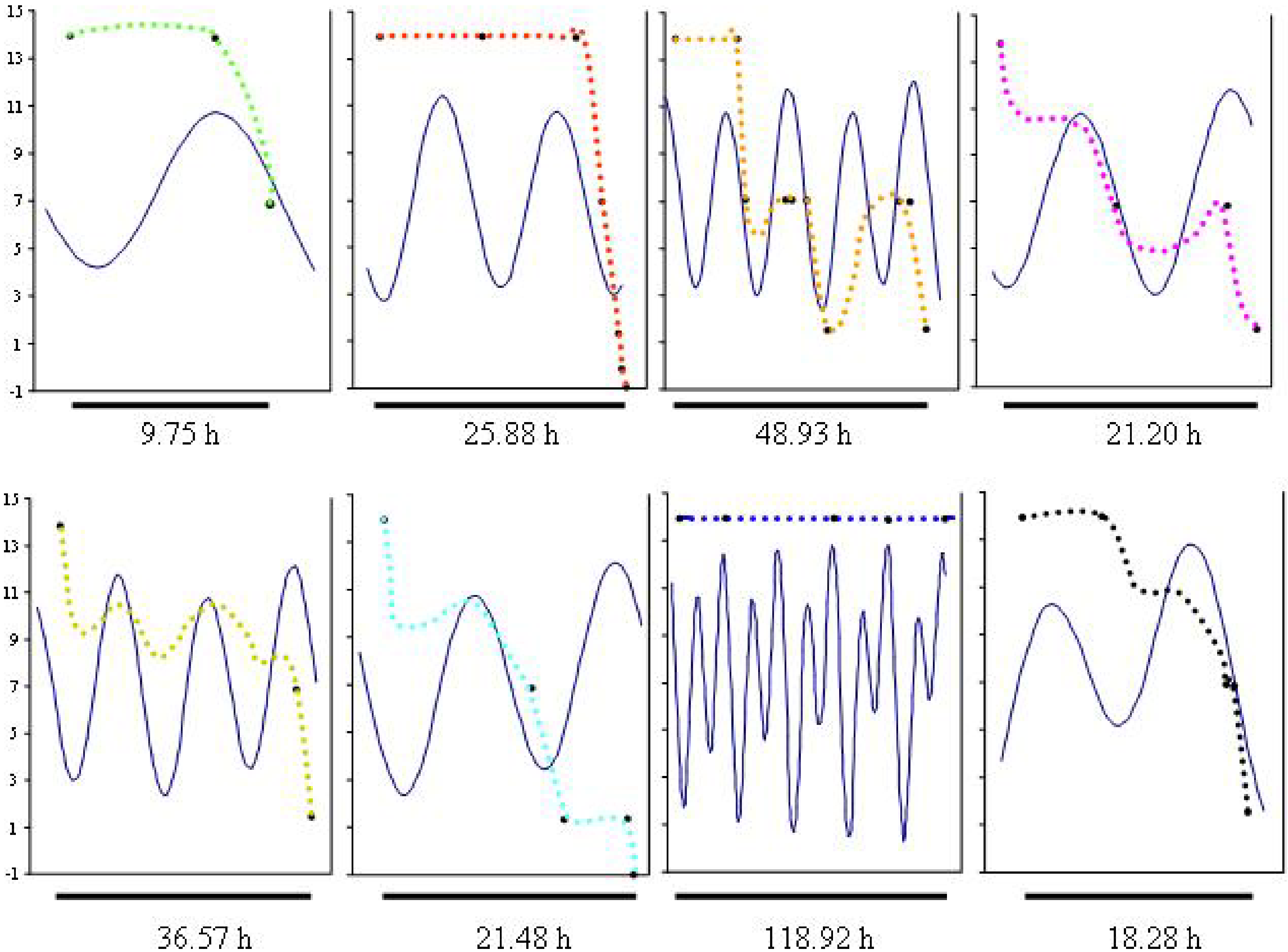
Release 1 (10 April)
Date fish were released into the river
Movement of individual fish
Y axis = distance from the mouth of the estuary
X axis = time
Tidal stage (units are given in graph below)
4.14 h
Time taken for fish to pass between first detection and last detection
Tidal stage (units are given on Y 2 axis)
Plots of fish movement
confluence
Y 1 axis =
Distance from mouth of estuary (Km)
and significant wave height (m)
Tidal stage (m)
Paradise Cove
Jetty Fishery
Ocean
Significant wave height
(units given on Y 1 axis)
4/11
4/12
4/13
4/14
4/22
Date

Release 1 (10 April)

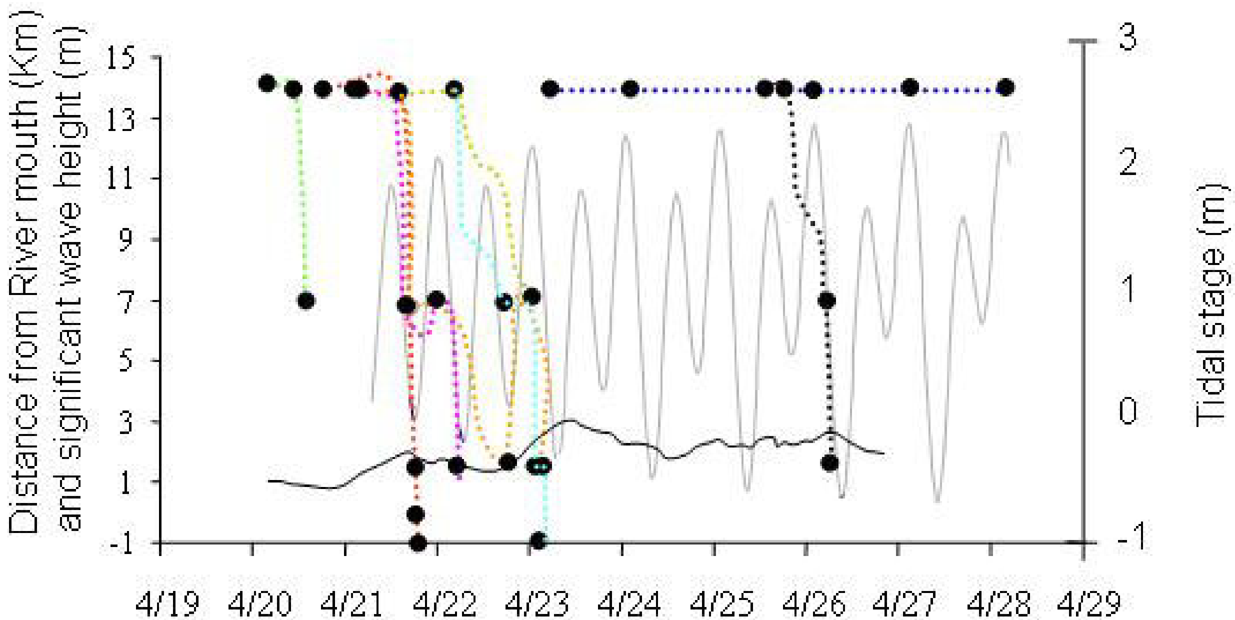




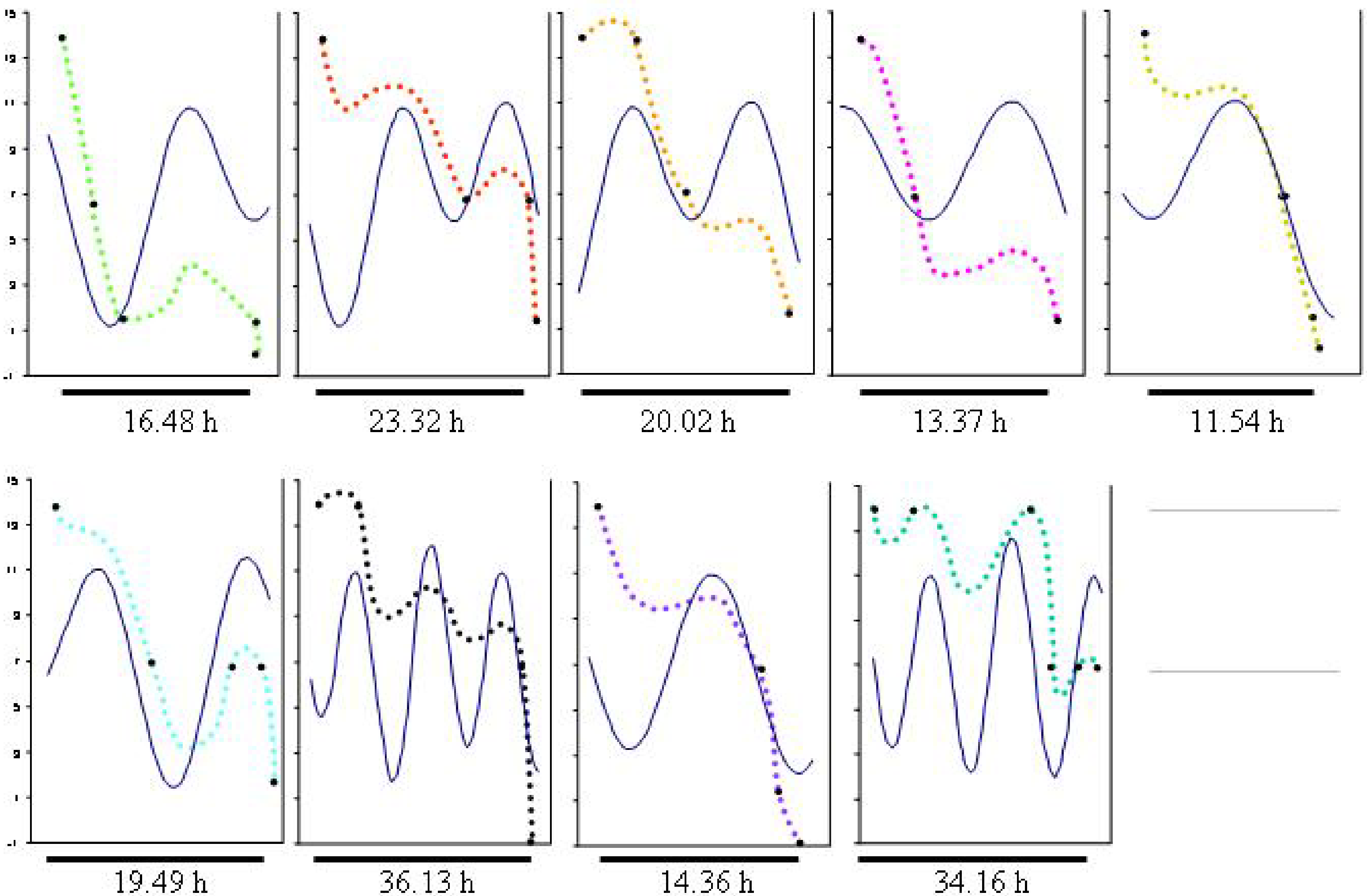
Release 2 (17 April)



Release 2 (17 April)



Release 3 (26 April)



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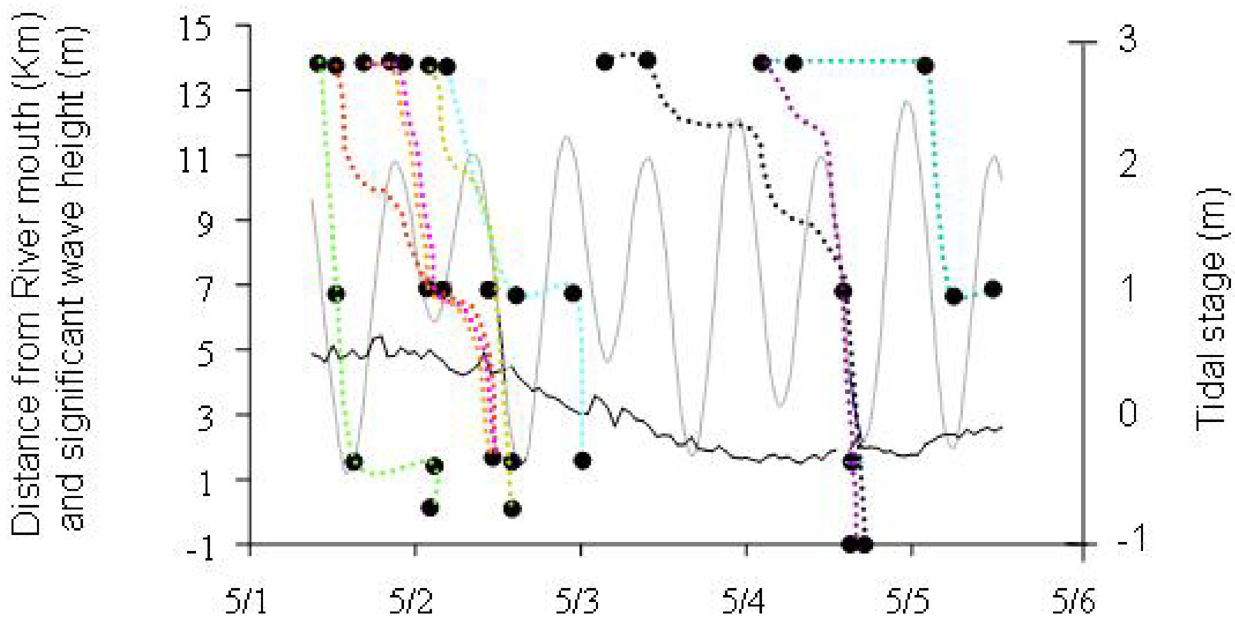
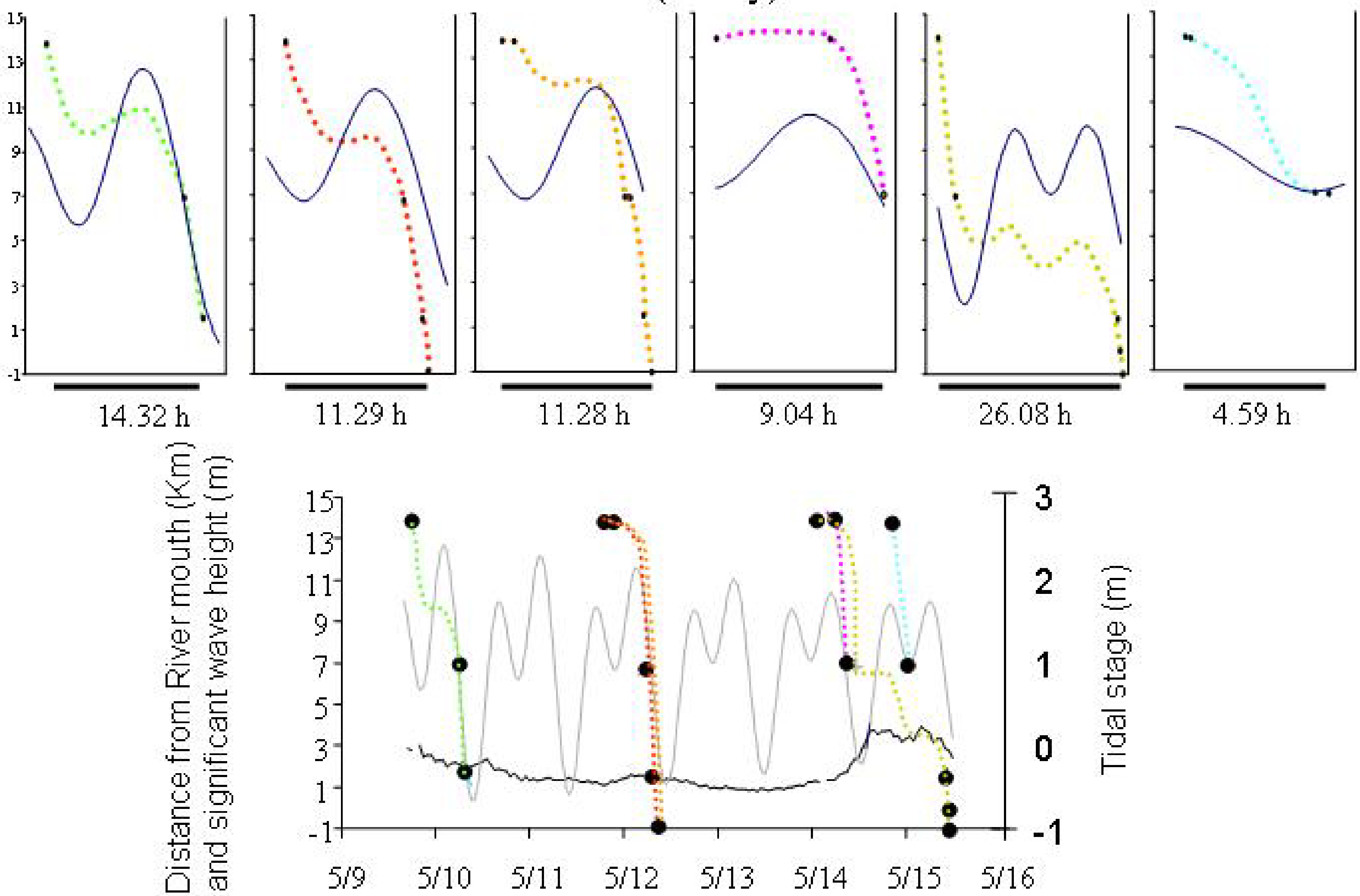
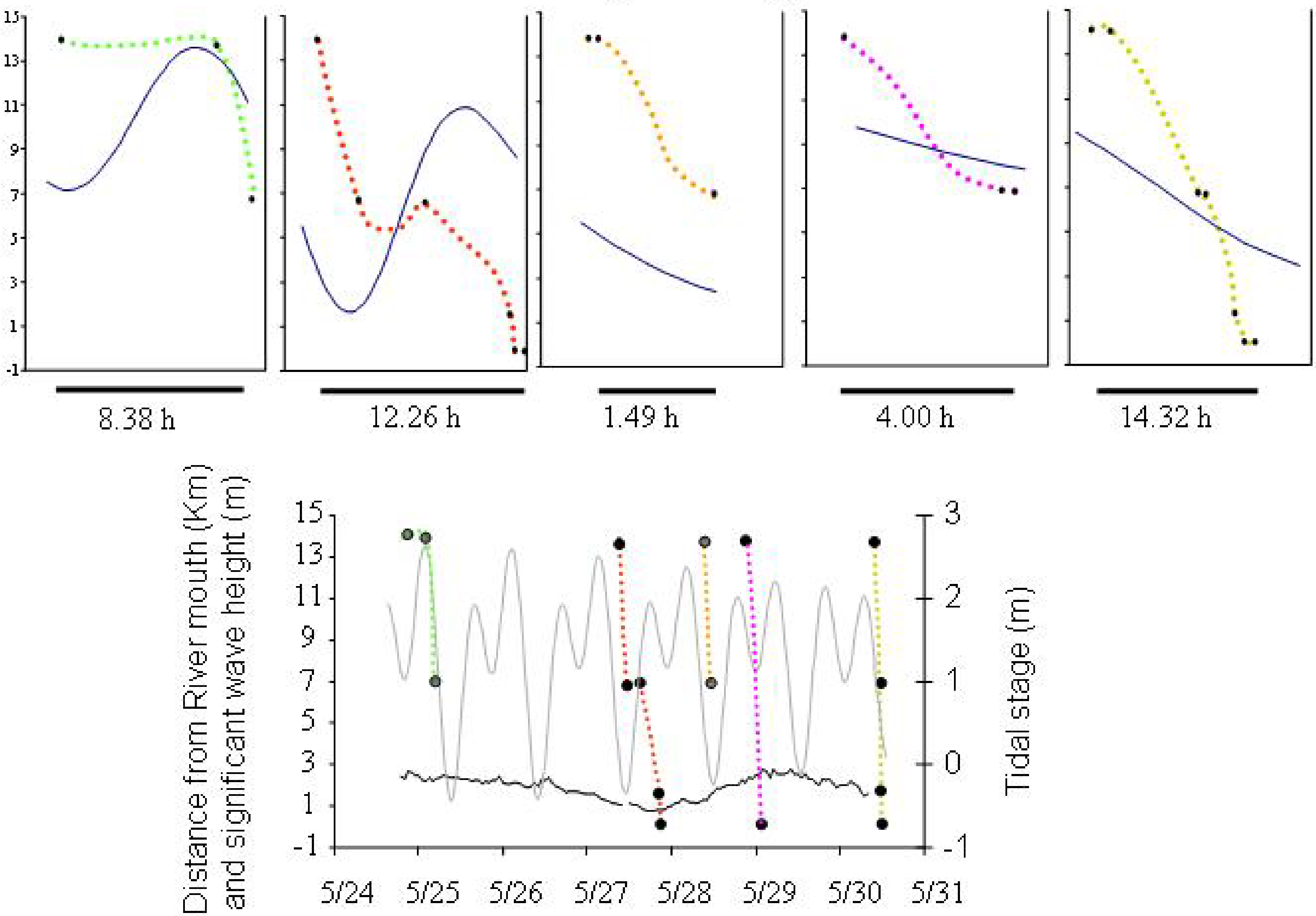


Release 4 (6 May)



Release 5 (20-25 May)



APPENDIX II

Figure A. River flows, measured at Foss, OR (USGS gaging station 14301000) on the mainstem of the Nehalem River, through time in 2001.

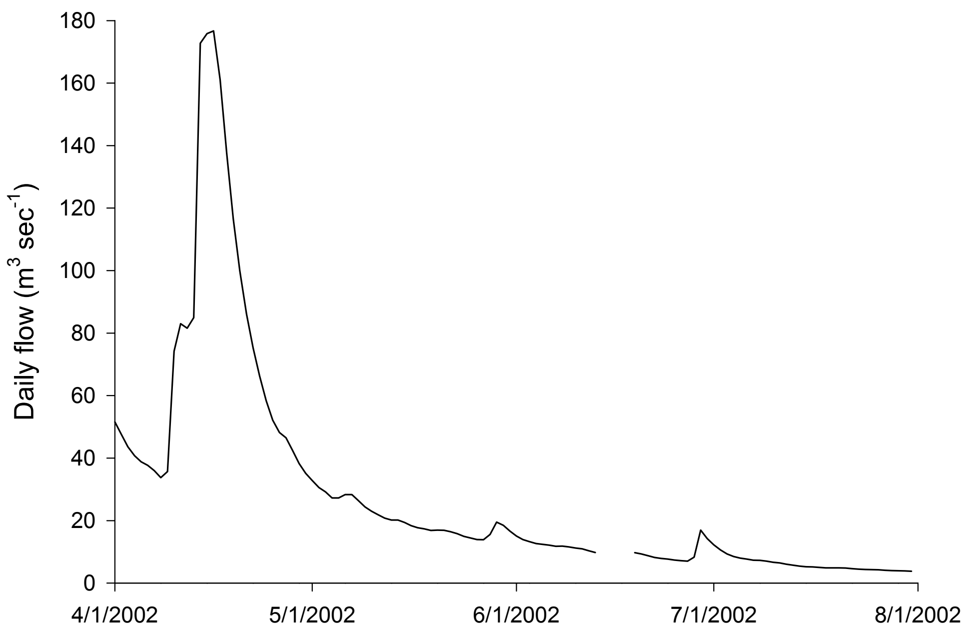


Figure B. Salinity (ppt) grouped by different depths at low tide at our four different hydrochemistry sites in Nehalem in 2001 through time. Site 1 is farthest downstream and site 4 is farthest upstream; refer to Figure 5 for site locations.

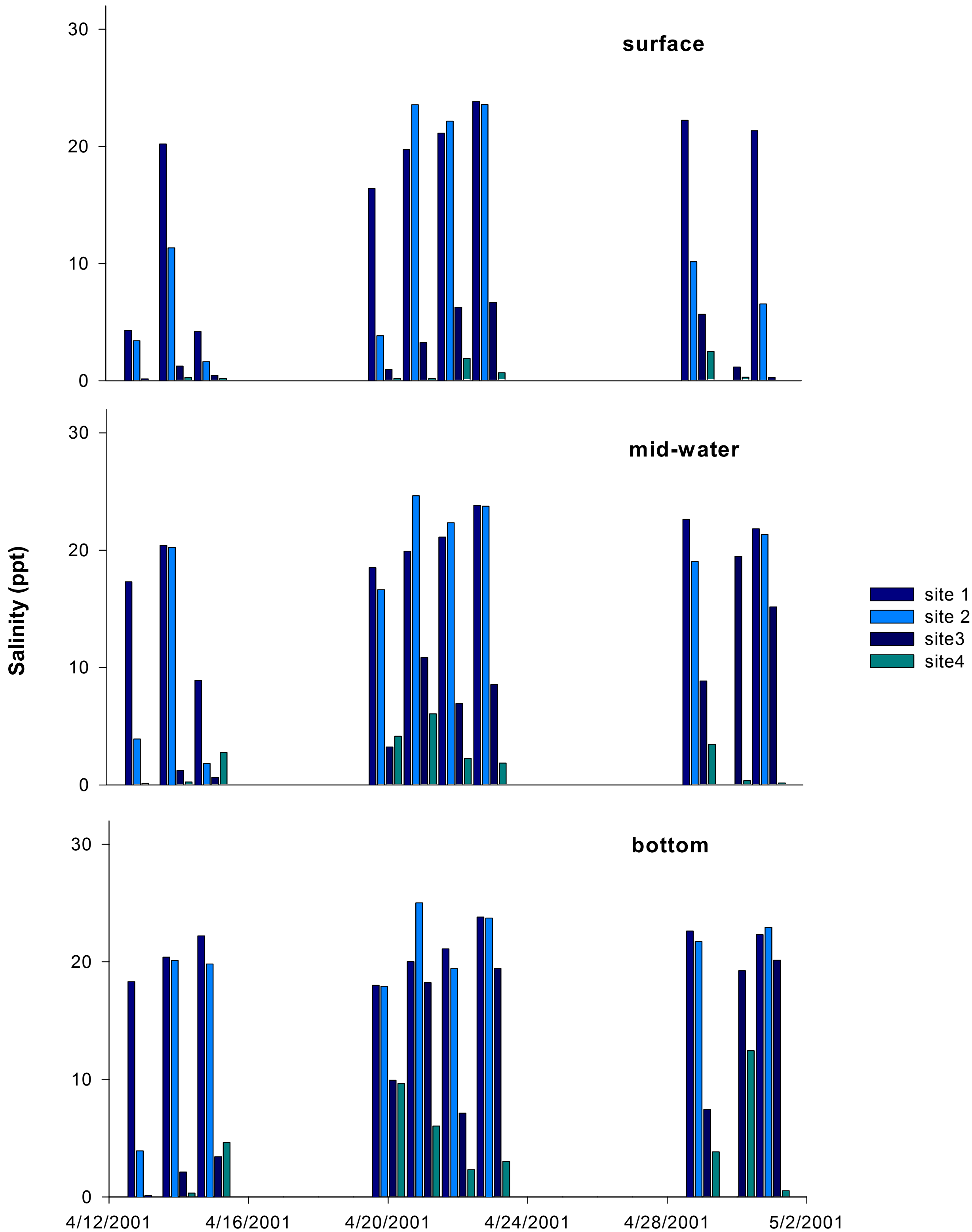


Figure C. Total number of boats observed by OCFWRU during predator surveys in the Nehalem estuary in 2001 for all sites.

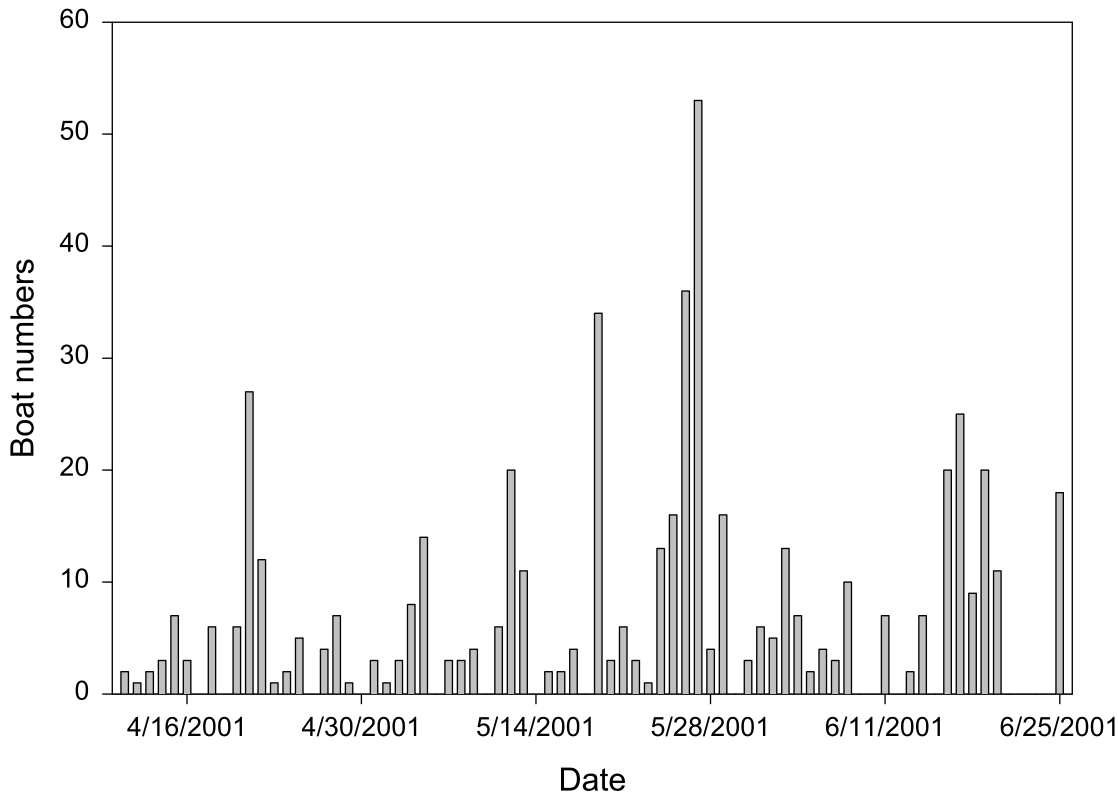


Figure D. Total number of boats observed by OCFWRU by site during predator surveys in the Nehalem estuary in 2001.

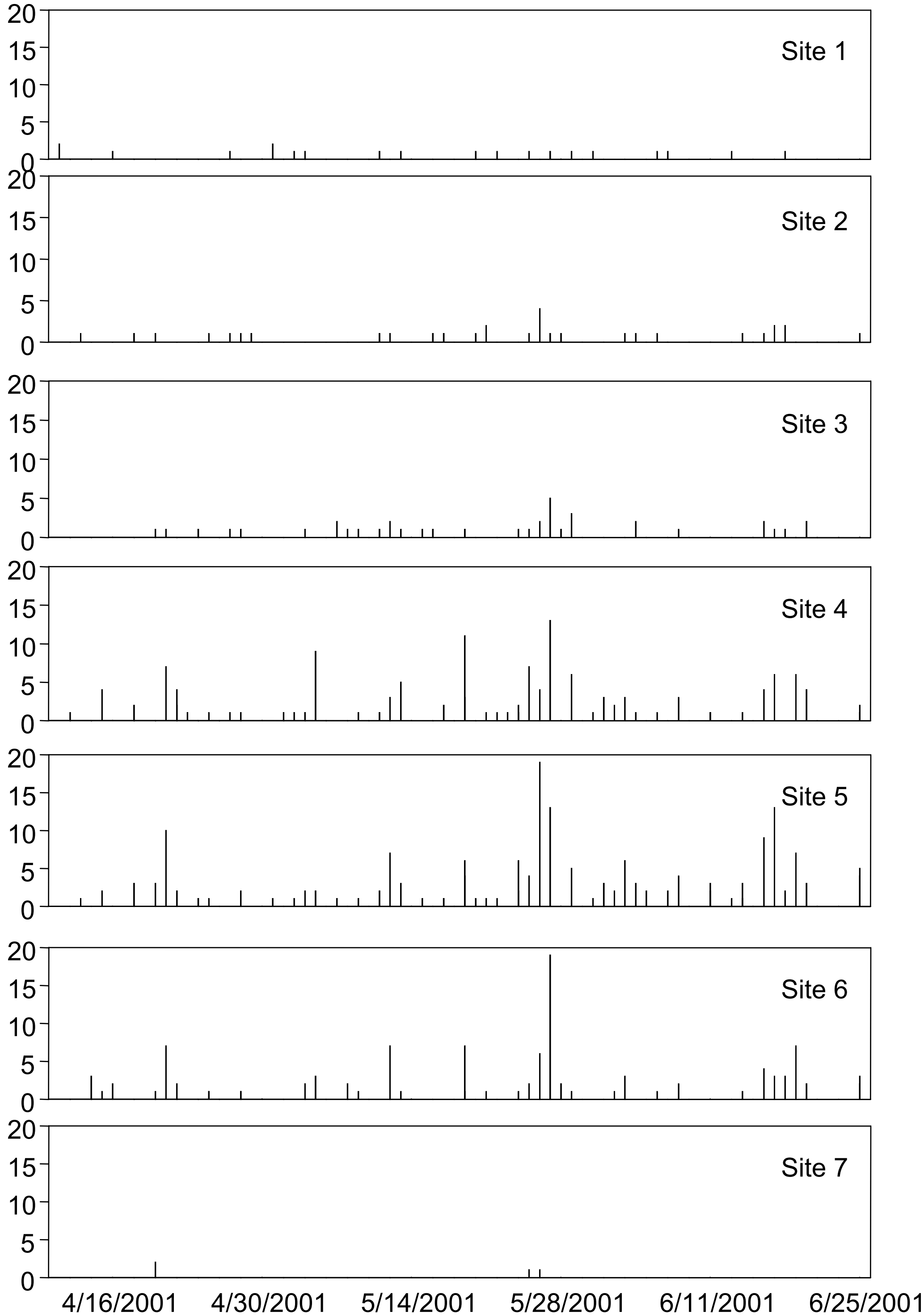


Fig E. Sample predator survey form

Notes on Datasheet

Estuary	– name of the Bay (NEH, TIL, NES)
Initials	– initials of the SPP person taking data. If there is more than one boat being used, each should complete a datasheet
Date	– MM/DD/YY
Start Time	– military; time when hazing starts for the day
Stop Time	– military; time when hazing stops for the day (do not put times of lunch breaks)
Weather	– general conditions (cloudy and rainy, sunny, etc...)
Wind Out Of	– prevailing wind direction (N, NE, E, SE, S, SW, W, NW, None, VAR=variable)
DCCO	– total number of unique (i.e., not counted more than once) individual double-crested cormorants per day
PECO	– total number of unique individual pelagic cormorants per day
BRCO	– total number of unique individual Brandt's cormorants per day
CO	– total number of unique individual unidentified cormorants per day (to be used if type of cormorant is unknown)
GBH	– total number of unique individual great blue herons per day
CATE	– total number of unique individual Caspian terns per day
Other	– total number and species of other unique individuals worthy of note per day
Seals	– total number of unique individual seals per day
Boats	– total number of unique boats per day
Feeding Frenzy	– total number of feeding bouts per day with numerous (>50) double-crested cormorants or double-crested cormorants and other predators (e.g., GBH, CATE, seals)
HOT Areas	– where the DCCO are located/gravitating towards in the system
Area Protected	– reference a standard map which should be turned in with report; use abbreviations
NOTES	– methods, change in methods, ideas, whatever strikes you about the situation, etc...

Estuary	Initials	Date	Start Time	Stop Time	Weather	Wind Out Of	DCCO	PE CO	BR CO	CO	GBH	CA TE	Other	Seals	Boats	Feeding Frenzies	HOT Area	Area Protected	NOTES

Figure F. Efficiency estimates of the VR2 acoustic receiver arrays in Nehalem estuary during 2002. The location of each array (X axis) is given in the adjacent map. Percentage detections for drones are based on the number of subsequent detections following release of 8-10 drones up river of each array (each array was tested 3 times). Percentage detections for fish are based calculated by taking the total number of fish detected at each array and dividing this by the same figure plus any additional fish that were not heard by this array but were subsequently detected downriver. We were not able to complete drone testing at site 3. Due to the lack of downriver arrays we cannot calculate the efficiency of the ocean array by the fish passage method.