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Collaborative Research on the Spawning Population of Night Smelt (*Spirinchus starksi*) in Humboldt and Del Norte Counties, California

Final Report

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Executive Summary

Project Goals

This report is the result of collaborative research funded by the Collaborative Fisheries Research–West and conducted by the California Commercial Beach Fishermen's Association, the California Department of Fish and Wildlife (CDFW) and the ecological consulting firm, H. T. Harvey & Associates, to describe characteristics of the night smelt (*Spirinchus starksi*) population in Humboldt and Del Norte counties, California during the core of the commercial night smelt harvest. There is relatively little information on the life history of night smelt and there has been no quantitative and objective assessment of bycatch in the commercial night smelt fishery. The goals of the study were: (1) to provide baseline life history information including size and age structure, sex ratio, and length-to-weight relationships, (2) to evaluate changes in these life history parameters over the course of a fishing season, and across the spatial extent of the night smelt fishing grounds in northern California, (3) to characterize the physical aspects of night smelt spawning habitat, and (4) to provide a bycatch assessment of the 2014 night smelt harvest in Humboldt and Del Norte counties.

Approach

The five main study regions where commercial night smelt landings historically occur, listed from north to south were: Kellogg Beach (Del Norte County), Gold Bluffs Beach (Humboldt County), Freshwater/Hidden Beach (Humboldt County), Mad River/Samoa Beach (Humboldt County) and Centerville Beach (Humboldt County). A sixth study region was located on Luffenholtz Beach between the Freshwater/Hidden Beach region and the Mad River/Samoa region. During the core of the 2014 commercial night smelt season, commercial fishermen collaborators collected fish samples and environmental data once per month from March to August. Fishermen located spawning aggregations and collected fish samples with commercial smelt nets. During the same sampling trip fishermen also collected environmental data including: 1) sediment samples, 2) water quality (temperature, salinity), and 3) percent grade of the wave slope. A subsample of at least 100 fish was taken during each sampling event, when fish were present, and the fish were returned to the laboratory for biological assessment. For each fish, a variety of parameters were measured including: length, weight, and sex. Otoliths were taken from a subset of each sample, and were washed, dried, and stored for future analysis.

To assess bycatch in the commercial fishery, between 5- and 11.5-gallon (approximately 40–80 pounds) samples of night smelt from the commercial harvest were examined as nets were emptied into trucks or totes on the beach and dockside, as fish were landed at the fish processing plant.

Findings and Recommendations

Night smelt aggregate to spawn on beaches under a relatively wide range of environmental conditions. Night smelt were present at each beach at some point throughout the sampling season, though they appear to be less abundant at certain beaches and patchily distributed within a beach. Male fish were more abundant than females and were generally larger and heavier at a given size. Male night smelt length, when plotted in aggregate over all sites and months, shows a clear uni-modal pattern that appears normally distributed. The length of male fish declined slightly during the study period. The length of female fish declined during the first half of the study period and increased during the last half. Males were the dominant sex in all samples, representing 93% of the fish for all sites and months combined. Although there was a large amount of variability in sex ratio among sampling location during any given month, overall, the percentage of females in samples increased from 1.8% in February to 12.2% in August. The variability in sex composition by site also appears to increase over the course of the season. The high proportion of males in the spawning population suggests that females may move inshore to spawn in smaller numbers, with the majority remaining offshore. We were unable to identify the population age structure because we were not able to determine fish age from otoliths.

There was very little bycatch observed during the course of the study. In subsamples of commercially harvested night smelt, five redtail surfperch (*Amphisticus rhodoterus*) were documented. During monthly regional sample collection at Freshwater/Hidden Beach, one shiner perch (*Cymatogaster aggregata*) and one steelhead (*Oncorhynchus mykiss irideus*) smolt were documented (both fish were released alive). Bycatch of shiner perch and steelhead in the commercial fishery were reported by night smelt fishermen to be unprecedented. Their occurrence as bycatch during sample collection was probably due to the orientation of Redwood Creek on the night of 3 June. The creek was flowing parallel to the surf zone and was entering the sea over a long stretch of beach. As a result, the sample was collected extremely close, likely within, the mouth of Redwood Creek.

This study is a step towards achieving the objectives of recent forage fish polices by providing additional life history information to support science-based management decisions. Future work recommendations include accurately determining the population age structure, identifying offshore life history behaviors, and identifying population-level response to environmental changes.

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Section 1.0 Introduction

This report is the result of collaborative research conducted by the California Commercial Beach Fishermen's Association, the California Department of Fish and Wildlife (CDFW) and the ecological consulting firm, H. T. Harvey & Associates, to describe characteristics of the night smelt (*Spirinchus starksi*) population in Humboldt and Del Norte counties, California during the core of the commercial night smelt harvest.

Night smelt are a small silvery fish in the family Osmeridae (Hubbs 1925) that occur from central California to southeast Alaska. They are nocturnal spawners, aggregating in the surf zone to spawn on sand or gravel. In Humboldt and Del Norte counties, spawning activity typically peaks between February and August. Beach spawning is an evolutionary strategy exhibited by members of several families of fishes including Osmeridae (night smelt, surf smelt [*Hypomesus pretiosus*]), Ammodytidae (sand lance [*Ammodytes hexapterus*]) and Atherinopsidae (California grunion [*Leuresthes tenuis*]). Night smelt support a small commercial and recreational fishery; when they aggregate to spawn, they are captured with nets in the shallow surf zone.

Forage fish species, including night smelt play an important role in marine ecosystems by providing the main trophic link between primary producers and larger fish, birds, and mammals (Cury et al. 2000, Kaplan et al. 2013). Among the species that rely on forage fish are commercially and recreationally valuable fish and threatened or endangered fish, seabirds and marine mammals (Pikitch et al. 2012). Fluctuations in the forage fish populations are often closely tied to environmental variability and because they are short lived, there may be rapid, population-level responses in which mortality rates are high (Pikitch et al. 2012).

Since 1985, more than 95% of night smelt landed in California were from Humboldt and Del Norte counties (Sweetnam et al. 2001). Based on CDFW landings data, commercial landings in northern California peaked in 1996 at 1.24 million pounds (lb). Since 1996, annual landings have generally fluctuated between 200,000 and 400,000 lb although in 2012 nearly 600,000 lb were landed (Figure 1, CDFW landings data). Recreational landings are believed to be very small in comparison. However, there are no formal estimates of recreational landings since California's recreational fisheries survey is not conducted at night when this fishery occurs.

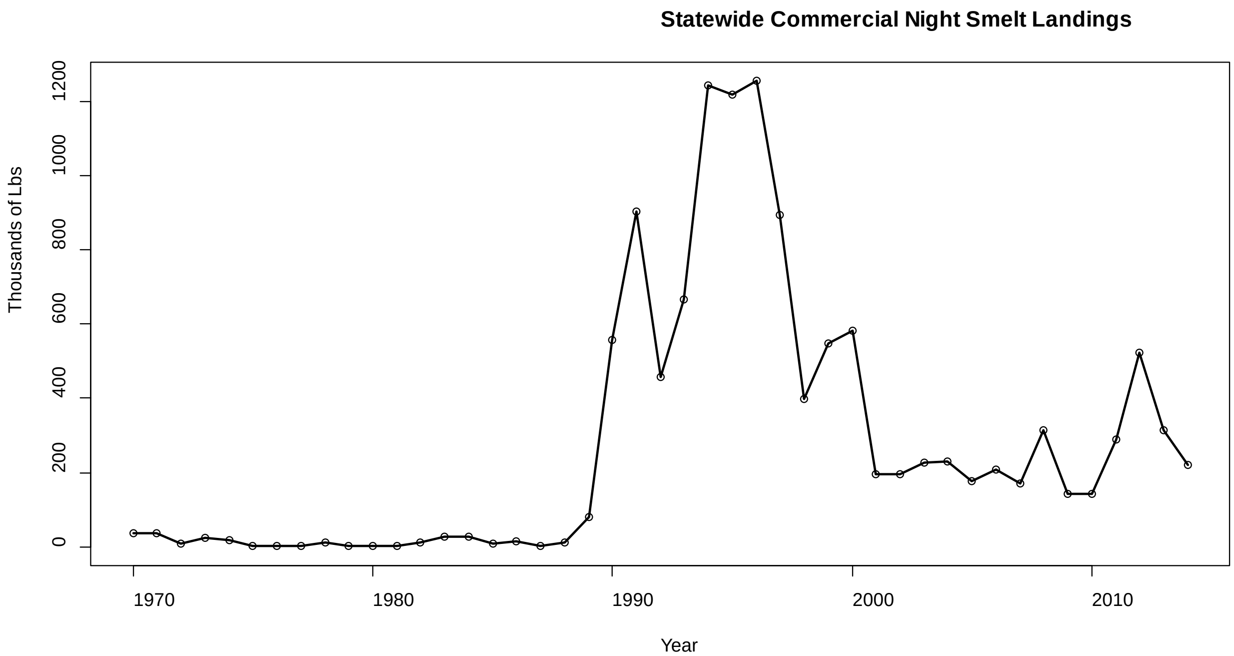

Figure 1. Statewide Commercial Night Smelt Landings from CDFW Landings Data

The California night smelt fishery is managed exclusively by CDFW and is subject to few regulations. In general, gear is limited to A-frame dip nets, throw nets and beach seines for both recreational and commercial fisheries The commercial fishery is open-access and has no limitations imposed on harvest weight or season, while the recreational fishery is subject to a daily bag limit of 25 lb of 'surf' smelt (i.e., night, day, and whitebait smelt species) in combination. Commercial and recreational smelt fishing is permitted along all beaches in Humboldt and Del Norte counties, except in Pyramid Point State Marine Conservation Area in Del Norte County, where commercial fishing is prohibited. However, Redwood National and State Parks off road vehicle use regulations create a de facto "limited access" fishery by restricting four wheel drive vehicle access to the night smelt fishing grounds located within the Parks (e.g., Gold Bluffs Beach, Freshwater Lagoon Beach) to a limited number of permitted smelt fishermen. The principal night smelt fishing grounds are located on Gold Bluffs Beach. Currently there are 14 fishermen permitted to drive on National Park beaches and 9 fishermen permitted to drive on State Park beaches; no new off road vehicle use permits will be issued, existing permits are non-transferable, and permits that are not renewed in a given year will be terminated (National Park Service and California Department of Parks and Recreation 2000).

Recently, resource managers have begun to adopt policies to insulate forage fish populations from the synergistic effects of fishing and potentially unfavorable environmental conditions. In March 2015, the Pacific Fishery Management Council (PFMC) adopted an initiative which prohibits the development of any new directed forage fish fisheries in federal waters along the west coast of the United States (PFMC 2014). In state waters, the California Fish and Game Commission (CFGC) adopted a similar policy, which also specifically outlines a need to identify and incorporate essential fishery information for existing forage fisheries, such as night smelt, into current management practices (CFGC 2012).

This study aims to improve the basic understanding of the commercial night smelt fishery in four principle ways: (1) to provide baseline life history information including size and age structure, sex ratio, and length-to-weight relationships, (2) to evaluate changes in these life history parameters over the course of a fishing season, and across the spatial extent of the night smelt fishing grounds in northern California, (3) to characterize the physical aspects of night smelt spawning habitat, and (4) to provide a bycatch assessment of the 2014 night smelt harvest in Humboldt and Del Norte counties. The results presented here draw on the experience and expertise provided by commercial fishermen and on objective documentation and quantitative analysis provided by experienced fish ecologists. The results from this study will provide resource managers with life history data on night smelt in Northern California and documentation of bycatch in the commercial fishery, and provide a basis for future research on the species.

Section 2.0 Methods

2.1 Sampling Locations

Five main sampling regions were chosen because they are locations from which commercial night smelt landings have been made (historically and/or currently), and because they were distributed across a broad spatial area encompassing approximately 103 miles of the California coastline (study area) (Figure 2). The five study regions from north to south were:

1. Kellogg Beach
2. Gold Bluffs Beach
3. Freshwater/Hidden Beach
4. Mad River/Samoa Beach
5. Centerville Beach

A sixth location, Luffenholtz Beach, was added as a fishery-independent region and was sampled primarily by CDFW and H. T. Harvey & Associates staff rather than by commercial fishermen. It lies near the center of the study area, between Mad River Beach and Freshwater/Hidden Beach (Figure 2).

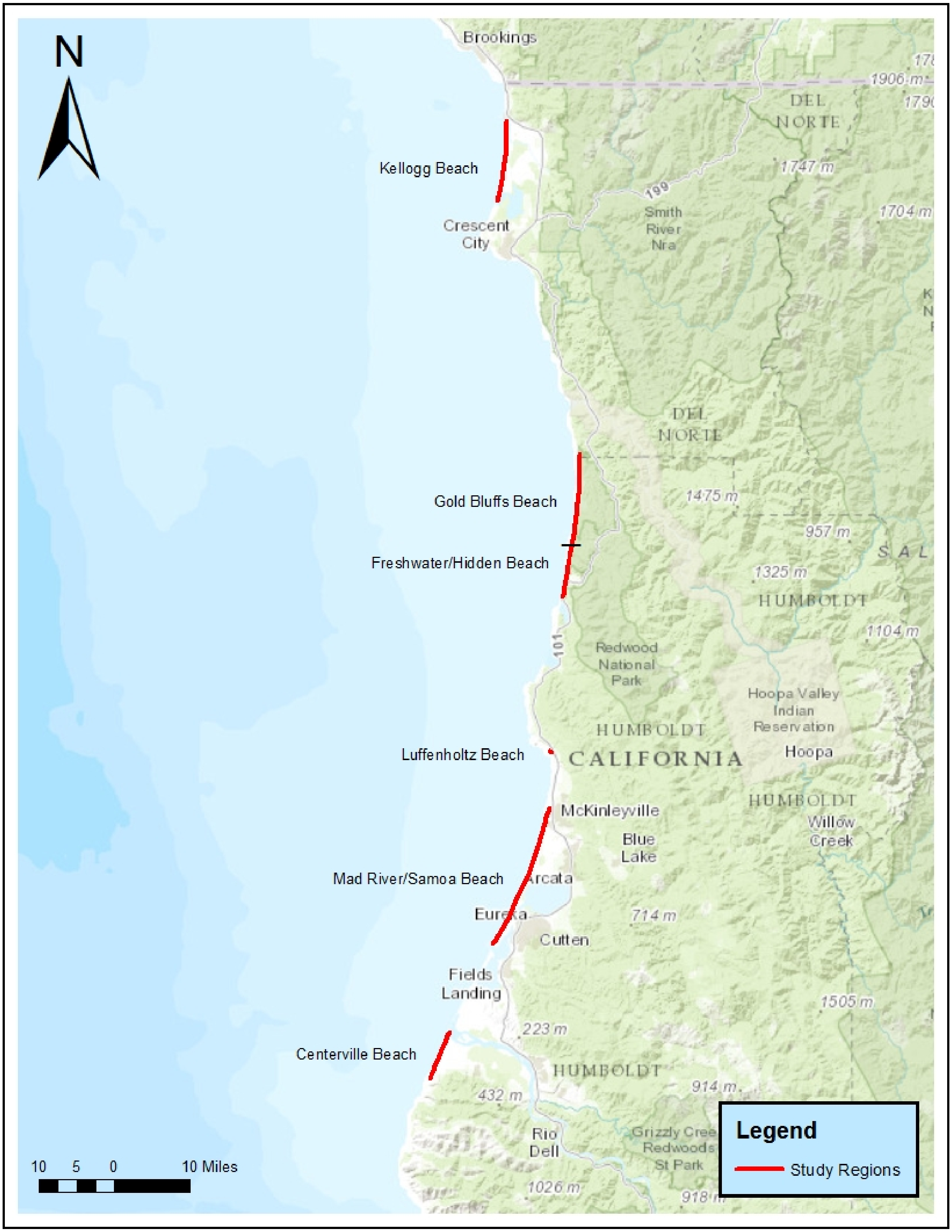

Figure 2. Study Regions

2.2 Number and Frequency of Sampling Events

Each region was sampled at least once per month for six months (March–August 2014); however, no smelt were captured during sampling efforts at Luffenholtz Beach in March or at Centerville Beach in June. Consecutive samples from each region were separated in time by between 7–46 days. All samples were collected during an outgoing tide after sunset and before sunrise (i.e., at night).

2.3 Physical and Chemical Data

Ocean water properties at each sampling site within regions were measured at or near the time of fish collection. Water samples were collected soon after collecting fish samples and stored in glass containers; water temperatures were measured at the site (Degrees Celsius [°C]) using a handheld thermometer, and salinity (parts per thousand [ppt]) was measured in the laboratory the following day in the office with a 'Yellow Springs Instruments Model Pro 30' salinity, temperature, conductivity meter. Physical characteristics of the sampling site were characterized by examining sediment composition and assessing the wave slope. A core and sieve method was adopted for sampling the sediments at spawning sites. Fishermen collected core samples rapidly from the sampling site during lulls in wave activity. Sediment core samples (depth: 13.2 centimeters [cm], volume: 429 cm^2) were collected from the spawning sites in the five main regions in March, July, and August; sediment samples were not collected from Luffenholtz Beach. Each sediment sample was washed through a set of four nested sieves (U.S. Sieve Size: #6 [3.36 millimeters {mm}], #10 [2.00 mm], #20 [0.841 mm], #40 [0.420 mm]) to determine the proportion, based on volume, of component sediment sizes in each sample. The wave slope (percent slope) was taken at or near the sampling site with a dial gauge angle finder.

2.4 Fish Data Collection and Analysis

To collect fish samples, at least once per month (Table 1), fishermen drove on the beach wave face and used a spotlight to search for signs of spawning night smelt as waves washed through the shallow (<15 cm deep) wash zone. When fishermen located the largest aggregation of night smelt, they collected a sample using commercial A-frame dip nets (3/8 inch mesh webbing). The method used by fishermen collaborators to find and collect night smelt is the normal way that fish aggregations are located and harvested in the commercial fishery. One hundred fish were sampled from the catch and placed in a labeled plastic bag. If night smelt aggregations were dense, fishermen continued to fish commercially. Fish samples were processed within two days of capture or frozen for processing at a later date. During processing, each fish was weighed (to the nearest 0.1 gram) and measured (total length, mm). After dissecting each fish to examine reproductive organs, the sex was also recorded. Otoliths were collected with the intention of determining the age structure of the population. A random subsample of 20 male fish and, because there were typically few females in samples, from the first ten female fish encountered in each sample were selected and the otoliths removed. Otoliths were washed in water, dried, and placed in labeled vials and coin envelopes for storage. Ultimately, the otoliths could not be surface-read because annuli could not be identified; however, the collection will be stored at the CDFW office in Eureka, California for possible future analysis.

Table 1. Location and Number of Samples Collected

	Number of Sampling Trips per Month						
Location	February	March	April	May	June	July	August
Kellogg Beach	0	1	1	1	1	1	1
Gold Bluffs Beach	2	1	2	1	1	1	1
Freshwater/Hidden Beach	1	1	1	1	1	1	1
Luffenholtz Beach	0	1[a]	1	1	1	1	1
Mad River/Samoa Beach	0	1[a]	1[a]	1[a]	1[a]	1	1
Centerville Beach	0	1	1	1	1[a]	1	1

[a] No fish were captured

A 2-way Analysis of Variance (ANOVA) of location and month was used to evaluate differences in fish length across the region and over time. Three sampling sites were chosen to span the entire study area, (Kellogg Beach, Gold Bluffs Beach, and Centerville Beaches Beach), and because no fish were captured at Centerville Beach in June, the analysis omitted June. Freshwater was not included in the analysis because it is located very close to Gold Bluffs Beach. Mad River/Samoa Beach was not included because in most months there were no fish captured. A random draw (n=95) of fish lengths was taken from each site and month combination to create a balanced dataset. This process was repeated 100 times to generate a range of model estimates.

2.5 Bycatch

Between 5 and 11.5-gallon (approximately 40–80 lb) samples were examined for bycatch as nets were emptied into trucks or totes on the beach. When assessing bycatch on the beach, fishermen were asked to deposit the entire unsorted contents from a single net load into an 11.5-gallon plastic sorting tote. Ecologists carefully examined the contents for bycatch species while commercial fishermen continued to fish. When the sorting tote was emptied, fishermen refilled the tote with the next available net load. The proportion of the catch sampled ranged from <1 to 20% and was a function of the total landing. Bycatch was also examined dockside as fish were unloaded for sale at the primary regional fish processing plant in Eureka, California. Bycatch was assessed dockside at the fish processing plant by sub-sampling the commercial catch. A plastic tote (11.5-gallon) or a 5-gallon bucket was filled with night smelt collected from one corner of the truck load. Each sample was then examined for bycatch.

2.6 Modifications to the Study Plan

The use of a research net made from smaller mesh (1/8 inch) to confirm that commercial nigh smelt nets are capturing the full spectrum of sizes that are present was discontinued after it was determined to be unsafe. The smaller mesh of the research net collected substantially more sediment than the commercial nets and became dangerously heavy and unwieldy in the surf zone.

The moon phase was not reported because the moon was often obscured by clouds, and therefore did not provide the variable level of illumination that was expected to influence night smelt catch. Moon phase is, however, highly correlated with tidal height and range—factors that are believed to influence night smelt catch for different reasons. Because we selected specific tidal conditions to sample, we did not test for the variable effects of moon phase as it relates to tidal influence and as a result the moon phase was not considered to be useful contextual data.

Section 3.0 Results

3.1 Spawning Habitat Conditions

Salinity ranged between 28.7 and 33.9 ppt, and temperature ranged from 7.0 to 15.5°C (Table 2); salinity and temperature data are provided as a range because of small sample sizes. At Centerville Beach and Mad River/Samoa Beach there was no apparent seasonal trend in water temperature. Water temperatures at the remaining beaches increased during the course of the season (March to August). Beach slope ranged between 3% and 12% among sites and over the course of the sampling period: wave slopes were lowest at Kellogg, Mad River, and Luffenholtz beaches; intermediate at Gold Bluffs and Freshwater/Hidden beaches; and highest at Centerville Beach (Table 2).

Table 2. Environmental Data Taken at Sampling Sites within Each Region (March–August 2014)

Location	Range of Salinities (ppt)	Range of Temperatures (°C)	Range of Wave Slopes (%)
Kellogg Beach	28.7–33.6	10.0–15.5	3.0–7.0
Gold Bluffs Beach	29.1–33.4	7.0–15.0	2.0–10.0
Freshwater Beach	29.1–33.4	11.0–15.5	2.0–10.0
Mad River Beach/Samoa Beach	30.1–34.0	11.0–13.3	3.0–8.0
Centerville Beach	29.3–33.9	9.4–12.2	5.0–12.0
Luffenholtz Beach	29.6–33.0	8.3–13.9	5.0–9.0

Sediment data are provided in aggregate as a range because of small sample sizes and lack of any apparent seasonal trends (Figure 3). Kellogg beach samples contained the coarsest sediment sizes, which were predominantly >3.36 mm, followed by Gold Bluffs Beach sediment that was dominated by the largest (>3.36 mm) and smallest size fractions. Sediment from Mad River/Samoa Beach was mostly smaller than the smallest size fraction (fines). Centerville and Freshwater/Hidden Beach samples were similar in composition and sediments at those sites were more evenly distributed among the size fractions than in the other sites.

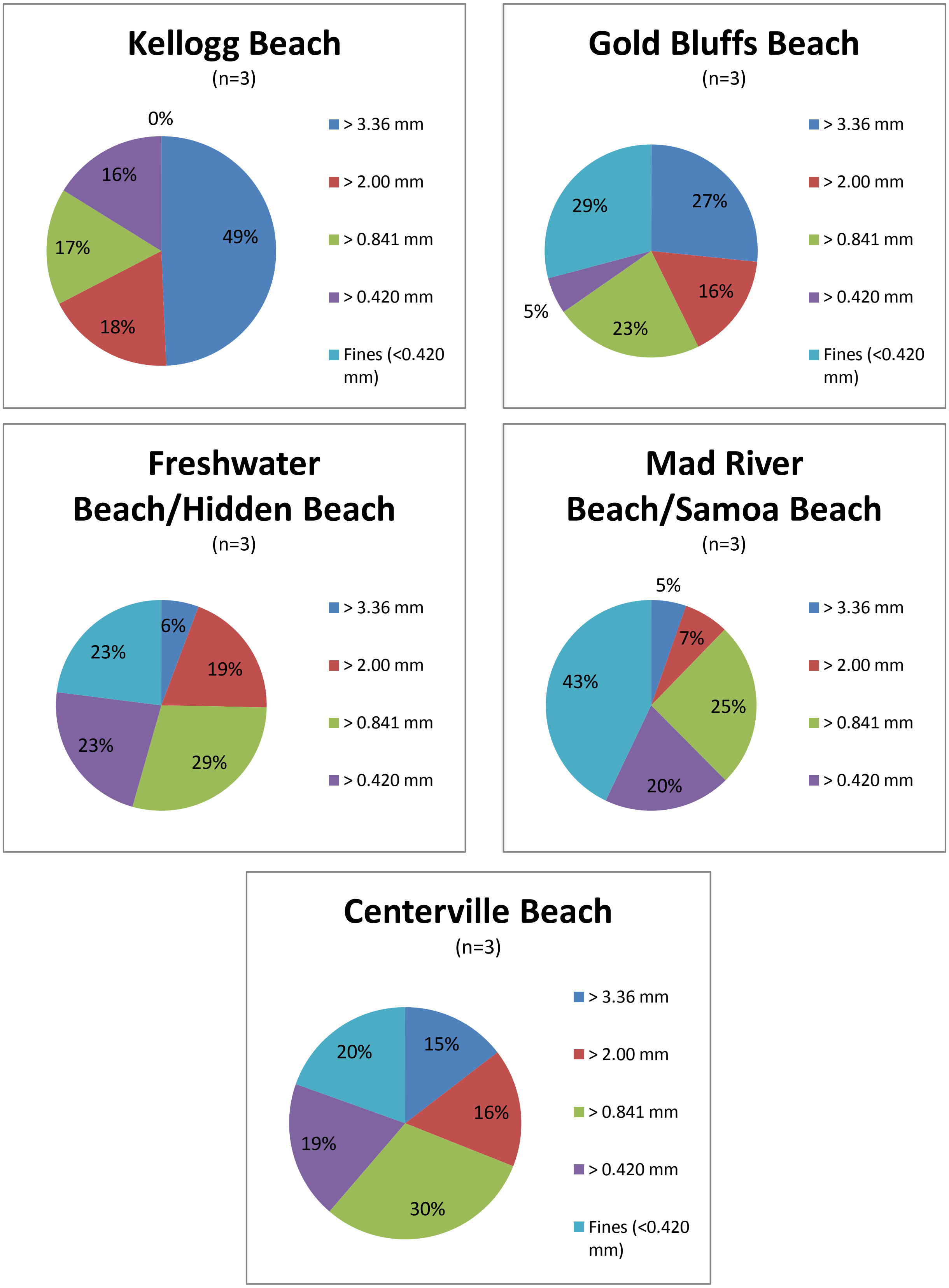

Figure 3. Sediment Size Distribution Averaged for All Months Sampled (March, July, and August)

3.2 Fish

The number of fish collected for biological analysis ranged from 0 to 701 from each site in each month (Table 3). The range in sample size resulted from several factors. Initially, a high number of fish from a random subset of samples was taken to assess whether multiple modes were present in the length-frequency distribution. After observing that the distribution was clearly uni-modal, the number of fish measured was scaled back to 100 fish per site, per month. In a few instances, the fishermen delivered more than one sample per month while commercial fishing, resulting in a larger sample size for that month; this is particularly the case with Gold Bluffs Beach samples. Therefore, the number of fish per site per month should not be interpreted as a representation of relative abundance, but instead reflects the presence or absence of fish at a given site during sampling. On some occasions there were no fish observed during sampling which resulted in zero fish analyzed for that particular site and month. No fish were observed at Mad River Beach between March and July, at Luffenholtz Beach in March and at Centerville Beach in June. Only Gold Bluffs Beach and Freshwater Beach were sampled by commercial fishermen during February, and those samples were added to the study analysis.

Table 3. Number of Night Smelt Collected in 2014 at Each of the Sampling Regions by Month

	Number of Night Smelt Collected at Each Sampling Region					
Month	**Kellogg**	**Gold Bluffs**	**Freshwater**	**Luffenholtz**	**Mad River**	**Centerville**
Feb	No sample	200	295	No sample	No sample	No sample
Mar	305	701	102	0	0	205
Apr	100	347	103	295	0	100
May	101	203	101	117	0	96
Jun	100	231	100	100	0	0
Jul	115	101	101	210	0	100
Aug	100	102	105	198	100	101

Male night smelt length, when plotted in aggregate over all sites and months, shows a clear uni-modal pattern that appears normally distributed (mean total length = 123.23 mm, sd = 5.14). Female fish were smaller (mean total length = 113.31 mm, sd = 7.67), and showed a much broader length distribution than males (Figure 4). Because of the small number of female fish in samples it is difficult to identify clear modes in the distribution. The mean length for male fish declined slightly over the course of the season (Figure 5). Although the female fish sample size was low, female fish length declined until May and then increased until August (Figure 5).

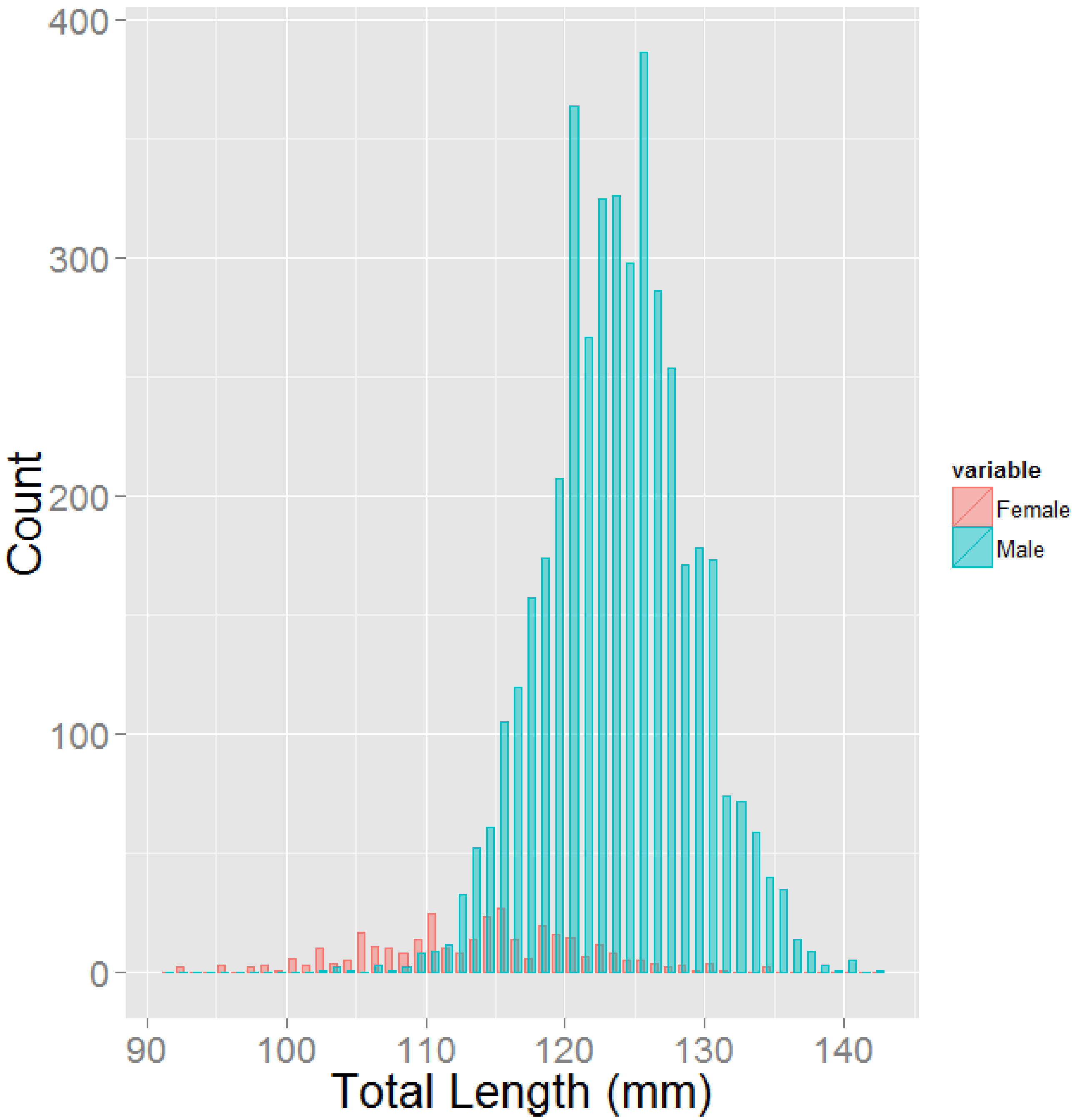

Figure 4. Length Frequency of Male and Female Night Smelt from All Sites Combined (February–August 2014)

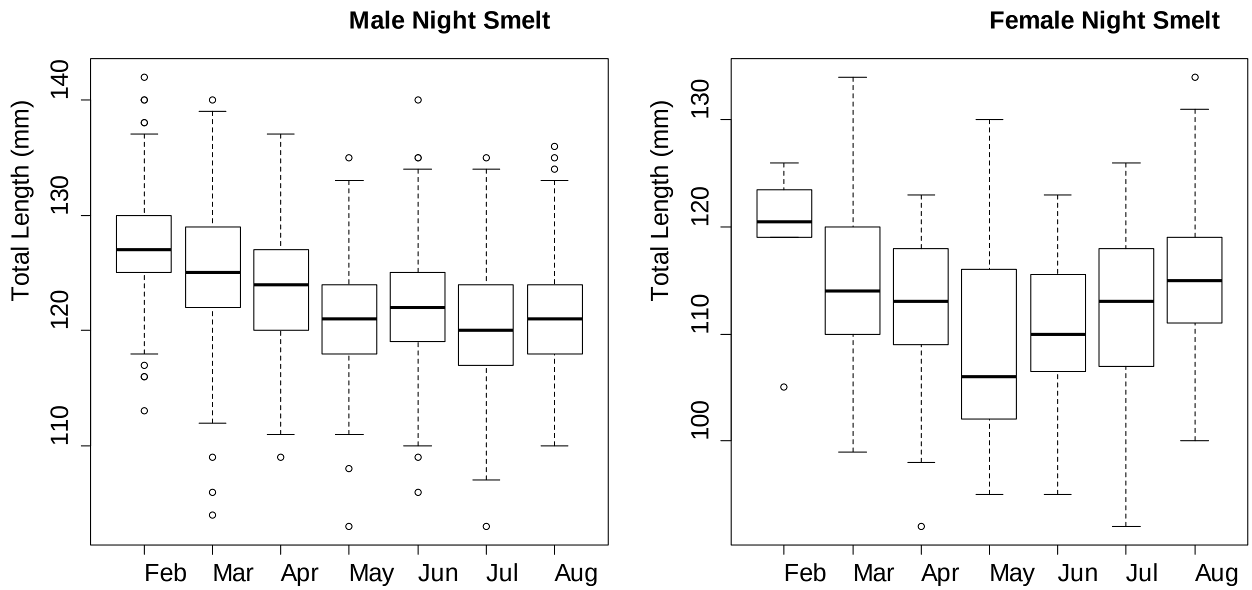

Figure 5. Boxplot of Fish Length (Total Length, mm) for Male and Female Night Smelt from All Sites Combined (February–August 2014)
The box represents the first and third quartile of the data, the dark line represents the median, the whiskers represent 1.5 times the inner quartile range, and the dots represent outliers.

For each sex, a linear model was used to fit the log of total length to the log of fish weight. Model coefficients are provided in equations 1 and 2, and coefficient estimates for each model were all highly significant (p-values <0.0001). The model is provided graphically, overlaying the data, in Figure 6.

Equation (1) $\log(Length_{male}) = -10.74 + 2.74 \times \log(Weight_{male})$

Equation (2) $\log(Length_{female}) = -11.8 + 2.94 \times \log(Weight_{female})$

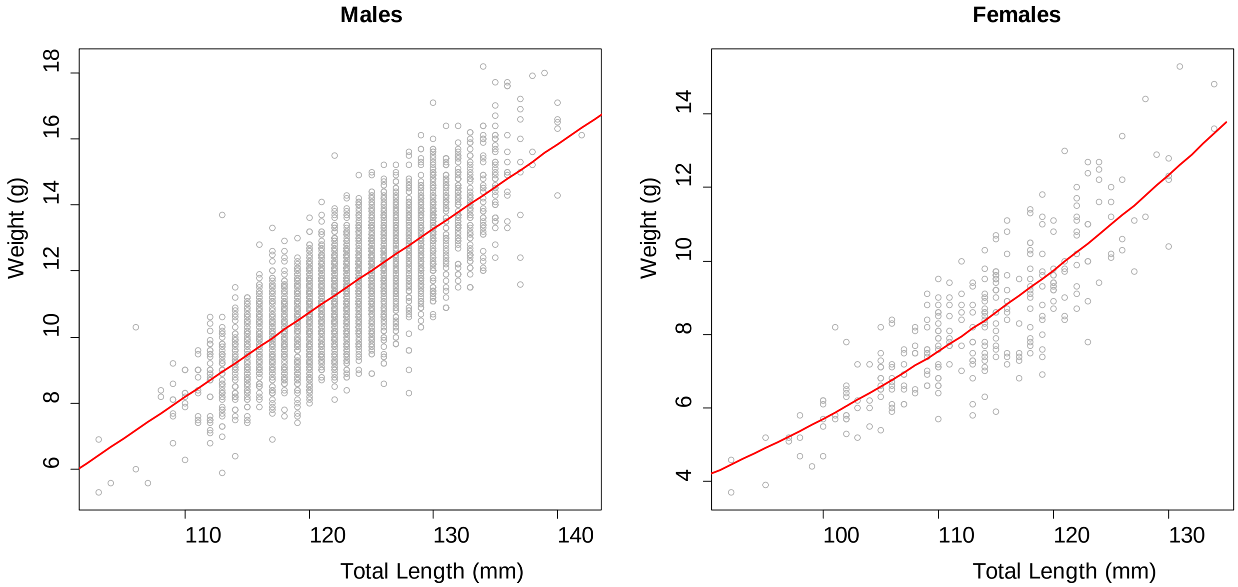

Figure 6. Length-Weight Relationships for Male and Female Night Smelt
The model is fit to data pooled from all sampling sites over the course of the season (February–August 2014).

Males were the dominant sex in all samples, representing 93% of the fish for all sites and months combined. There was an increasing trend in male/female sex ratio over the course of the season when the data were examined collectively across all study sites. Overall, the percent of females in the population increased from 1.8% in February to 12.2% in August. However, there was a large amount of variability in sex ratio among sampling location during any given month when the data were assessed at a finer spatial scale (Figure 7). The variability in sex ratio by site also appears to increase over the course of the season.

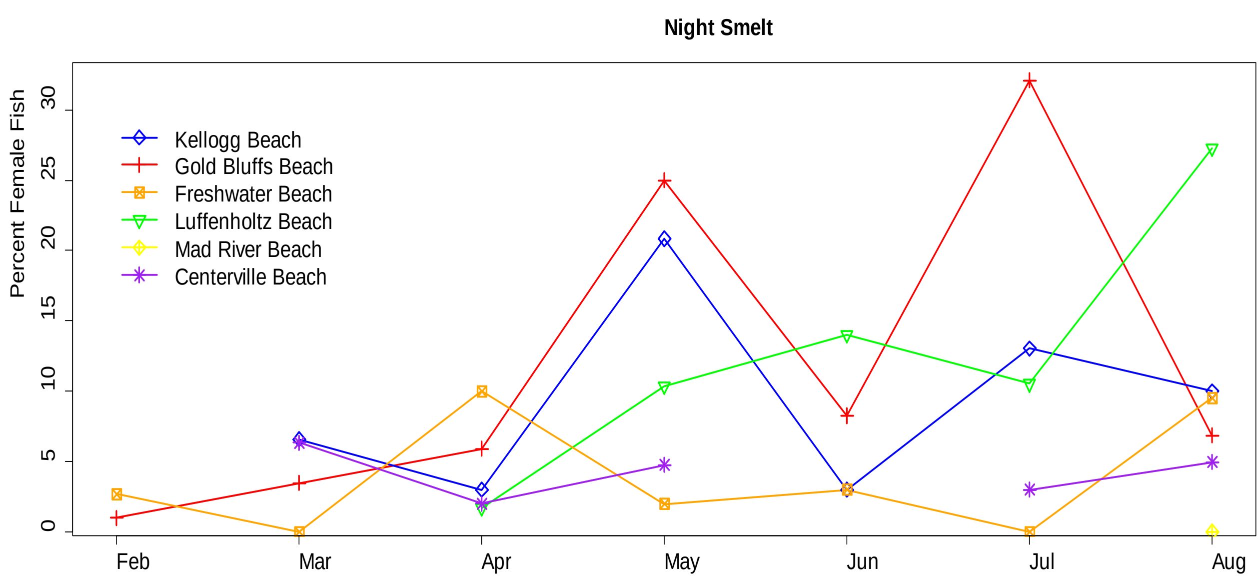

Figure 7. Percentage of Female Night Smelt from Each Site over the Course of the Study Season

Results from the 2-way ANOVA indicate that the factor "month" explained 8% of the variability in fish length while the factor "location" explained 0.4%. The results were calculated from the mean sum of squares values taken during 100 random draws from the fish length data. The factor "location" was highly significant for all 100 draws, while the factor "month" was marginally significant on average but exceeded the significance threshold on several draws (Table 4).

Table 4. Summary of Results from a 2-Way ANOVA of Fish Length (mm) with Location and Month as Factors

	Mean Sum of Squares	Mean p-value
Location	217.69	0.03757
Month	3653.07	<0.000001
Residuals	39978.36	

Note: n=95 fish/site

3.3 Bycatch

Fish species observed in the night smelt catch during beach sampling included redtail surfperch (*Amphisticus rhodoterus*), shiner perch (*Cymatogaster aggregata*), and steelhead (*Oncorhynchus mykiss irideus*). Dockside, only redtail surfperch were observed (Table 5). Invertebrate bycatch included Pacific molecrab (*Emerita analoga*), ctenophores, sipunculans, and a small (<2 cm), unidentified marine gastropod. Invertebrate species were not enumerated.

Table 5. Summary of Vertebrate Bycatch

Month	Sampling Type	Samples (n)	Volume (gallons)	Total Bycatch	Species	Total Length (mm)
March	Dockside	2	10	0	0	
	Beach	4	34.5	0	0	
April	Dockside	2	10	0	0	
	Beach	0			0	
May	Dockside	4	33	0	0	
	Beach	9	74	1	Redtail surfperch	203
June	Dockside	1	5	0	0	
	Beach	17	146.5	4	Redtail surfperch	102,254,305
					Shiner perch	76
					Steelhead	140

Month	Sampling Type	Samples (n)	Volume (gallons)	Total Bycatch	Species	Total Length (mm)
July	Dockside	8	23	0	0	
	Beach	0			0	
August	Dockside	2	23	1	Redtail surfperch	228
	Beach	0			0	

Section 4.0 Discussion

We found variable site characteristics among each of the beaches sampled, including beach slope and sand grain size composition. Night smelt were present at each beach at some point throughout the sampling season, though they appear to be less abundant at certain beaches and patchily distributed within a beach. Fishermen we spoke with over the course of this study reported targeting beaches with steep wave slopes and coarse sand or small gravel, and that certain beaches are much more productive than others. Our results showed that night smelt spawn on a variety of sediment sizes, but were found the least often at beaches that were dominated by fine sand and that had a low gradient wave slope (e.g., Mad River/Samoa Beach). Wave slope is primarily controlled by wave action and is highly correlated with sediment size (Bascom 1951). Consequently, it is not entirely clear which of these physical factors, or combination of factors, contributes to night smelt spawning location preference, but it is clear that not all sandy beach habitat equally supports spawning night smelt, something which should be considered when evaluating spatial management strategies.

Although population abundance appears to be variable across the overall study area, we found little indication that differences in population size structure existed between beaches. Fish length structure varied more over the course of the season than across sampling sites. On average, females were nearly 10 mm shorter than males. Males were also generally heavier than females at a given length, although the observed length to weight relationship may be slightly confounded because both male and female fish were in various stages of spawning. Though these observations were consistent across the spatial extent of our study area, night smelt are found from central California to southeast Alaska and there may be latitudinal differences in population structure across larger spatial scales than those examined during this project.

We were unable to assess population age structure over the course of this study, although it remains an important component towards understanding the population dynamics of night smelt. Because forage species respond rapidly to environmental variability (Pikitch et al. 2012), determining the age structure of the spawning night smelt population may contribute towards understanding population-level response to environmental change. In the male portion of our sample, we observed a length structure with one clear mode, indicating either the presence of only one age class, or differences in size among age classes that were too small to detect in a length-frequency analysis. Previous work on spawning night smelt populations used scale annuli to determine that spawning night smelt were composed primarily of 2-year old fish (Slama 1994), a finding that corroborates our observation of a single length mode during this study. However, the use of night smelt scales for age analysis has not been validated and should be confirmed with current aging techniques. It was not possible to determine age using the surface of night smelt otoliths. However, otoliths were collected and are being stored for future analysis when time and funding allow for the use of more sophisticated methods to determine age, such as polishing (e.g., McFarlane et al. 2010) or laser-ablation (e.g., Clark et al. 2007).

Consistent with past reports (Slama 1994, Sweetnam et al. 2001), and anecdotal information provided by commercial night smelt fishermen, we found that the spawning population was largely dominated by male fish. However, previously reported seasonal patterns in the percentage of females in the population were inconsistent with our observations. The average percentage of females in the population observed in our study changed over the course of the season from approximately 2% in February to approximately 12% in August, though there was a large and apparently random degree of variability in the percentage of females among beaches. In contrast, Sweetnam et al. (2001) reported male to female ratios in nearly the opposite seasonal pattern. The percentage of females in the population observed by Slama (1994) was between 2% and 6% from April, 1992 through September, 1992 and between 3% and 5% from March 1993 through July 1993; in August 1993 females comprised 18% of the population. The disparity in the relative number of females observed speaks to the need for longer term studies that may help account for high sampling variability. Longer-term and larger-scale studies may also provide insight into the factors that influence observed sex ratio such as tidal timing, time of night, temperature, or patchy distribution along beaches. Determining the presence of seasonal patterns in sex ratio with certainty could be useful to fishery managers who may want to select management strategies that minimize fishing mortality on the spawning stock.

Sweetnam et al. (2001) also reports that night smelt captured during the offshore portion of their life history phase are reported to have a 1:1 sex ratio. This finding suggests that while males form nearshore aggregations during spawning season, females may move inshore to spawn in smaller numbers, with the majority remaining offshore. This behavior likely represents an effort to minimize terrestrial and nearshore predation on female fish, one of the primary tradeoffs of the beach spawning life history strategy (Martin and Swiderski 2001). During this study, an abundance of predators were observed awaiting night smelt to begin spawning on the beach, including river otter, harbor seal, and numerous species of piscivorous birds. One of the primary benefits of beach spawning is the warmer temperatures experienced on the wave slope, which stimulates egg development. Given this theoretical framework, future research into the relationships between the ratio of female fish and spawning abundance, and wave slope temperature and seasonal differences in the rate of terrestrial predation may prove insightful.

Based on our observations, commercial night smelt landings contained very little bycatch. The most common bycatch species, redtail surfperch, were easily seen by fishermen and were typically released alive at the site of capture. Bycatch of shiner perch and steelhead were reported by commercial fishermen to be unprecedented. The single occurrence of the two species during sampling probably resulted from fishing extremely close to the mouth of Redwood Creek (both fish were released alive). On that occasion, the Redwood Creek channel ran nearly parallel to the shoreline so that it was difficult to determine, in the dark, where the margins of the creek mouth were located. Future research into the occurrence of bycatch in the night smelt fishery, especially in proximity to features such as river mouths, would be highly informative for future fishery management actions. Eulachon (*Thaleichthys pacificus*) are an anadromous smelt in the family Osmeridae that spawn in the lower reaches of coastal rivers and streams from central California to Alaska. The southern distinct population segment is listed as Threatened under the Endangered Species Act. Eulachon are reported to be rare in Mad River, Redwood Creek and the Klamath River (Sweetnam et al. 2001, Moyle 2002); no Eulachon were caught or observed during this project. Longfin smelt (*Spirinchus thaleichthys*) are also a member of the Osmeridae family and are listed as Threatened under the California Endangered Species Act. No longfin smelt were documented during this project. However, longfin smelt are similar in appearance to night smelt and may be difficult to distinguish among the night smelt catch, so it is possible that longfin smelt were present in samples but were not recognized. Longfin smelt are primarily found in estuarine habitats, though they can also occur in coastal marine habitats (Baxter 1999, Moyle 2002), and consequently the occurrence of longfin smelt as bycatch in the night smelt fishery is considered unlikely but not impossible.

Although this study provides information on characteristics of the night smelt population in northern California and the occurrence of bycatch in the commercial night smelt fishery, there is a clear need for future research before a full evaluation of the life history of this species is possible. In particular, it is critical to accurately determine the population age structure since this has such large implications for population dynamics, particularly for short-lived species such as night smelt. Virtually nothing is known about night smelt from the point of hatching until the point of returning to shore to spawn. The extent to which they exist offshore, or are caught as bycatch in other fisheries is obscured by difficulties associated with identifying Osmerid smelt, especially juveniles, to species. Osmerid smelt have historically been a significant portion of the bycatch in the pink shrimp fishery (e.g. Hannah and Jones 2007), though it remains unclear which species dominates the catch. Identifying key species interactions and population-level response to oceanographic variability will prove essential to understanding the role of this forage fish in the ecosystem, particularly as the unforeseen effects of climate change unfold. Given that, this research marks a small step towards achieving the objectives of recent forage fish polices by providing life history information to support informed science-based management decisions in the future.

Section 5.0 References

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