Progress Report: Year 4 Characterization of Larval and Juvenile Fishes in San Diego Bay, CA

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1.0 Introduction

1.1 Background

Bays and estuaries are some of the most dynamic marine environments, which nearshore animals utilize (Allen and Horn 2006). These highly variable habitats can have great physical and chemical changes over space and time as well as intense anthropogenic inputs (Emory and Stevenson 1957). Both top-down and bottom-up ecological controls drive a rich trophic environment, which can support a wide diversity of species. San Diego Bay (SDB) is the largest naturally occurring marine embayment between San Francisco and Scammon's Lagoon in central Baja California (Allen and Horn 2006). The bay is a long narrow crescent shaped body of water stretching to a length of 25 kilometers (km) with widths ranging between 1 to 3 kilometers (km) and depths between 1-18 meters (m) (DoN 2013).

Today, SDB is part of a highly urbanized ecosystem subject to anthropogenic watershed development and subsequent resource degradation and eutrophication. The bay is also home to the largest naval complex in the world and California's second largest incorporated city. Despite the anthropogenic influence on the bay, it serves as a crucial ecosystem for several sensitive marine species. The shallow water habitats of SDB support seagrass beds (*Zostera marina*) that provide vital spawning, nursery areas, and migration routes for nearshore marine fishes and invertebrates. Seagrass habitat provides food supply, shelter, and suitable physical conditions for development of eggs, larvae, and juvenile fishes and invertebrates (Cronin and Mansueti 1971; Haedrich and Hall 1976). Due to its overall ecological importance, the entirety of SDB has been designated as Essential Fish Habitat (EFH) under the Magnuson-Stevens Fisheries Conservation and Management Act (MSA).

Under the MSA, EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity". Generally, fishes have a distinctive planktonic mode at larval and juvenile life stages. These planktonic fishes, or ichthyoplankton, are fish eggs and larvae that are found in the upper layers of the water column moving with the currents (Moser and Watson 2006). Within the Southern California Bight, the maximum length of most fish larvae ranges from about 10-20 mm, however, the larvae of some species can either be much larger or can transition out of the plankton at a much smaller size (Moser and Watson 2006). Ichthyoplankton are considered vital ecosystem components of marine communities and serve as a food source for many taxa including marine invertebrates, baleen whales, and piscivorous birds (Curry et al. 2000; Sydeman et al. 2001; Bakun et al. 2010).

Of particular concern is a federally endangered bird that nests on the beaches of Naval Base Coronado (NBC), the California Least Tern (*Sternula antillarum browni*) (Photo 1). Least Terns are small-bodied (45 g), migratory seabirds that nest along coasts and inland waterways in North America. The California Least Tern is a subspecies that nests along the Pacific coast of North America from San Francisco Bay to Baja California (USFWS 2006), feeding on shallow-bodied fish in freshwater, estuarine, and saltwater environments, typically within a mile of shore (Atwood and Minsky 1983). Silversides (Atherinidae) and anchovies (Engraulidae) form the bulk of their diet, but prey composition varies over time and space (Atwood and Kelley 1984, Elliott 2005, Elliott *et al.* 2007). From mid-April to mid-September, the birds reside on Coronado's beaches to nest and fledge their young. Throughout the nesting season, terns forage in and around San Diego Bay, as well as along the coast of the Pacific Ocean, although areas of use differ among breeding stages (Baird

1997). While adult terns are capable of eating larger fish, chicks typically require smaller fish, about 3.5-6.8 cm (Baird 1997).

Tern nest monitoring has occurred on NBC since the late 1970's in an effort to responsibly manage the endangered species that inhabit Navy property. Since 2004, San Diego Zoo Institute for Conservation Research has performed nest monitoring and conducted analyses. In previous years where tern chick mortality has been unusually high, San Diego Zoo's research team has identified several potential contributing factors. Some significant threats to the population include: habitat limitation, reduced quality of nesting and foraging habitat, predation, disturbance by humans (e.g., noise, military activity, domestic animals, recreation), prey shortages, degradation or loss of winter habitat, invasive plants, disease, and climate change (Murbock et al 2017). One factor in particular has been observed more frequently and has contributed to chick mortality in recent years. In recent years, non-predation mortality of chicks likely due to starvation has occurred more frequently. From necropsy reports, these chicks often have poor body condition with little or no fat stores, or evidence of recent feeding (Murbock et al 2017).

Photo 1: Least tern adult feeding chick (Ursala Dubrick, 2015)

As an operational user of SDB and its nearshore waters, the Navy is required to manage its natural resources and comply with a suite of Federal environmental laws and regulations, including the Endangered Species Act (ESA) and MSA. NBC includes one of the largest remaining populations of terns and their breeding success or failure at NBC may have significant impacts on the entire population (Murbock et al 2017). Management of the SDB resources and compliance with federal laws is facilitated through the San Diego Bay Integrated Natural Resources Management Plan (INRMP). Currently, studies of the distribution and abundance of larval fishes in San Diego Bay have been limited to the southern half of the bay without any bay-wide efforts to date (McGowen 1981; McGowen 1977). This limited data on ichthyoplankton species distribution and abundance is identified as an information gap in the SDB INRMP (DoN 2013). For this reason, the most recent year of this project has been tailored as a pilot study to address the question of prey availability for terns on NBC and provide natural resource managers with a characterization of ichthyoplankton distribution and abundance occurring in SDB during the nesting season.

1.2 Project and Report Objective:

The main objective of this project is to provide information regarding the prey availability of larval and juvenile fishes in San Diego Bay to natural resource managers. More specifically, the purpose of this project is to better understand the temporal and spatial changes in prey resources as they relate to the breeding success of the California Least Tern. This progress report is intended to provide a summary of work completed to date. All data collection efforts took place through collaboration between biologists at Space and Naval Warfare Systems Center, Pacific (SSC PAC) Environmental Readiness Division and Naval Facilities Engineering Command, Southwest (NAVFAC SW). Under funding provided by Commander, Naval Installation Command, SSC PAC Environmental Readiness Division Team initiated four years of larval and juvenile fish surveys. The first year was conducted from May 2012-April 2013 with results summarized in 2015 (Bredvik and Graham 2015). The second and third years were conducted November 2013-October 2014 and May 2016-April 2017, respectively, with data entry still ongoing. The first three years are intended to provide a baseline characterization of larval and juvenile fishes in SDB.

May 2017 marked the beginning of the fourth and most recent year of sampling, which was intentionally designed with a more focused and targeted approach. Sampling in the fourth year occurred simultaneously with the tern nesting season (mid-May to mid-September 2017). In addition to boat surveys, the fourth year incorporated the use of beach seining to obtain prey resource data in the nearshore areas utilized by foraging terns. Prey resources were evaluated by sampling period (early, middle, and late), which are intended to correspond with the various breeding stages of the tern (nesting, hatching, and fledging). This project was not funded for 2018, therefore, additional field efforts were not conducted. This progress report focuses on continued efforts during FY18 in fish identification and preliminary results of the fourth year of data collected on larval fishes.

2.0 Methods

2.1 Location

The Southern California Bight (SCB), an area of the eastern Pacific Ocean, that follows the California coastline from Point Conception (Santa Barbara County, California) to Cabo Colnett (south of Ensenada, Mexico), has subtropical waters flowing nearshore with cooler subarctic waters flowing offshore creating a unique convergence pattern that forms a biological transition zone, which allows for an abundance of marine species to thrive within this area. Plankton, as primary and secondary producers, serve as a vital marine ecosystem component within the biogeographic area. San Diego Bay is the largest embayment within the SCB and is the location for the seasonal effort of surface plankton tows and beach seines (Figure 1).

Surface plankton tows occurred in all four ecoregions of the bay, while beach seines focused specifically on the north ecoregion. The focus on the north ecoregion, for the purposes of this year, was chosen based on a tern foraging study conducted in 2009 which indicated that the northern region of San Diego Bay was utilized more frequently by foraging terns (Baird 2009). However, three surveys were also completed in the south central ecoregion to serve as a snapshot of prey availability adjacent to one of the tern's primary nesting colonies. In total, eight beach seine sites were sampled (six in the north and two in the south central ecoregions).

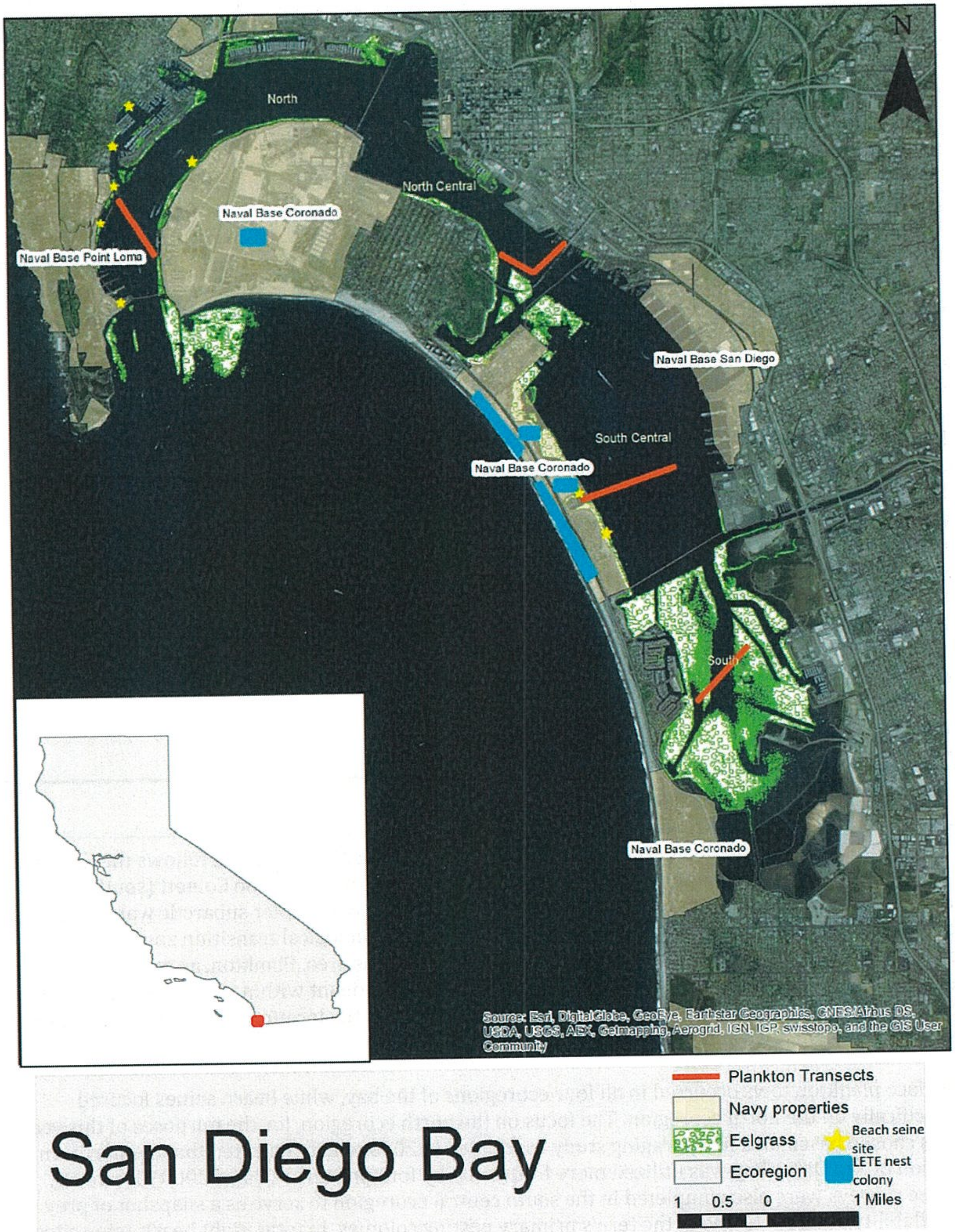

Figure 1: Overview map of San Diego Bay ecoregions, surface tow transects, beach seine sites, and least tern nesting colony locations

2.2 Field Collections

Sampling for both surface plankton tows and beach seines was conducted according to three sampling periods – early, middle and late – and were designed to roughly correspond with the various tern breeding stages. For the 2017 field season the sampling periods were designated as follows:

- Early: 21 May to 1 July 2017
- Middle: 2 July to 12 August 2017
- Late: 13 August to 16 September 2017

Surface Plankton Tows

Year four surface trawls followed a similar sampling regime as previous efforts (Bredvik and Graham 2015) with a few exceptions. Instead of conducting monthly diurnal and nocturnal surveys over the course of one calendar year, this year, prey resources were evaluated by sampling approximately every two to three weeks during the early, middle, and late nesting periods. These surveys were conducted only during the daytime within the four ecoregions in San Diego Bay (Figure 1). In addition, a full (diurnal and nocturnal) survey was conducted once per sampling period.

All trawl transect lines were designed to sample across different habitats (vegetated, un-vegetated, deep and shallow waters) in each of the ecoregions. A 27-foot SeaArk was used for full surveys (diurnal and nocturnal) and survey transect lines were uploaded to a Garmin 740s chart plotter for coxswain navigation. A 17-foot Penetrator was used for diurnal-only surveys. A manta net (28 centimeters [cm] x 62 cm) with 33 micron mesh was deployed from a perpendicularly mounted fiberglass rod on the starboard side of the vessel. The fiberglass pole extended the net out approximately 1 meter from the boat to maintain an appropriate towing angle off the stern to prevent propeller wash during collection (Photo 2). The net was trawled at the surface for approximately 20 minutes at the same location for every sampling effort. The net was towed at 2.0 knots and sampled approximately the upper 15 cm of the water column. Volume of water filtered through each tow was estimated with a flowmeter (G.O. Environmental) fixed to the mouth of the net. Samples collected in the cod end of the manta net were rinsed and fixed in a 10 percent formalin solution, labeled and stored for processing in the laboratory (Photo 3).

Environmental data and other parameters were collected at the end of each transect. Using a SonTek CastAway-Conductivity, Temperature, Depth (CTD) instrument, surface water temperature and salinity were measured and recorded. Sea state, lunar cycle, tide and wind speed and direction were also noted.

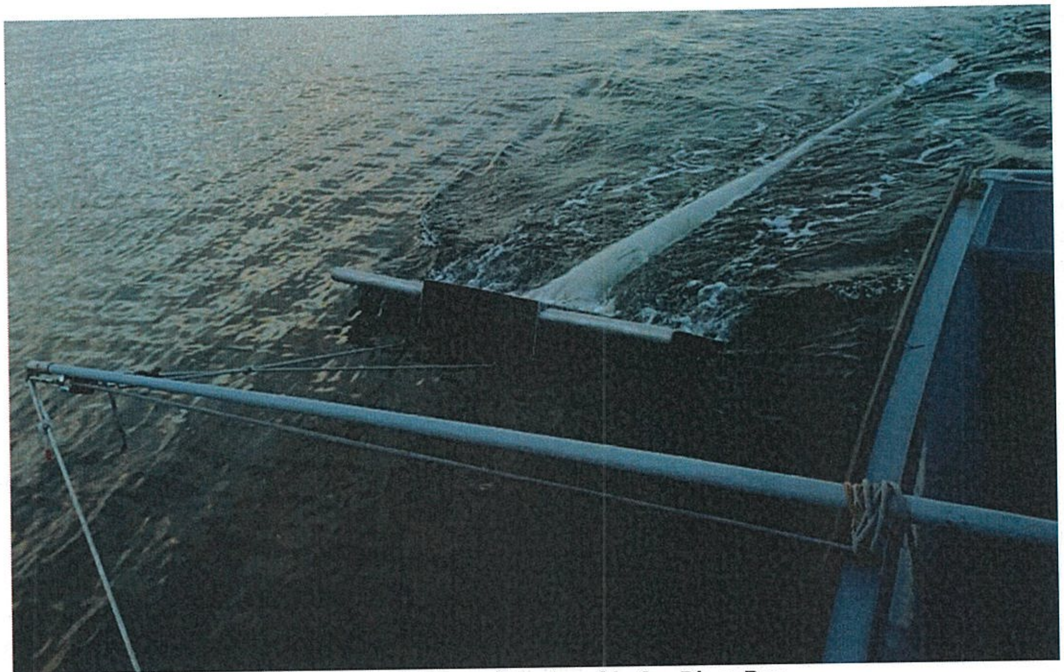

Photo 2: Manta trawl deployed in San Diego Bay

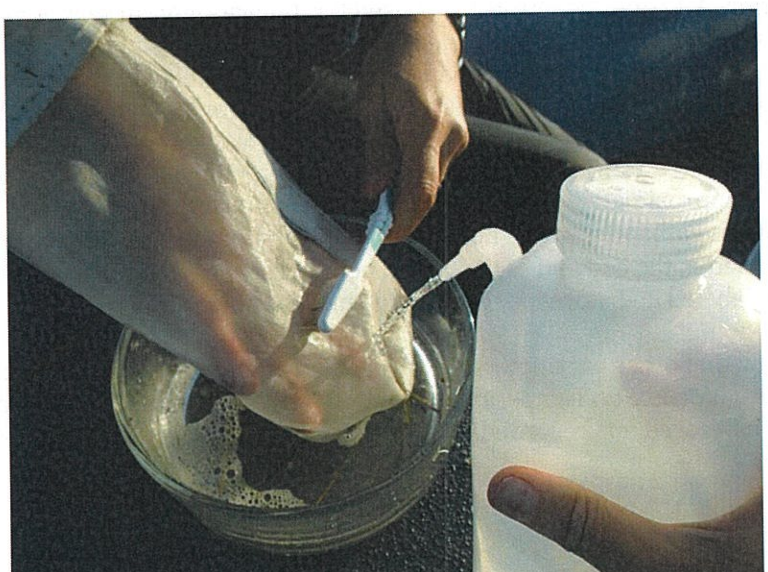

Photo 3: Plankton sample being processed in the field from the cod end

Beach Seines

Another variation in year four sampling was the addition of beach seining. A 4.6 m x 1.2 m small seine (3 mm mesh) was employed to collect juvenile and adult fishes occupying the shallow, inshore areas (0-0.5 m depth) (Photo 4). The small seine was hauled 10 m along shore and pivoted shoreward yielding a consistent areal coverage of 62 m^2. This gear was used to sample both vegetated and non-vegetated intertidal habitat. Sampling efforts occurred approximately every two to three weeks. In total, five sampling days occurred during the early sampling period, four during the middle and three during the late. Individual fishes were measured in the field and a group weight was taken for each species to the nearest gram using Pesola hanging scales (10 g-50 kg) then were returned to the bay.

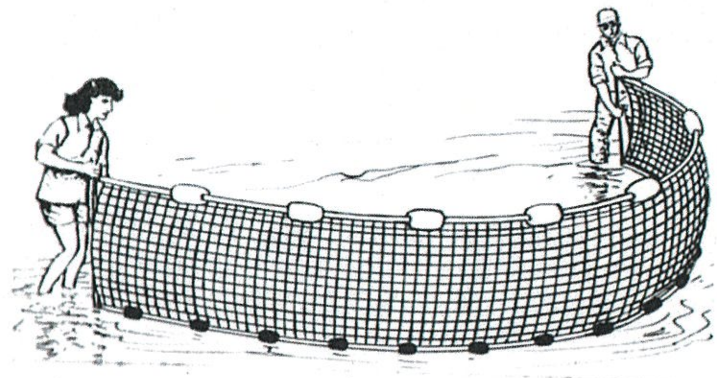

Photo 4: Illustration of beach seine being walked into shore (Bountiful Seines, 2017)

2.3 Laboratory Sample Processing

Following each survey, samples collected with the manta net were transferred from 10 percent formalin solution into freshwater for a 24-hour period then stored in 70 percent ethyl alcohol for processing and identification. Using a dissecting microscope, collections were sorted for larval and juvenile fishes (Photo 5). Fish identification is still underway. Fishes are being identified to the lowest taxonomic level using a reference book (Moser 1996) as the primary source. Finally, each sample's fishes will be individually counted, measured (standard length, to the nearest mm), and weighed (to the nearest 0.0001 gram). Biological samples will be archived in 70 percent ethyl alcohol for future reference and potential further studies.

Photo 5: Dissecting microscope used for sorting plankton samples

3.0 Preliminary Results

A Microsoft Access Database was built to house all data collected in this study and previous years. Data entry is still ongoing.

3.1 Species Trends

Surface Plankton Tows

Nine survey days were completed in SDB between 5 May and 14 September 2017, of which four were full surveys (diurnal and nocturnal) and five were day-only surveys (diurnal), resulting in 51 samples. Sample processing has been completed and species identification of surface tows is 45% complete. So far, 558 fish have been identified.

Of this, the majority of fish identified are California grunion (*Lueresthes tenuis*), unidentified blennies (*Hypsoblennius* sp.) and topsmelt (*Atherinops affinis*), which are species preferred by terns (Figure 2). Spatially, the majority of fish collected have come from the North ecoregion (266 fish or 47%; Figure 3). Temporally, the early sampling period has shown the greatest abundance of all fishes so far, with 387 fish collected overall (69%, Figure 4).

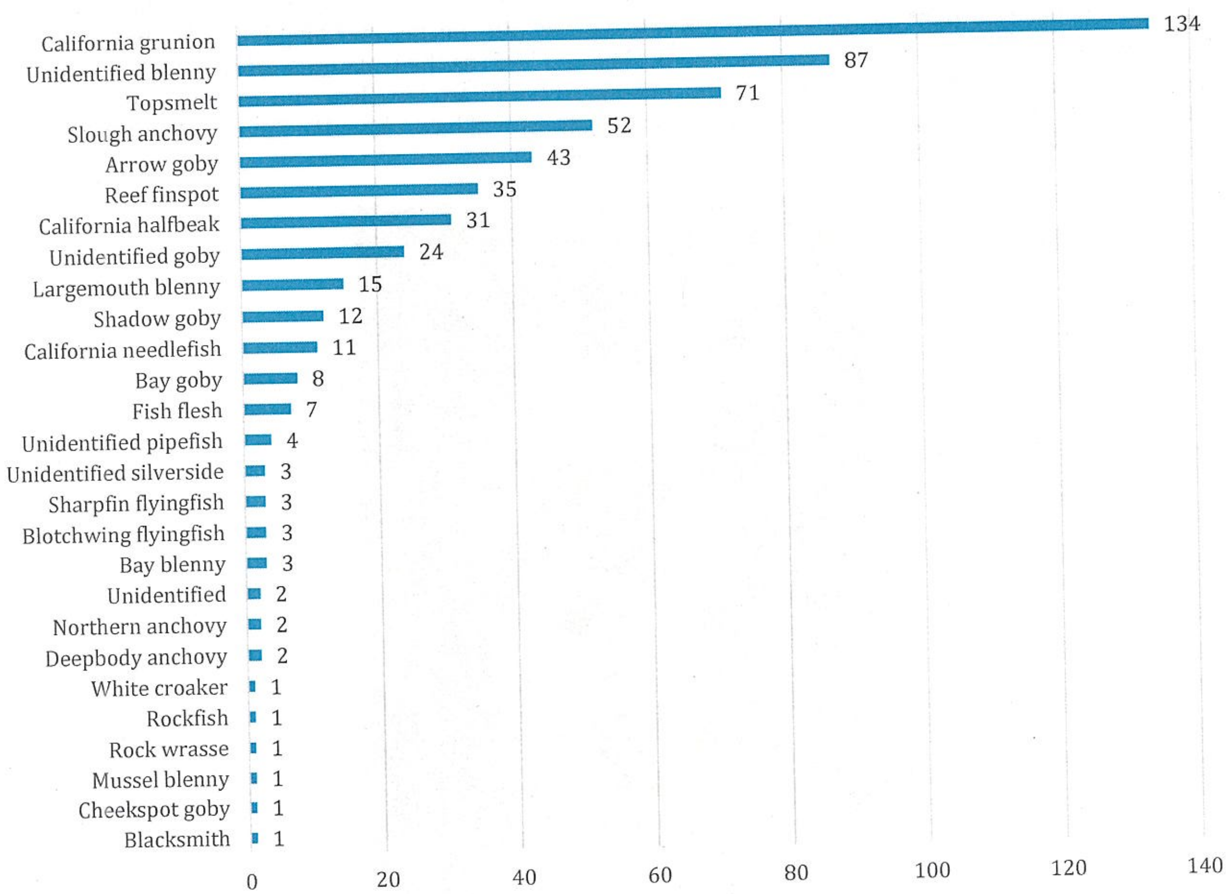

Figure 2: Abundance of larval fish by species in San Diego Bay from June to September 2017. N=558.

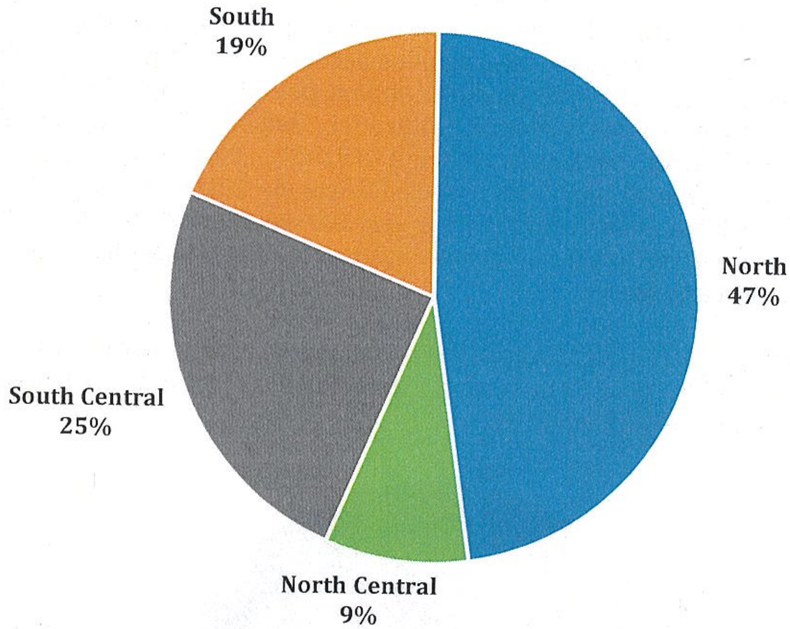

Figure 3: Abundance of larval fish by ecoregion in San Diego Bay from June to September 2017. N=558.

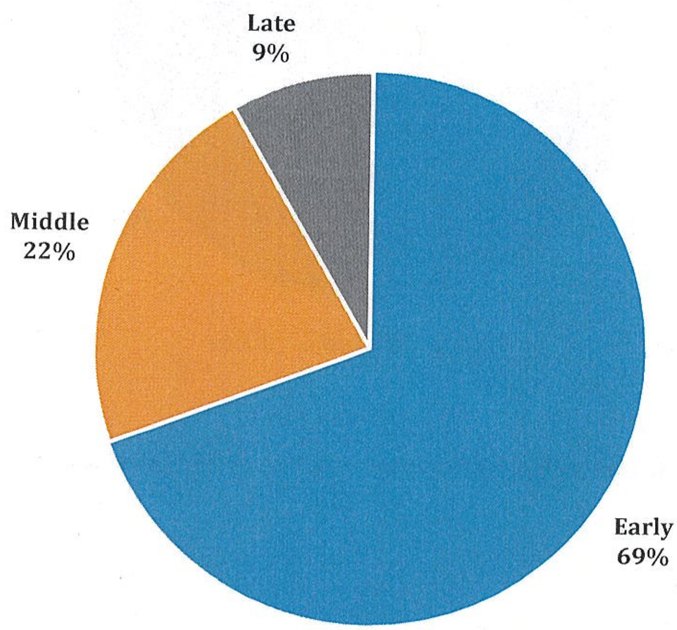

Figure 4: Abundance of larval fish by sampling period in San Diego Bay from June to September 2017. Early: 25 May to 29 June. Middle: 11 July to 8 August. Late: 17 August to 14 September. N=558.

Beach Seines

Twelve beach seine survey days were completed in SDB between 13 June and 5 September 2017, of which nine occurred in the north and three in the south central ecoregions. It should be noted that sampling efforts slightly decreased in the late sampling period (three samples were collected as opposed to five in the early and four in the middle sampling periods). All beach seine sample processing and species identification is complete. Altogether, samples yielded a total of 3,979 fish, which included 17 species across ten families (Table 1). Of the ten families, Atherinids comprised 97% of all fishes caught. The most commonly collected fish in the Atherinidae family was topsmelt (*Atherinops affinis*), which is a preferred tern forage species. This species' abundance decreased in the beach seine samples over the course of the nesting season (Figure 5), with a majority of topsmelt collected in the early season.

Overall, the early sampling period had the greatest abundance of all fish species by far, with a total of 2,831 fish collected (71%). The least number of fish were collected during the late sampling period, with 152 individuals (4%) (Figure 6).

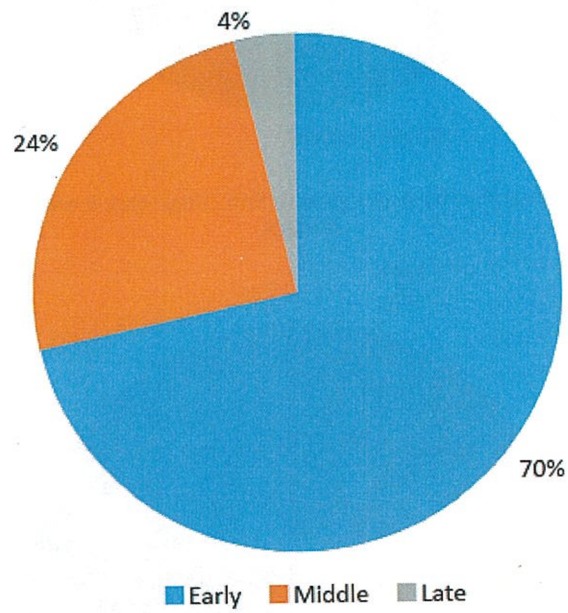

Figure 5: Topsmelt abundance by sampling period (all size classes)

Table 1: Overall family and species abundance by ecoregion collected with beach seines

North				
Family	Scientific Name	Common Name	Family Count	Species Count
Atherinidae	*Atherinops affinis*	Topsmelt	3880	3870
	Lueresthes tenuis	California grunion		10
Gobiidae	*Ilypnus gilberti*	Cheekspot goby	14	12
	Quietula y-cauda	Shadow goby		3
	Clevelanida ios	Arrow goby		1
Kyphosidae	*Medialuna californiensis*	Halfmoon	1	1
Paralichthyidae	*Paralichythys californicus*	California halibut	1	1
Scorpaenidae	*Sebastes melanops*	Black rockfish	1	1
Serranidae	*Paralabrax clathratus*	Kelp bass	4	4
Urotrygonidae	*Urobatis halleri*	Round stingray	3	3
Total			**3906**	

South Central				
Family	Scientific Name	Common Name	Family Count	Species Count
Atherinidae	*Atherinops affinis*	Topsmelt	35	34
	Atherinopsis californiensis	Jacksmelt		1
Clinidae	*Gibbonsia elegans*	Spotted kelpfish	4	1
	Heterostichus rostratus	Giant kelpfish		3
Cyprinodontidae	*Fundulus parvipinnis*	California killifish	1	1
Engraulidae	*Anchoa delicatissima*	Slough anchovy	1	1
Gobiidae	*Ilypnus gilberti*	Cheekspot goby	9	1
	Quietula y-cauda	Shadow goby		7
	Acanthogobius flavimanus	Yellowfin goby		1
Serranidae	*Paralabrax maculatofasciatus*	Kelp bass	2	2
Syngnathidae	*Syngnathus leptorrhynchus*	Bay pipefish	21	21
Total			**73**	

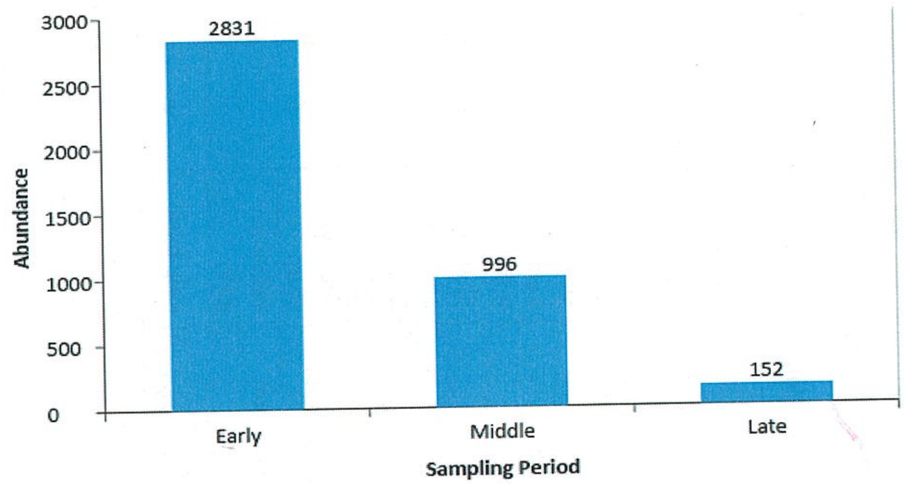

Figure 6: Abundance of all species by sampling period

3.2 Weights and Lengths

Fishes from year four surface plankton tows are in the process of being identified, weighed, and measured. Thus far, all samples have been sorted and approximately 45% of samples have been identified. After identification has been completed, weights and lengths will be measured for all fish.

All fishes from beach seine surveys have been measured and weighed. The average size class across all species was 5 cm with the largest fish measuring 20 cm (*Urobatis halleri*) and the smallest fish measuring 0.5 cm (*Atherinops affiinis*). The average group weight across all species was 34 grams, with the heaviest species weighing 843 grams (*Urobatis halleri*) and the lightest species weighing 0.05 grams (*Atherinops affiinis*).

Specific size classes of juvenile topsmelt (≥3cm, preferred tern size) were distributed across the early and middle sampling periods pretty evenly with very few topsmelt of this size collected in the late season (Figure 7).

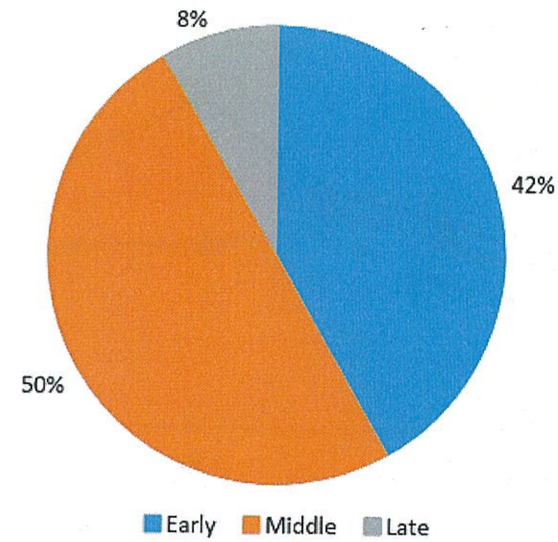

Figure 7: Topsmelt abundance by sampling period collected by beach seine (tern preferred size classes only, ≥3cm)

3.3 Environmental Data

Surface Plankton Tows

Generally, sea surface temperatures varied by sampling period and ecoregion. The highest average sea surface temperature was recorded from the south ecoregion on 27 July 2017 at 30.75 degrees Celsius (°C) and the lowest temperature of 15.57°C was recorded in the north ecoregion on 25 May 2017 (Figure 8).

Salinity measurements were averaged for day and night samples (for full surveys only) as thethe two time periods did not vary greatly. Salinity was highest in the south bay on 8 August 2017 and lowest in the north ecoregion on 25 May 2017 (Figure 9).

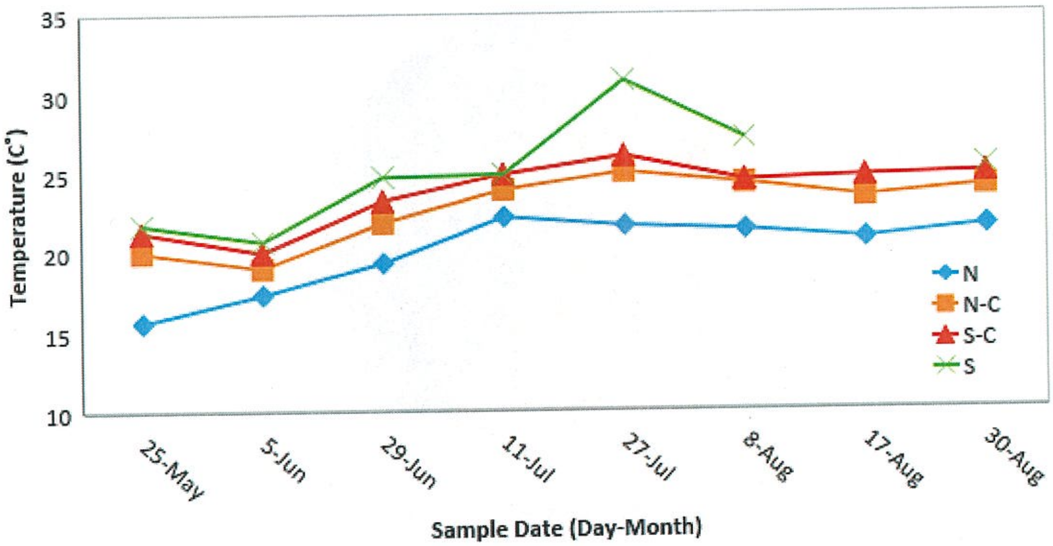

Figure 8: Average sea-surface temperature recordings from May through August 2017 (N=31).

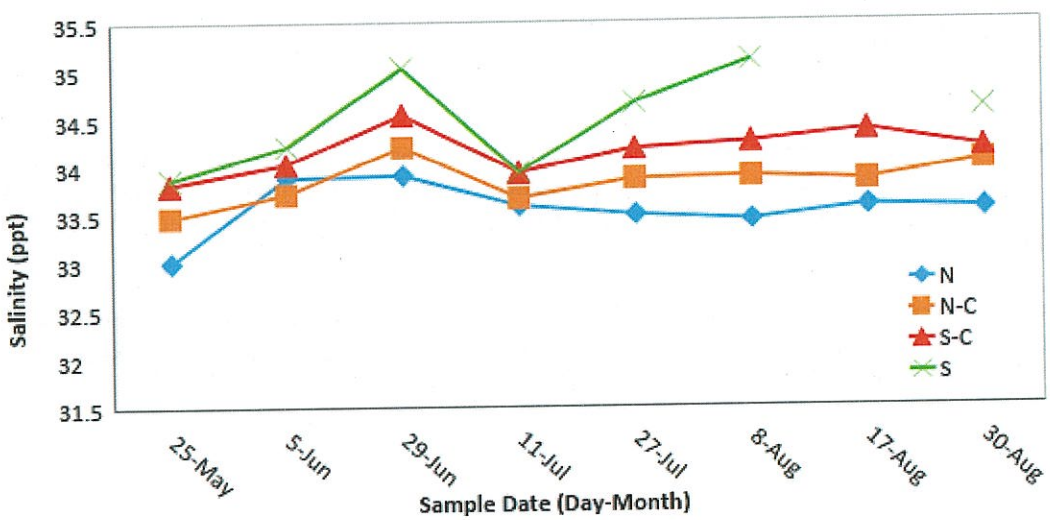

Figure 9: Average sea-surface salinity recordings from May through August 2017 (N=31).

3.4 Continued Efforts

Samples from surface tow surveys will continue to be identified to the lowest taxonomic level and will consequently be weighed and measured. All data will be entered into the Microsoft Access Database. Upon completion of all four years of sampling and processing, an overall trend analysis will be conducted.

4.0 Recommendations

While the first three years of data collection focused on characterizing an overall baseline of ichthyoplankton abundance and diversity in San Diego Bay, it is recommended that following seasons be focused more heavily on the interaction between ichthyoplankton and the California least tern as it relates to the tern's prey availability. Going forward, it is recommended that the plankton field season continue to coincide with the tern nesting season (approximately mid-May to mid-September). Additionally, this will entail better coordination with Naval Base Coronado's installation biologist and tern management team in order to better define sampling periods according to the nesting status of the birds. It is also recommended to continue to supplement the boat survey sampling method that has historically been utilized with beach seining, however beach seining should be conducted seasonally at a bare minimum. This information provides real time data that is reflective of forage fish populations available to the terns. The beach seine method also requires much less post-field processing and is significantly more cost effective.

Additionally, further research is needed to better understand the foraging behaviors of terns including: when terns are foraging (i.e. day, night, dawn, or dusk), where terns prefer to forage within the bay (i.e. which ecoregions and what habitat type), and the species and sizes of preferred forage fish. More conclusive knowledge of this information will allow for a more rigorous sampling regime, which in turn will provide a more accurate assessment of prey availability for the terns. Ultimately, continuation of this project will provide instrumental data to assist natural resource managers in the recovery of this species. The more focused approach that was piloted this year is necessary to assess prey availability for the least terns and will provide critical information to the region at large that has previously been unknown.

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