Final Performance Report

December 4, 2017 — December 31, 2021

As Required By

Texas State Wildlife Grant Program
TX T-172-R-1
F17AF01067

Extensive Field Effort Using a Novel Gear Type to Detect Recruitment of American Eel (*Anguilla rostrata*) in Texas

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February 15, 2022

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Location(s):

Statewide

Objective(s):

1) Document distribution and abundance of glass and elver American Eel along the central and upper Texas coast.
2) Determine habitat use and associated water quality needs of glass and elver American Eel along the central and upper Texas coast.
3) Assess efficacy of varying collection methodologies to optimize glass and elver American Eel capture.
4) Identify the temporal recruitment window of glass and elver American Eels in Texas.

Significant Deviation(s):

Despite a significant field effort that spanned two years and encompassed two-thirds of the Texas Coast, juvenile American Eel were not collected during this study. This final report describes the nekton community documented by this effort and provides a general description of environmental conditions that were present when other species of Elopomorphs were collected.

Acknowledgements:

We would like to thank the team of EIH staff and graduate students that assisted with the field sampling for this project including: Josh Jaeger, Sherah Loe, Natasha Zarnstorff, Tyler Swanson, Kaylei Chau, McKenzie Farrell, Mandi Gordon, Cory Scanes, Randon Peirson, and Samantha Salas; as well as the field assistance from our Texas Parks and Wildlife Department partners and support staff. Internal support for the project was provided by numerous UHCL departments and especially EIH's Department Assistant III, Patti Koch. All sampling was conducted under Texas Parks and Wildlife Department Scientific Collection Permit SPR-0504-383.

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Final Report

EIH Technical Report #EIH21-002
December 2, 2021

Prepared by the Environmental Institute of Houston University of Houston - Clear Lake in cooperation with the Texas Parks and Wildlife Department and the United States Fish and Wildlife Service

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Recommended Citation: Oakley, J.W., J. Hansen, T. Molina, S. Curtis, and G.J. Guillen, 2021. Extensive field effort using a novel gear type to detect recruitment of American Eel (*Anguilla rostrata)* in Texas. Final Report (Report No. EIH21-002). Prepared for the Texas Parks and Wildlife Department (Contract 505077) 42 pp.

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Executive Summary

The American Eel (*Anguilla rostrata*) is a facultative, catadromous freshwater fish. They undergo extensive migrations throughout each developmental stage of their life cycle including larval (leptocephalus), juvenile (glass and elver eels), sub-adult (yellow eel), and breeding adult (silver eel). An important area of study for the American Eel is related to juvenile recruitment along the continental shelf and into bays and estuaries along the Atlantic, Gulf of Mexico (GoM), and the Caribbean. The ingress of juveniles, especially metamorphic larvae, may heavily influence the outcome of their respective adult population success. Within Texas, sub-adult and adult American Eel have been found in major river basins from the Sabine River to the Rio Grande. However, there have been no verified reports of glass American Eel and only a few historic records of elvers in the state. American Eel are considered a Species of Greatest Conservation Need by the Texas Parks and Wildlife Department (TPWD). The Environmental Institute of Houston (EIH) is partnering with TPWD to study the distribution and abundance of glass and elver eel in the central and upper Texas coast to evaluate habitat associations and identify the recruitment window for American Eel in Texas.

The primary sampling gear used in the study were small-mesh fyke nets which represent a novel gear type for Texas waters, although they are used extensively along the east coast of the U.S. for American Eel monitoring. These nets are specifically designed and deployed to select for small-bodied (e.g. laterally and dorsoventrally compressed organisms) that display a net upstream movement, like the glass and elver stages of American Eels. Ambient water quality and habitat data were collected at each site. In addition, moon phase and percent illumination were recorded for the night of net set. A secondary gear type, eel mops (artificial habitat), were continuously deployed at select sites and checked during each net set. The study design was divided into two phases. In order to identify the recruitment window and optimal site conditions for capturing glass and elver eels. Phase one focused on a year-round field effort with a broad spatial scale. During phase one, a total of 330 net sets were deployed at 130 unique sites from Corpus Christi Bay to Sabine Lake from August 2018 through November 2019. There were no detections of American Eel in phase one of the study, however it was determined that the fyke nets were effective at collecting fishes from the super order Elopomorpha, which share early-life body morphology and recruitment similar to the American Eel. The initial goal of phase two was to use the recruitment window and site condition data collected from phase one to focus efforts on a smaller number of sites with increased frequency to better define the recruitment window. Available historic data of early life stage American Eel in the Gulf of Mexico and data collected for other elopomorphs during phase one were used to define an optimal sampling time period of March through July 2020. A total of nine sites were sampled every other week during phase two with a total of 80 net sets.

Throughout both phases of field sampling, the cumulative effort in total soak time for fyke net sampling events was 6,851.77 hours. A total of 130,860 fishes were collected in the cod end of the nets representing 71 species from 34 families. Additionally, 25 species of fish and invertebrates representing 23 families were collected in the eel mops. While no American Eel were captured during the study, other elopomorph species were collected including the Speckled Worm Eel (*Myrophis punctatus*) which were collected during every month of the study at various life stages and Ladyfish (*Elops saurus)* which were collected during their known recruitment window. Habitat and water chemistry variables were examined for correlation to Elopomorph catch per unit effort and presence. Water temperature (a factor of seasonality of recruitment), salinity, dissolved oxygen, secchi depth, and total percent cover of in-stream cover in front of the fyke net were all significant variables in predicting elopomorph presence during a sampling event. These findings suggest the fyke nets used in this study are effective at capturing

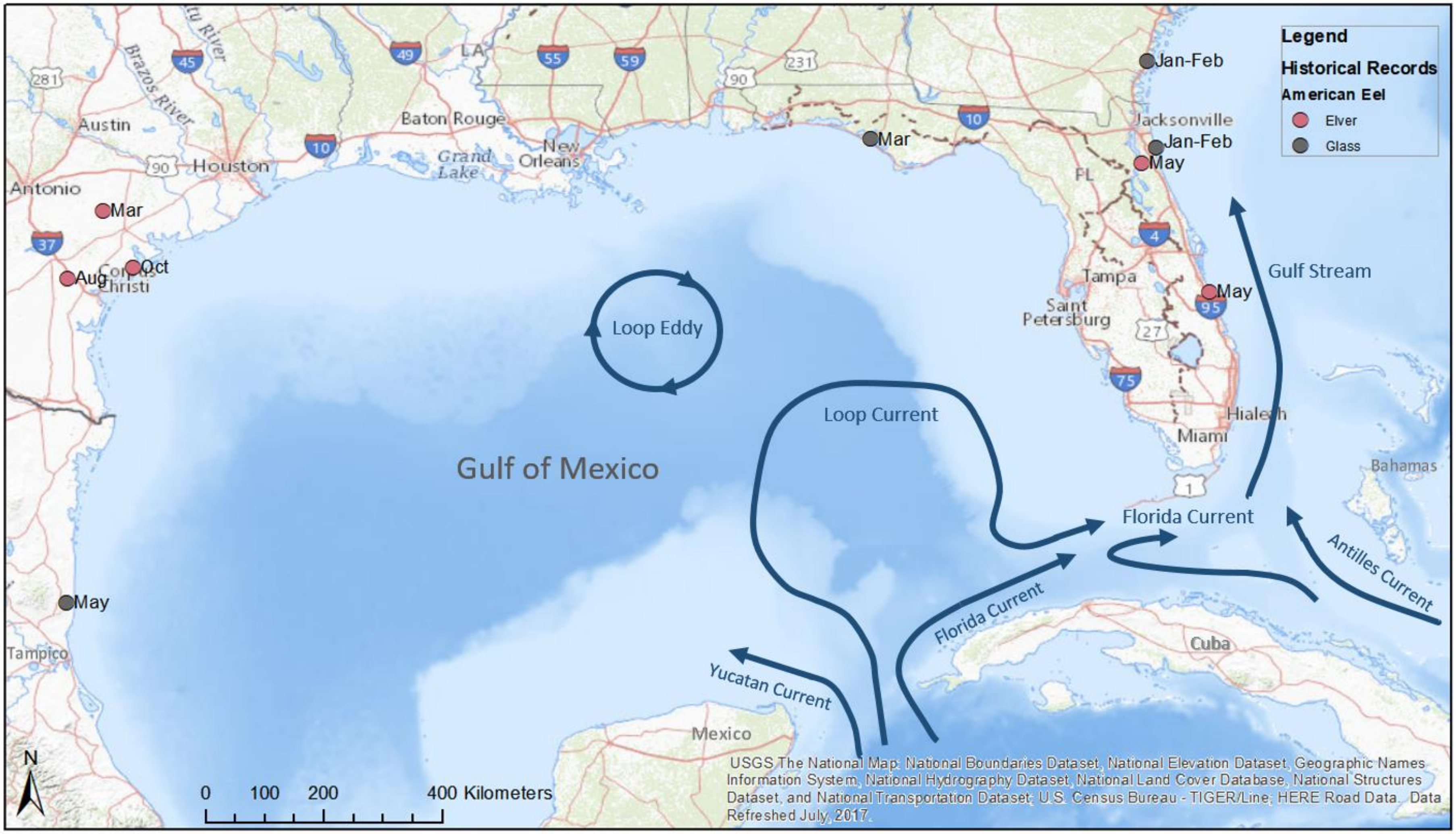
the early life stages of elopomorphs as they ingress and settle which reinforces this approach as a potential method for the detection of juvenile American Eel. It is likely that if juvenile American Eel were present, in high abundances, during the dates and locations surveyed, we would have been able to detect their ingression.

Recommendations for future work include continuation of fyke net deployments at select long-term monitoring sites since recruitment of American Eel to the Texas coast is likely sporadic and may occur only during uniquely timed Gulf currents. Results of an ongoing range wide assessment of American Eel genetics as well as an otolith microchemistry and aging study could help elucidate the complex conditions driving American Eel distribution and movement patterns within the Gulf of Mexico. Another recommendation is to deploy eel ramps to continually sample at key sites which would allow researchers to continue year-round effort, increasing the likelihood of detecting intermittent recruitment events.

Introduction and Background

The American Eel (*Anguilla rostrata*) is a facultative, catadromous freshwater fish inhabiting North America, the Caribbean, and the northern reaches of South America. They undergo extensive migrations throughout each developmental stage of their life cycle including larval (leptocephalus), juvenile (glass and elver eels), sub-adult (yellow eel), and breeding-adult (silver eel). Silver eels travel from inland waters to the Sargasso Sea, where they are assumed to undergo panmictic, semelparous reproduction (ASMFC, 2017). More recently, extensive spatial and temporal genetic efforts have supported this assumption (Côté et al., 2013), however theories of a shifted spawning location supported by advanced ocean current and particle tracking models have recently emerged (Chang et al., 2020). Spawning is estimated to occur from February to April with peak spawning between March and April (Miller et al., 2015), although some estimates have calculated hatching to occur as early as December (Kuroki et al., 2017). The Gulf Stream is the primary transport mechanism by which the leptocephali are transported throughout their Atlantic distribution (Kleckner and McCleave, 1982). However, the mechanism for which larvae enter the Gulf of Mexico (GoM) and the northern Caribbean has not been well studied. The southernmost spawned larvae are suggested to utilize southwest and south-northwest currents (the Yucatan, Florida, and subsequent Gulf Loop Currents) to successfully enter the GoM (Rypina et al., 2014; Miller et al., 2015) (Figure 1). Alternatively, other data indicate that there could be a separate spawning population in the eastern GoM, but this theory is highly disputed and requires genetic analysis and comparison between the Gulf and East coast eels, which is underway (Miller et al., 2015).

Elopomorpha is a superorder of bony fishes that all exhibit a characteristic leptocephalus larval stage. American Eels belong to this superorder along with other common estuarine species including (but not limited to) Ladyfish (*Elops saurus*) and Speckled Worm Eel (*Myrophis punctatus*). Both Ladyfish and Speckled Worm Eel have similar reproduction and recruitment histories, spawning off the coast and relying on currents to deliver leptocephalus or early metamorphizing stages into coastal estuarine waters (Able et al., 2011; Adams et al., 2014). The timing of recruitment to the coastal estuarine waters in North Carolina and Florida in the winter and early spring are similar for both American Eel and Speckled Worm Eel (Warlen and Burke, 1990; Able et al., 2011; Bonvechio, 2016). The ingress of larval fishes, especially metamorphic larvae, may heavily influence the outcome of their respective adult population success (Able et al., 2011). Glass and elver American Eel entering estuaries along the east coast are the primary life stage harvested by commercial and recreational fishermen (ASMFC, 2017). Significant work has been done to understand larval drift of the leptocephalus stage of American Eel (Kleckner and McCleave, 1982; Miller, 2009; Miller et al., 2015). While information regarding metamorphosis into juvenile glass eels is limited, metamorphoses is thought to last between 18 to 52 days with recruitment occurring between 171 and 252 days later (Antunes and Tesch, 1997; Arai et al., 2000).



USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE Road Data. Data Refreshed July, 2017.

Figure 1. Examples of the typical ocean currents that likely impact American Eel recruitment to the Gulf of Mexico, and historical records of juvenile American Eel labeled with the month they were observed.

An important area of study for the American Eel is related to juvenile (glass eel and elvers) recruitment along the continental shelf and into the bays and estuaries of the Atlantic, GoM, and the Caribbean. Recently, European glass eels (*A. anguilla*) were found to utilize the geomagnetic field to orient towards the Gulf Stream after being displaced from European waters, which likely maximizes successful migration back to Europe (Cresci et al., 2017). This compliments the hypothesis that the link between olfaction and fresh water cues plays a vital role in the migration and settlement of recently metamorphosed glass eels (Sola and Tongiorgi, 1996; Sullivan et al., 2006). As metamorphosis concludes, a shift in habitat preference from the water column to settlement along the substrates of near shore water occurs. Using otolith microchemistry, Jessop et al. (2002) discovered four juvenile behaviors associated with large scale habitat preference in the East River, Nova Scotia. Juvenile eels would either directly ingress, stay for a year or more then ingress, transition between fresh and estuarine water, or stay in estuarine water. The majority of eels that were found to recruit to freshwater are considered elvers, but up to 25% recruit as glass eels (Jessop et al., 2008).

Glass eels and elvers undergoing their upstream migration likely utilize Selective Tidal Stream Transport, a mechanism used by most catadromous fishes to synchronize their upstream movement with the incoming tide (Trancart et al., 2014). Glass eels have been shown to follow a rhythm of activity that corresponds to the changing tidal cycle and then forego this behavior in the non-tidal reaches of streams and rivers (Wippelhauser and McCleave, 2009). Fresh water eels in New Zealand are known to utilize stream margin habitat during the outgoing tide as to not be displaced by high current velocity in the centroid of the flow (Jellyman and Lambert, 2003a; Jellyman, 1979). Post-larval eels tend to be bottom-dwellers when not actively migrating by hiding in burrows, tubes, snags, plant masses, or the substrate itself (Fahay, 1978).

Conservation Status

Trends in American Eel biology and life history have undergone extensive review over the past several decades to determine the respective status of American Eel under the Endangered Species Act (ESA). Strong declining trends in American Eel commercial landings emerged in the 1980s and 1990s though data were limited and most likely underrepresented providing an incomplete understanding of the declines (Haro et al., 2000). Due to this perceived population decline, the United States Fish and Wildlife Service (USFWS) were tasked with evaluating the potential protection of American Eels under the ESA. In 2007, the USFWS determined threatened or endangered protection of the American Eel was not justified with the available evidence (USFWS, 2007). Later, a petition filed by the Council for Endangered Species Act Reliability in 2010 presented substantial information that warranted the initiation of a more extensive status review of the species. A second review of the species status in 2015 found that ESA protection for the American Eel was not warranted (Shepard, 2015). In the 2017 American Eel Stock Assessment Update, the Atlantic States Marine Fisheries Commission (ASMFC) concluded that the status of the American Eel population is similar to the 2012 American Eel Benchmark Stock Assessment and the American Eel stock is still considered depleted (ASMFC, 2012; ASMFC, 2017).

Within Texas, American Eel are considered a Species of Greatest Conservation Need (TPWD, 2012). Sub-adult and adult American Eel have been found in major river basins from the Sabine River to the Rio Grande. More recently, they have been determined to be largely extirpated from several drainages, attributed to reservoirs that impede upstream migration of juveniles (Hubbs, 2002). Recent studies have been conducted in preparation for relicensing of hydropower within the Sabine River Basin at Toledo Bend Reservoir (HDR, 2011). These studies suggest only a limited number of juvenile eels migrate to this point of the river each year, during mostly warmer months extending from April to November. Consequently, due to projected growth in water diversions and construction of large reservoirs, the State of Texas is concerned about the potential impacts of these activities on this highly migratory, catadromous species.

While little is known about American Eel recruitment within the GoM, yellow eel have been captured regularly during freshwater field surveys by various state, federal, and academic institutions. As of this report, glass-stage American Eel have not been collected and only three elvers have been reported in Texas (Hendrickson and Cohen 2015) (Figure 1). Within the Coastal region of the GoM, there are only two reported observations of glass eel (Hendrickson and Cohen 2015; K. Bonvechio pers. Comm.). On a broader spatial scale, the National Oceanic and Atmospheric Administration-supported Offshore Nekton Sampling and Analysis Program conducted surveys as a result of the 2010 GoM Deepwater Horizon oil spill and captured 28 leptocephali of the American Eel from 2010-2011 in the offshore environment of Louisiana and Mississippi (Moore et al., 2020). These occurrence data are limited in the literature and provide a small, but useful insight into the spatial extent and early life history of American Eel in the GoM.

In order to assess the current status of American Eel in Texas, life history information (focused on their juvenile forms) including their distribution, abundance, habitat use, and population structure throughout the upper Texas coast were assessed by compiling historical data and conducting extensive field surveys utilizing novel gear types to the Texas coast. These data can be used to assist resource management agencies in determining the conservation need of American Eel and direct future projects that may impact the well-being and longevity of this species.

Objectives and Conservation Benefits

Data from this study will be used to support conservation and management decisions and inform future determination of protection for American Eel.

The objectives of the research are to:

1) Document distribution and abundance of glass and elver American Eel along the central and upper Texas coast.
2) Determine habitat use and associated water quality needs of glass and elver American Eel along the central and upper Texas coast.
3) Assess efficacy of varying collection methodologies to optimize glass and elver American Eel capture.
4) Identify the temporal recruitment window of glass and elver American Eels in Texas.

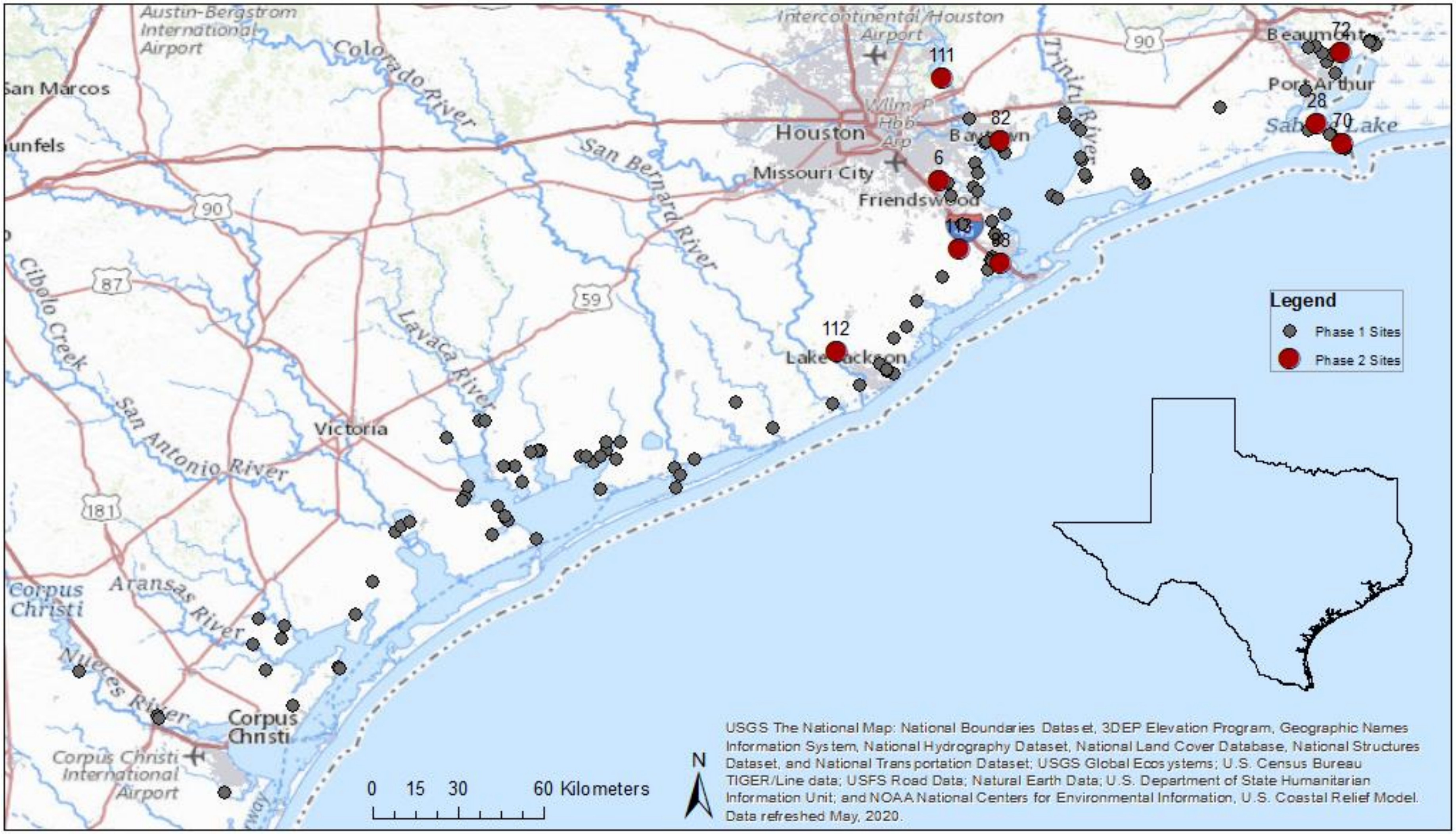
Methods

The study utilized a two-phase design, with the first year of field sampling (phase one) focusing on spatial distribution and detection of a temporal recruitment window. The second year of field sampling (phase two) was designed to utilize detections obtained in phase one and then focus continued efforts in an acute spatial and temporal window with more frequent monitoring to assess recruitment abundance.

Study Sites

The phase one study area ranged from Corpus Christi Bay to Sabine Lake, spanning a linear distance of approximately 350 km (Figure 2, **Error! Reference source not found.**). The Environmental Institute of Houston (EIH) team sampled sites from San Antonio Bay to Sabine Lake, while the Texas Parks and Wildlife Department (TPWD) team sampled sites from Corpus Christi Bay to Aransas Bay. Sites were selected primarily within estuarine areas of the Texas coast with most sites located in tidal/non-tidal transitional zones of major rivers, streams, and bayous. Additionally, site selection was based on the American Eel's probable routes between major bays and the GoM and the limitations of the sampling gear (described in the Equipment and Deployment section). When possible, sites were prioritized if they received a direct and consistent inflow of freshwater into a tidal waterway and were located near an impediment to upstream movement such as a water control structure. Sites were sampled on a rotating basis by major bay system, with six to eight sites being sampled within each bay system, every other month, for one year from June 2018 through November 2019.

During phase one, some sites were visited multiple times throughout the study period (index sites), and other sites were visited only once (non-index sites). Index sites were selected for their optimal site conditions and spatial distribution in order to evaluate potential temporal shifts in American Eel catch. Non-index sites were selected to maximize the spatial scale of the study. The bi-weekly sampling effort allowed coverage in these areas within reasonable resource and manpower limitations. In phase two of the study, we intended to focus sampling efforts geographically and temporally based on American Eel detections documented in phase one. Unfortunately, with no detections during phase one, we determined the most likely recruitment period based on limited historic records of occurrence along the Gulf Coast. Historic capture records for glass American Eel occurred in March (panhandle of Florida) and May (Tamaulipas, Mexico) (Figure 1). Based on likely transport mechanisms, recruitment in Texas is predicted to occur after recruitment in Florida; therefore, phase two sampling occurred between March and July 2020. During phase two, nine sites ranging from the Brazos River basin to Sabine Lake were sampled every other week (Figure 2 and Appendix 2). Phase two sites were selected based on the detection of Speckled Worm Eel leptocephalus and glass eel during phase one in areas where water bodies met the consistent freshwater flow and impediment criteria.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed May, 2020.

Figure 2. Map of study sites, includes both phase one and phase two sampling efforts.

Equipment and Deployment

Fyke nets are generally accepted as the most effective passive sampling technique used to target juvenile and sub-adult life stages of Anguillids (Bowser, 2020; Jellyman and Graynoth, 2005; Lake, 2013; Oliveira, 1999). Due to their success along the Atlantic coast, small-mesh fyke nets were utilized as the standard sampling method to sample glass and elver American Eel during both phases of the project. Nets were designed following specifications used by the Hudson River Estuary Program who have successfully collected glass and elver American Eel along the east coast of the U.S. (Bowser, 2020). Each net was 4 feet tall, constructed using a $^{1}/_{32}$ inch mesh aperture, and consisted of a 3 ½ foot square opening that opens extended to a cod end fitted with a ¼ inch mesh aperture excluder designed to selectively capture only small-bodied individuals (Figure 3). Sampling occurred on a bi-weekly basis with a series of three to four nets deployed each day over the course of two days for a total of six to eight net deployments per sampling event. Nets were allowed to soak overnight for up to 24-hours to maximize coverage of a full incoming tidal cycle (i.e. when glass eel are expected to move upstream) (Jellyman and Lambert, 2003b).

In phase two, eel mops (artificial habitat) were included in the field sampling effort with one mop continuously deployed at each site and checked during each site visit (every other week). Mops were allowed to condition for approximately four weeks before their first check (Sullivan et al. 2009). Eel mops measured 10 inches tall with a 12-inch base and were constructed from $^{5}/_{8}$ inch diameter frayed brown polypropylene rope weighted down by a cylindrical concrete slab and tethered to polyvinyl chloride (PVC) post (Silberschneider et al., 2001; per description in: Bowser, n.d.) (Figure 4).

Ambient water quality and habitat data were collected at each site during the net deployment and retrieval. Typical water quality variables including water temperature (°C), dissolved oxygen (mg/L), conductivity (µS/cm), salinity (ppt) and pH (standard units) were measured using a YSI ProDSS multiparameter datasonde. Turbidity was inferred by measuring water clarity using a Secchi tube or disk (m). Water depth (m) was measured using a stadia rod at the mouth of the net and in the thalweg of the channel. As all depth readings were taken in-situ, depths greater than two meters were not measured. Stream width (m) was measured using a range finder or survey tape. In the event when stream width was not obtainable in the field, the measurement tool in Google Earth Pro was used to estimate width. Shoreline habitat along bank nearest to net location was characterized based on the dominant type of macro-habitat present (emergent aquatic vegetation, woody vegetation, bare ground, oyster, rip/rap and artificial substrate). The dominant aquatic vegetation species was identified to the lowest taxonomic level, typically genus or species. In-stream habitat was quantified as percent cover from the area directly in front of the net (wing to wing and 10 meters downstream from the net). An Onset U24 HOBO conductivity and temperature logger was attached to each net approximately one foot from the bottom during deployment and logged on a 15-minute interval. Data loggers were only deployed in upper coastal systems (San Antonio Bay to Sabine Lake). In addition, moon phase and percent illumination were recorded for the night of net set. Water quality and numerical habitat variables (i.e., percent in-stream cover by type and total, percent moon illumination, stream width and water depth at net mouth) were evaluated for their ability to predict if elopomorphs were present at the site.

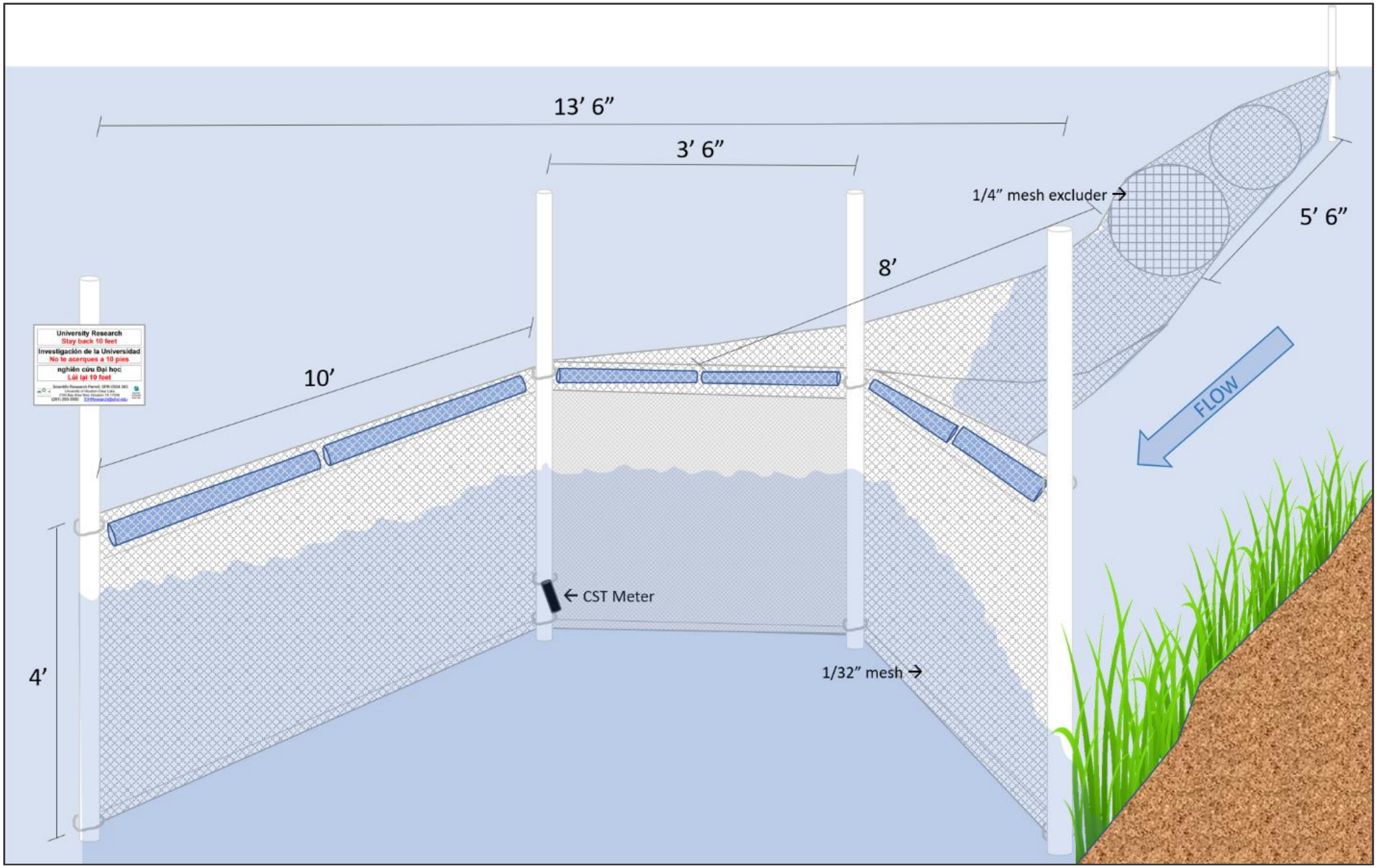


Figure 3. Fyke net design and specifications used to sample for glass and elver American Eel.

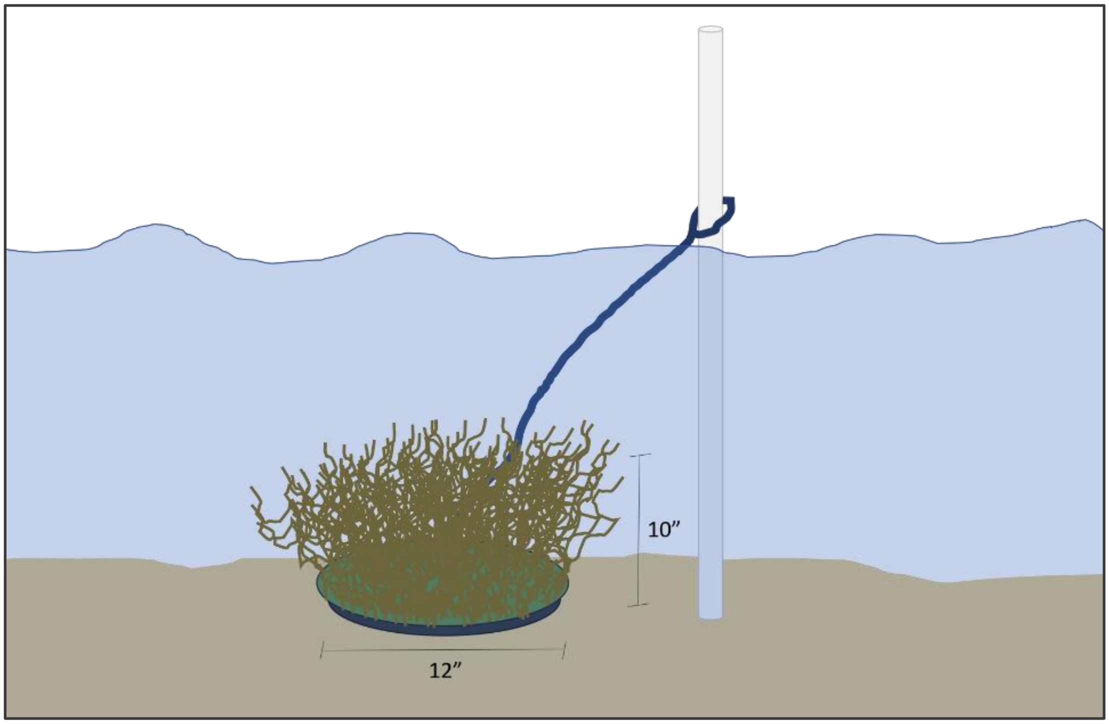


Figure 4. Eel mop design and specifications.

Sample Processing

Fish captured in the cod end of the net or in the eel mop were identified to species and enumerated. Invertebrate catch were assigned relative abundance categories (1 = rare, 2 = common, and 3 = abundant). Nekton (swimming-capable organisms, both fish and invertebrates) trapped at the excluder, but not captured in the cod end of the fyke net, were identified and placed in the same relative abundance categories as invertebrates. If proper identification was not feasible in the field or when biomass or abundance were exceptionally high, specimens were administered a lethal dose of MS-222, preserved in a buffered 10% formalin solution and later transferred to 70% ethanol and identified in the lab. Any Anguilliformes captured were retained in site water and stored on ice until a positive identification could be made (which often required returning to the laboratory to use a dissecting microscope to confirm identification of small individuals; per Bonvechio, 2016).

Data Analysis

Nekton community structure was characterized by calculating total taxa abundance (N), relative abundance (%), taxa richness (S), and catch per unit effort (CPUE). For fyke nets, catch per unit effort was calculated as CPUE = N / T where N = the number of individuals captured and T = total number of hours of soak time. Catch per unit effort was not calculated for eel mop data since organisms could come and go freely from the mops, making catch at the time of sampling only a snapshot of the organisms utilizing the mop at that date and time. Because only fishes captured in the cod end of the net were enumerated (while invertebrates and amphibians were assigned abundance categories), only fishes are included in CPUE and abundance results. All target nekton were included in presence/absence analysis. Water chemistry, environmental, and physical habitat data collected during fyke net set and retrieval events were averaged prior to statistical analyses.

All physicochemical and habitat variables were tested for normality prior to statistical analysis (Shapiro and Wilk, 1965). If data were non-normal, nonparametric statistical methods were used. Statistical analyses were conducted using R 4.1.2 (R Core Team, 2018). Because American Eel were not captured during the study, CPUE and presence/absence data for the two other elopomorphs (Speckled Worm Eel and Ladyfish) were evaluated ($\alpha = 0.05$) to determine the site characteristic(s) that maximized their catch and predicted occurrence. The relationship between CPUE of elopomorphs and multiple environmental variables were evaluated using either zero-inflated binomial (for integer data such as abundance) or binomial Generalized Linear Model (GLM) (for presence absence prediction analysis) (for (R, package pscl). The relationship between the CPUE of elopomorphs and categorical variables were evaluated using the Kruskal-Wallis rank sum test with subsequent post-hoc Pairwise Wilcoxon Rank Sum Test. Multiple linear regression was conducted on water chemistry and physical habitat variables to determine which variables best explained the likelihood that an elopomorph would be present in fyke net catch. Models were compared using Akaike's 'An Information Criterion' (AIC).

Results

Throughout phases one and two of the study, 330 net sets were deployed at 130 unique sites (Figure 2). The cumulative net soak time for all deployments was 6,851.77 hours. A total of 109 species of nekton across 59 families were collected in the cod end of the net and observed before the excluder at the mouth of the net. Within the cod end, 93 species of nekton represented by 51 families were captured. Individuals captured in the cod end were primarily juveniles or relatively small-bodied fishes, likely due to the size of the excluder (¼ inch) which intentionally biased catch to fish that are laterally or dorsoventrally compressed. A total of 130,860 fishes were captured representing 71 species from 34 families. Overall CPUE in fyke nets was 19.1 fish per hour when all data were pooled for the duration of the study. There were no American Eel collected throughout the study.

Community Composition – Phase One

During phase one, 127 sites were sampled across the full survey area with a total of 250 nets deployed. Twelve deployments yielded zero catch past the excluder. A total of 75 species of nekton across 40 families were collected in the cod end of the nets. A total of 109,312 fish were collected across 61 species with the 10 most abundant species comprising over 90% of the total catch (Table 1, Appendix 3). The five most abundant fish species by relative abundance were Gulf Menhaden (*Brevoortia patronus*) at 31.52%, Bay Anchovy (*Anchoa mitchilli*) at 18.91%, Ladyfish (*Elops saurus*) at 14.35%, Sheepshead Minnow (*Cyprinodon* variegatus) at 9.90%, and Atlantic Croaker (*Micropogonias undulatus*) at 5.25% (Table 1). These five fishes comprised nearly 80% of the total catch for phase one. All Ladyfish were either leptocephalus larvae or in their metamorphic transitional phase.

Table 1. Summary table of the total number collected, relative abundance, overall CPUE (total catch by species divided by total number of hours of effort) for the top ten species of fish captured in the cod end of the fyke nets throughout phase one of the study. Complete list of catch provided in Appendix 3.

Family	**Scientific Name**	**Common Name**	**Count**	**Relative Abundance**	**CPUE**
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	39,795	31.52	7.82
Engraulidae	*Anchoa mitchilli*	Bay Anchovy	23,880	18.91	4.69
Elopidae	*Elops saurus*	Ladyfish	18,115	14.35	3.56
Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	12,501	9.90	2.46
Sciaenidae	*Micropogonias undulatus*	Atlantic Croaker	6,624	5.25	1.30
Fundulidae	*Lucania parva*	Rainwater Killifish	4,802	3.80	0.94
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	2,484	1.97	0.49
Ophichthidae	*Myrophis punctatus*	Speckled Worm Eel	2,272	1.80	0.45
Poeciliidae	*Poecilia latipinna*	Sailfin Molly	2,096	1.66	0.41
Clupeidae	*Dorosoma petenense*	Threadfin Shad	1,877	1.49	0.37

Community Composition – Phase Two

During phase two, nine sites were sampled along the upper Texas coast with a total of 80 deployments. Nine deployments (11.3%) yielded zero catch past the excluder. A total of 51 species of nekton representing 31 families were collected in the cod end. A total of 4,590 fish were collected across 40 species with the 10 most abundant species comprising over 91% of the total catch (Table 2, Appendix 4). The five most abundant fish species by relative abundance were Gulf Menhaden at 49.75%, Rainwater Killifish (*Lucania parva*) at 20.69%, Bay Anchovy at 5.60%, Inland Silverside (*Menidia beryllina*) at 3.88%, and Striped Mullet (*Mugil cephalus*) at 3.55% (Table 2). These five fishes comprised over 83% of the total catch for the sampling year.

Table 2. Summary table of the total number collected, relative abundance, overall CPUE (total catch by species divided by total number of hours of effort) for the top ten species of fish captured in the cod end of the fyke nets throughout phase two of the study. Complete list of catch provided in Appendix 4.

Family	**Scientific Name**	**Common Name**	**Count**	**Relative Abundance**	**CPUE**
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	2,282	49.75	1.29
Fundulidae	*Lucania parva*	Rainwater Killifish	949	20.69	0.54
Engraulidae	*Anchoa mitchilli*	Bay Anchovy	257	5.60	0.15
Atherinopsidae	*Menidia beryllina*	Inland Silverside	178	3.88	0.10
Mugilidae	*Mugil cephalus*	Striped Mullet	163	3.55	0.09
Gobiidae	*Ctenogobius boleosoma*	Darter Goby	116	2.53	0.07
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	92	2.01	0.05
Elopidae	*Elops saurus*	Ladyfish	55	1.20	0.03
Fundulidae	*Fundulus grandis*	Gulf Killifish	54	1.18	0.03
Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	46	1.00	0.03

Additionally, during phase two, one eel mop was deployed at each site, and checked every other week. Across all phase two sampling events, 25 species of organisms, representing 23 families, were collected in the eel mops. A total of 220 fish were collected across 13 species and 11 families (Table 3). Species richness (11) was highest at sites 70 and 83. Gobiidae was the most represented fish family with three species present. The Naked Goby (*Gobiosoma bosc*) was the most numerically abundant species with 110 individuals captured from six of the sites. The second most numerically abundant species was the Gulf Toadfish (*Opsanus beta*) with 76 individuals captured across three of the sites.

Table 3. Summary table of the total number collected and relative abundance for all fish captured in the eel mops throughout phase two of the study.

Family	**Scientific Name**	**Common Name**	**Count**	**Relative Abundance**
Gobiidae	*Gobiosoma bosc*	Naked Goby	110	50.00
Batrachoididae	*Opsanus beta*	Gulf Toadfish	76	34.55
Eleotridae	*Dormitator maculatus*	Fat Sleeper	9	4.09
Gobiidae	*Gobiosoma robustrum*	Code Goby	6	2.73
Elassomatidae	*Elassoma zonatum*	Banded Pygmy sunfish	5	2.27
Gobiesocidae	*Gobiesox strumosus*	Skilletfish	3	1.36
Sparidae	*Lagodon rhomboides*	Pinfish	3	1.36
Ictaluridae	*Notorus gyrinus*	Tadpole Madtom	2	0.91
Ophichthidae	*Myrophis punctatus*	Speckled Worm Eel	2	0.91
Centrarchidae	*Lepomis macrochirus*	Bluegill	1	0.45
Cichlidae	*Oreochromis aureus*	Blue Tilapia	1	0.45
Gobiidae	*Ctenogobius boleosoma*	Darter Goby	1	0.45
Syngnathidae	*Syngnathus scovelli*	Gulf Pipefish	1	0.45

The most frequent shoreline habitat type across all sites was emergent aquatic vegetation with the most common dominant plant being Smooth cordgrass (*Spartina alternilfora*) (34% of sites). The primary sediment types across the study area were clay (49% of sites), silt (22% of sites), and sand (25% of sites). Water quality variables were within expected seasonal and spatial patterns (Table 4).

Table 4. Summary statistics for water quality and habitat variables measured during phase one and phase two at all sampling sites.

Parameter	**Min**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max**
Dissolved Oxygen (mg/L)	2.4	5.8	7.0	7.1	8.4	13.5
Water Temperature (°C)	11.8	19.9	24.8	24.0	28.7	35.9
Salinity (psu)	0.1	0.5	3.0	5.6	8.4	32.3
Secchi Depth (m)	0.0	0.2	0.2	0.3	0.3	1.0
pH (standard units)	6.7	7.5	7.8	7.8	8.0	9.3
Depth of Net (m)	0.1	0.4	0.6	0.6	0.7	1.3
Stream Width (m)	4.0	17.7	43.3	76.0	101.4	1,503.0
Percent Moon Illumination	0	14	46	48	79	100
Percent of In-water Cover	0	6	15	23	35	100

Patterns in Elopomorph Distribution & Abundance

While no American Eel were captured during the study, Speckled Worm Eel and/or Ladyfish were collected during every month of the study. In total, 18,170 Ladyfish and 2,305 Speckled Worm Eel were collected in fyke nets. On two events, Site 14 (an unnamed tributary to Carancahua Bay in East Matagorda Bay) had irruptive catch of elopomorphs (01 February 2019 = 1,521 Specked Worm Eel; 30 March 2019 = 17,693 Ladyfish). This site is a relatively narrow stream (average width = 5.1 m) in close proximity to Carancahua Bay. Because of the narrow stream width, the deployed fyke net extended nearly the entire width of the waterbody, effectively catching all ingression to the tidal creek.

Speckled Worm Eels and Lady Fish were captured in highest numbers in the late winter and early spring during both phases of the study. During phase one, Ladyfish were detected in March through June with the peak CPUE occurring in March during both phases of the study (Figure 5 and Figure 6). Speckled Worm Eel were detected every month of the study (both phases) but had peak detections in February during phase one and in April during phase two (Figure 5 and Figure 6). More in-depth analyses of the recruitment and morphometrics of Speckled Worm Eel captured throughout the study are summarized in Hansen (2020). Glass eel of Speckled Worm Eel were observed from December through April while metamorphic eels (leptocephalus) were observed only in January through March (Hansen, 2020).

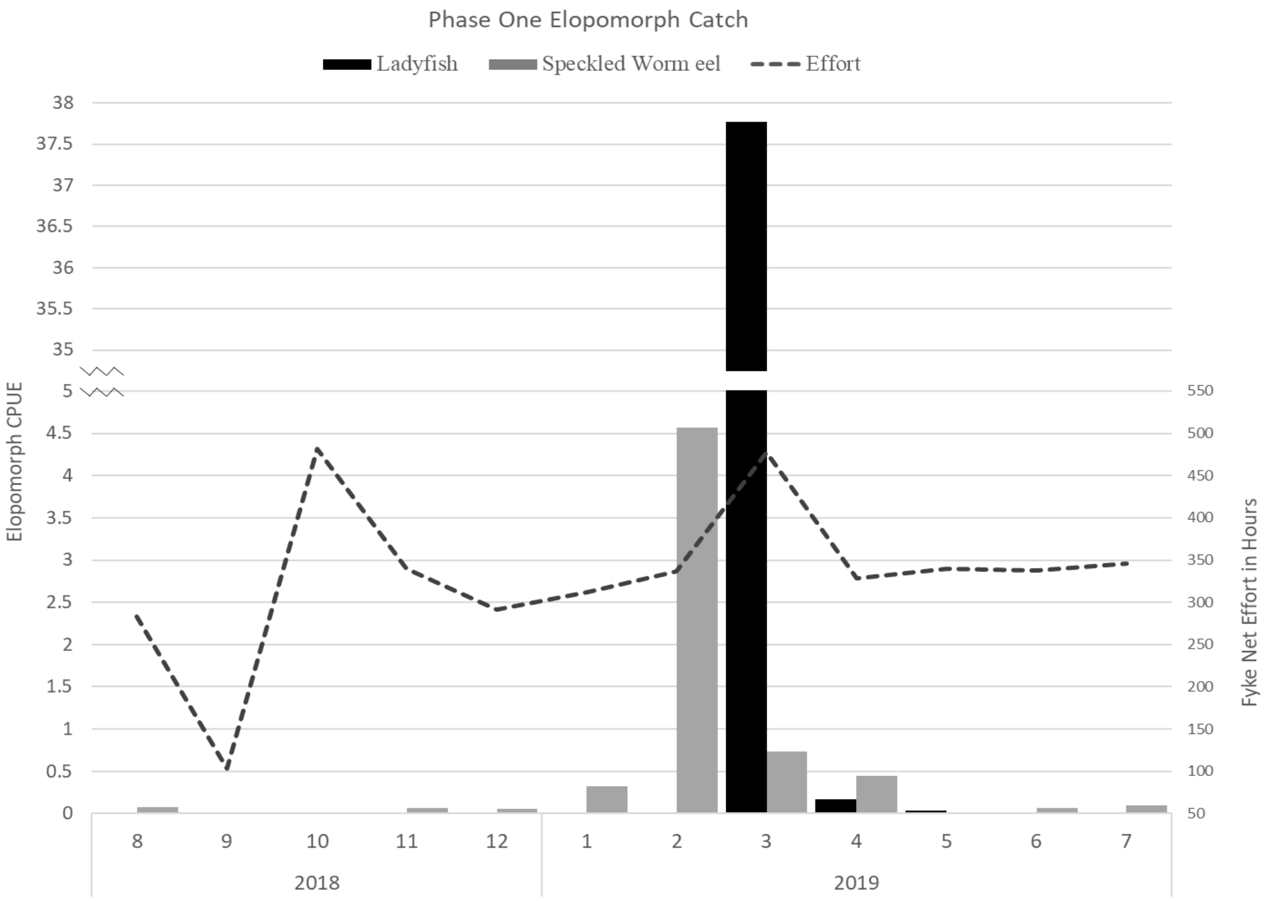


Figure 5. Catch per unit effort of all elopomorphs captured in fyke nets during phase one of the study by month (grey bars) and total effort in hours (black line).

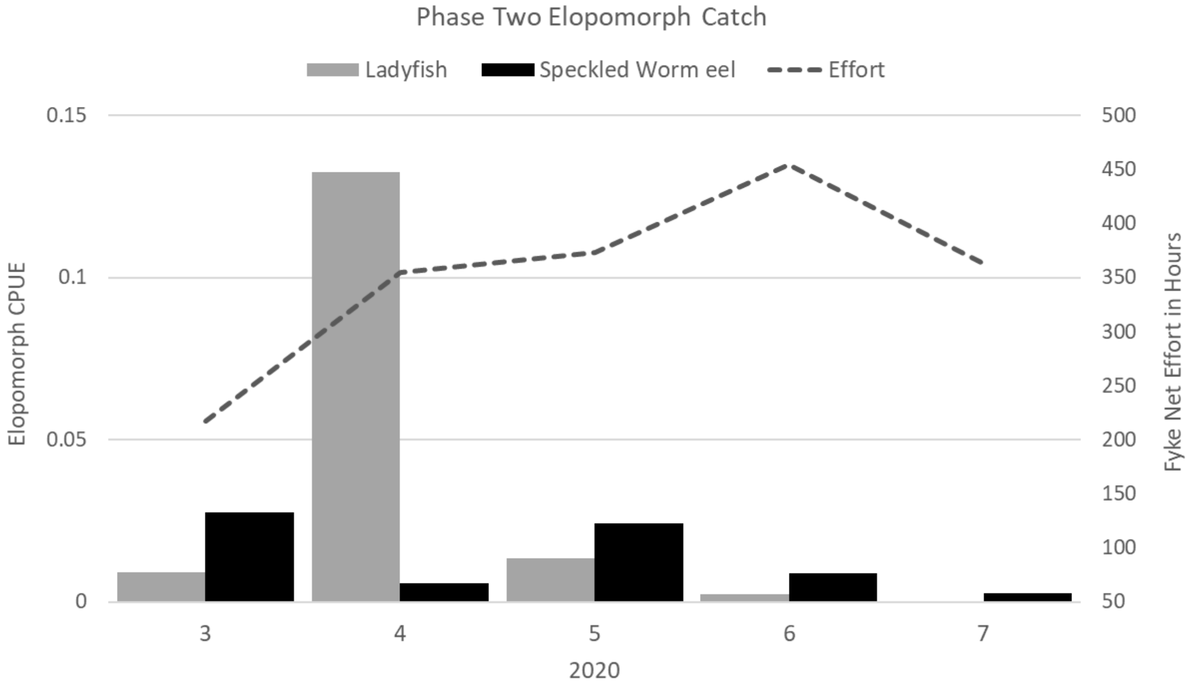


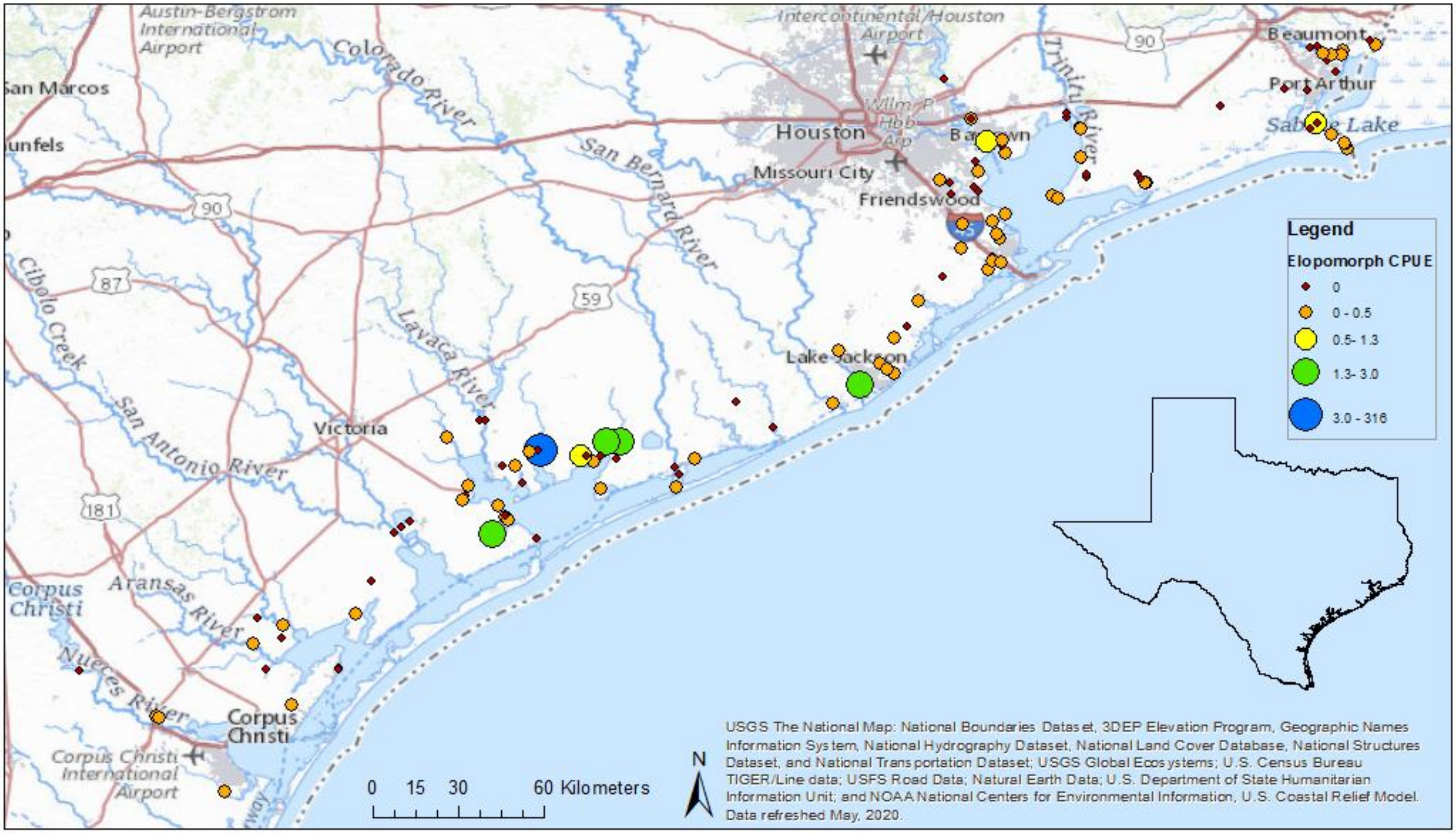
Figure 6. Catch per unit effort of all elopomorphs captured in fyke nets during phase two of the study by month (grey bars) and total effort in hours (black line).

Multiple linear regression was conducted on water chemistry and physical habitat variables to determine which variables best explained the likelihood that an elopomorph would be present in fyke net catch. A generalized linear model (GLM) combining temperature, salinity, total in-stream cover, and secchi was the best predictor of elopomorph presence (model coefficients are presented in Table 5).

Spatially, Elopomorphs were captured within each major river basin throughout the study area, with no apparent spatial pattern observed (Figure 7). Ladyfish abundance was more sporadic than Speckled Worm Eel with an average CPUE of 2.32 Ladyfish per hour; however, the single net set of 17,693 inflates that value which would be 0.06 if that outlier were removed (Appendix 5). Ladyfish were captured at 7% of net sets and detected at 17 % of the sites surveyed. Speckled Worm Eel distribution was more widespread than Ladyfish with an average CPUE of 0.31 eels per hour (Appendix 6). Speckled Worm Eel were captured at 17% of net sets and detected at 33 % of the sites surveyed.

Table 5. Summary of generalized linear model coefficients to predict the presence of elopomorphs in fyke nets including phase one and phase two data.

Parameter	Estimate	Std. Error	Z value	P-value
(Intercept)	1.559235	0.615322	2.615	0.011276
Salinity	0.056316	0.018093	3.113	0.001855
Temp	-0.081158	0.022455	-3.614	0.000301
Secchi	-1.866703	0.893193	-2.090	0.036625
Total In-stream Cover	-0.012420	0.006117	-2.030	0.042322



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed May, 2020.

Figure 7. Map of all study sites from phases one and two. Size and color of the points represent total Elopomorph catch per unit effort (CPUE; number of fish per net-hour) for each site.

Water temperature, salinity, dissolved oxygen, and Secchi were significantly different among sites where elopomorphs were present versus those where they were absent. Water temperature was significantly lower at sites where elopomorphs were caught ($p = 0.0044$) (Figure 8a). A predictive binomial GLM ($p = 0.0071$) provided a probability catch curve for elopomorphs based on site water temperature (Figure 8b). Salinity and dissolved oxygen were significantly higher at sites where Elopomorphs were caught ($p = 0.0269$ and 0.0313, respectively) (Figure 9a, Figure 10a). A predictive binomial GLM ($p = 0.0190$ and $p = 0.0279$) provided a probability catch curve for Elopomorphs based on site salinity and dissolved oxygen (Figure 9b, Figure 10b). Secchi depth (m) was lower at sites where elopomorphs were caught ($p = 0.0333$) but the predictive binomial GLM was not significant at the $\alpha = 0.05$ level ($p = 0.0857$) (Appendix 7). Total percent in-stream cover was lower at sites where Elopomorphs were caught, although not significant at the $\alpha = 0.05$ level ($p = 0.0567$) (Appendix 8).

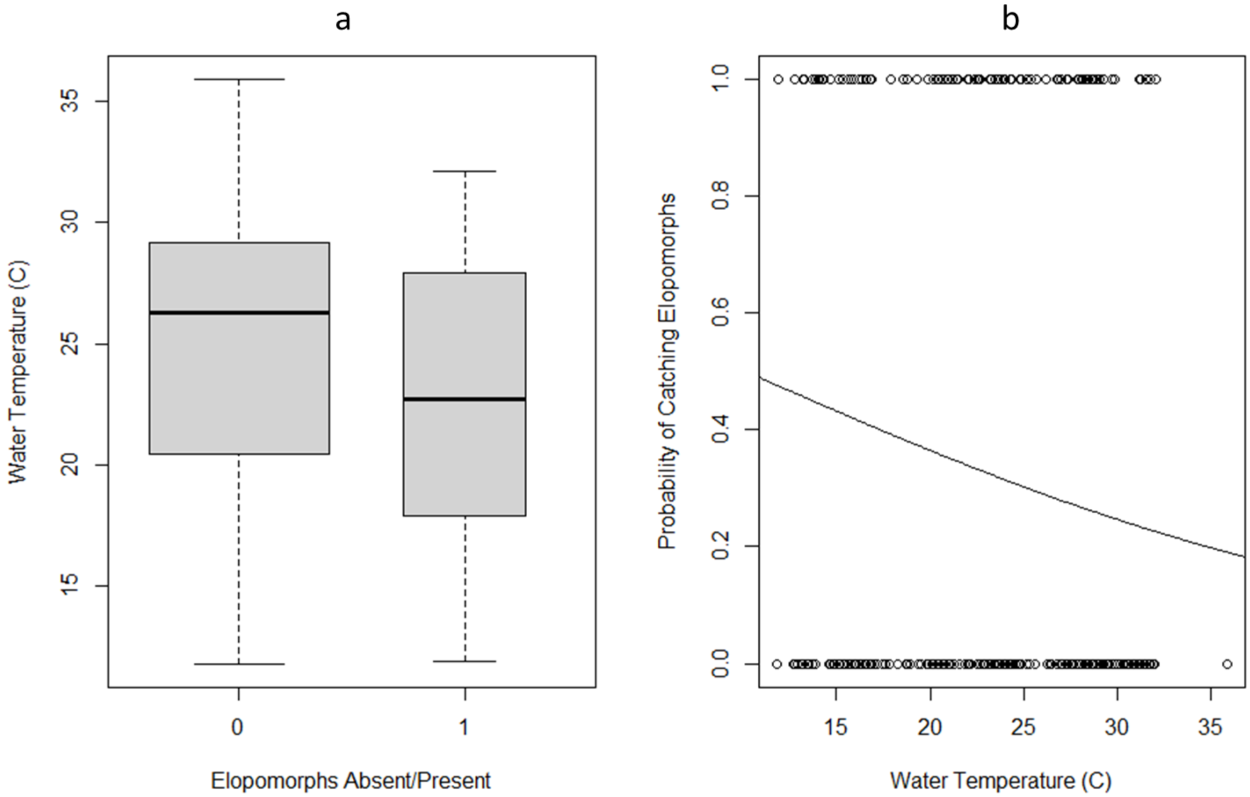


Figure 8 a) Boxplot of the water temperature (°C) at sites where elopomorphs were captured versus not captured and b) fitted binomial Generalized Linear Model (GLM) applied to the presence/absence of elopomorphs by water temperature (°C).

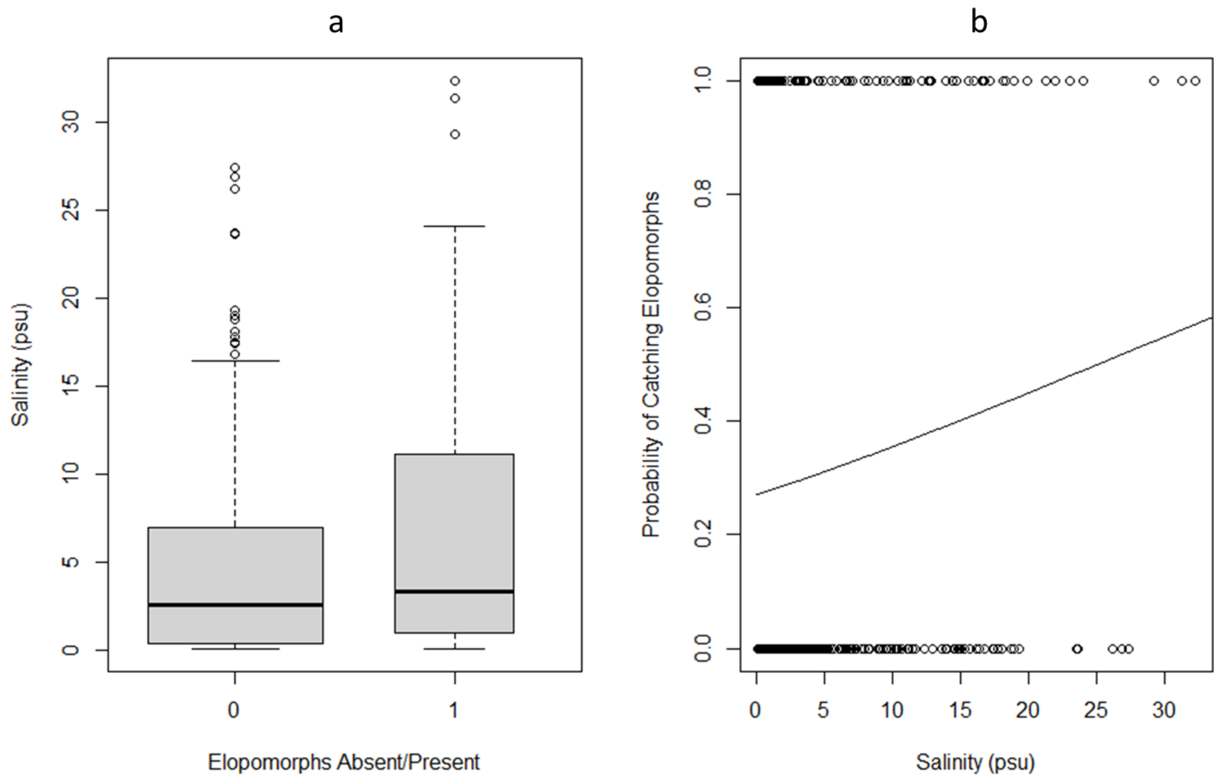


Figure 9 a) Boxplot of salinity (psu) at sites where elopomorphs were captured versus not captured and b) fitted binomial Generalized Linear Model (GLM) applied to the presence/absence of elopomorphs by salinity.

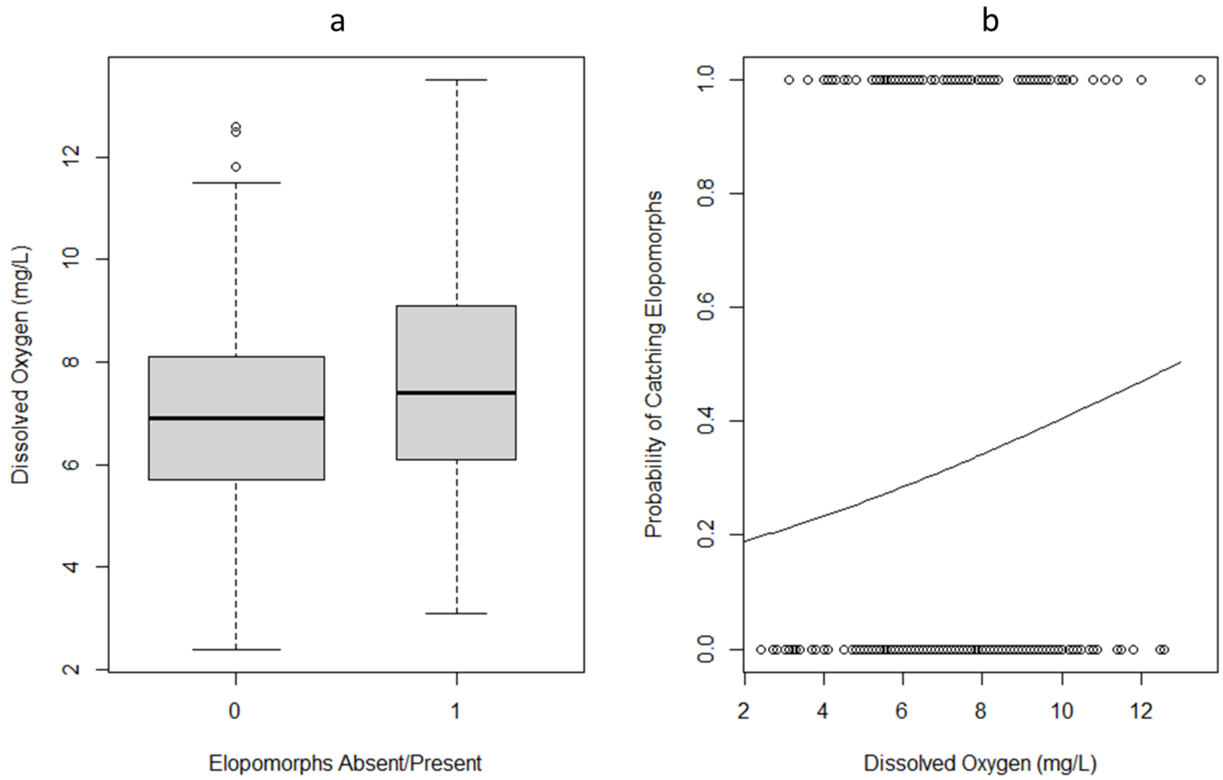


Figure 10 a) Boxplot of dissolved oxygen (mg/L) at sites where elopomorphs were captured versus not captured and b) fitted binomial Generalized Linear Model (GLM) applied to the presence/absence of elopomorphs by dissolved oxygen.

Discussion

Despite extensive field efforts, we did not collect glass or elver American Eel and were not able to define the recruitment window of this species into the estuarine and freshwater systems of the central and northern Texas coast. However, we were able to detect fishes from the super order Elopomorpha, which share the leptocephalus larvae life stage with American Eel as a prominent derived characteristic. Early life stages of Ladyfish (leptocephalus and metamorphs – defined as the transition between larval and juvenile form) and Speckled Worm Eel (leptocephalus, glass, and elver eel) were detected with variable relative abundances using fyke nets and, less frequently, eel mops. Furthermore, Speckled Worm Eel were captured during every month of sampling. Mechanistically, on a broad spatial scale, leptocephalus and metamorphic larvae are subject to oceanic currents and fronts (Munk et al., 2010) and are transported to nearshore environments in which settlement occurs in estuarine nursery habitats. Although American Eel metamorphosis is assumed to occur as they approach the continental shelf, the general gross transport mechanisms of larvae are functionally the same between American Eel and Speckled Worm Eel (Miller, 2009; Miller and McCleave, 2007; Miller et al., 2015; Miller and Tsukamoto, 2016).

Our findings suggest that the fyke nets used in this study are effective at capturing the early life history stage of elopomorphs as they ingress and settle, and reinforces that fyke nets are likely a suitable method for the detection of glass and elver American Eel (Jellyman and Graynoth, 2005; Lake, 2013; Oliveira, 1999). The Speckled Worm Eel life history stage and body size captured in this study are analogous to the targeted glass and elver stages of American Eel. In addition, Speckled Worm Eel, like American Eel, utilize stream sediment and substrate to hide and bury themselves and are not typically captured with traditional sampling methods (Able et al., 2011; Springer and Woodburn, 1960). Interestingly, at the Guana River Dam in Florida, glass Speckled Worm Eels were incidentally enumerated as glass American Eels until a large ingression of glass Speckled Worm Eel occurred, which helped to better distinguish the similarly transparent glass eels (Bonvechio, 2016). Similarly, we were unable to positively identify some glass and elver stage eels in the field, and more thorough lab analysis was needed to confirm species as Speckled Worm Eels. Repeated co-occurrence of these two species implies there may be a shared underlying mechanism driving their ingression. In the Florida Keys, onshore transport of leptocephalii and glass eels were driven by overnight new moon flood tides and strong onshore winds (Harnden et al., 1999). Thus, if glass or elver American Eel were present in high abundance during the dates and locations we surveyed, we can reasonably presume that we would have been able to detect their ingression.

While fyke nets were effective at capturing elopomorphs, they also captured large quantities of juvenile fish from other species and invertebrates that were also recruiting into these tidal creeks and rivers. There are opportunities to utilize these data to analyze potential recruitment of other under-studied organisms. Fyke nets can be cumbersome to deploy and require careful consideration to avoid high-flow pulses of freshwater that can easily disturb or wash away the net. Because of this potential risk, we did not sample during or immediately following freshwater pulses (i.e., on the falling end of the hydrograph). Furthermore, we had problems with net damage, primarily from predatory blue crabs, which would penetrate the cod end of the net and feed on the catch. This was reduced by attaching metal window screen and chicken wire materials over the cod end of the net. This will likely be a persistent challenge with this gear type in the highly productive coastal waters of Texas and should be considered when planning future research with fine mesh fyke nets.

Based on the modeled probability of catching an elopomorph, the optimal water quality and habitat conditions for future research that would create the highest likelihood of catching elopomorphs would be at sites with generally higher salinity and dissolved oxygen in the late winter and early spring when water temperatures are lowest. Water temperature likely represents a spurious correlation associated with seasonal recruitment rather than environmental differences related to the physical site characteristics, though our analyses were unable to determine how this may have affected catch rates. Additionally, salinity naturally varies spatially among study areas and temporally within a given study site. Because Ladyfish and Speckled Worm Eel are both true estuarine species rather than catadromous, like the American Eel, this may not be a transferable variable. Previous research has demonstrated conflicting results where Ladyfish and Speckled Worm Eel have been shown to benefit from lower salinity pulses into the estuary in Texas (Tolan, 2008). While existing research suggests that water cues may mediate the migration and settlement of recently metamorphosed glass eels (Sola and Tongiorgi, 1996; Sullivan et al., 2006), further research is needed to investigate how fresh water pulses and general salinity regimes may affect American Eel recruitment in Texas.

Recommendations for future work include continuation of fyke net deployments at select long-term monitoring sites, as recruitment of American Eel in Texas are likely sporadic and may occur only during uniquely timed Gulf currents. Additionally, inclusion or testing of other passive gear types (such as eel ramps) are suggested to continually sample at key sites which would allow researchers to detect intermittent recruitment events. To supplement these efforts, use of environmental DNA (eDNA) could be helpful to detect the presence of American Eel in coastal, tidally influenced, streams and rivers, as this technique has been proven effective along the Atlantic Coast (see Chin et al., 2021). Additionally, on-going research on the GoM-wide genetic structure of American Eels will be key in illuminating the spawning location of Gulf and Caribbean American Eels, which could provide more insight into larval recruitment patterns in Texas (Casarez et al., 2021). Finally, efforts to age and conduct otolith microchemistry on juvenile and sub-adult yellow eels in Texas are underway which may provide the opportunity to determine if there are distinct cohorts of American Eels and if so, when those cohorts likely recruited to the estuaries. This information would allow for further investigation into large-scale gulf currents, weather patterns, freshwater inflow, and other variables that may influence successful recruitment of American Eel in Texas

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Appendices

Appendix 1. Phase one study sites by Hydrological Unit Code (HUC) 8 and corresponding sub-basin name. n = total number of events sampled at that site. Coordinates in WGS84.

HUC 8	Sub Basin	Waterbody Name	Site	Latitude	Longitude	n
12010005	Lower Sabine	Cow Bayou	46	30.02201	-93.76083	1
12010005	Lower Sabine	Cow Bayou	49	30.03442	-93.77769	1
12010005	Lower Sabine	Cow Bayou	50	30.03259	-93.77866	1
12020003	Lower Neches	Neches River	48	29.99092	-93.86979	4
12020003	Lower Neches	Molasses Bayou	51	29.96941	-93.91475	2
12020003	Lower Neches	Old River	72	30.00084	-93.86671	3
12020003	Lower Neches	Neches River	92	29.99010	-93.89979	1
12020003	Lower Neches	Neches River	93	29.99480	-93.92631	1
12020003	Lower Neches	Lower Neches WMA	94	30.01679	-93.94823	1
12020003	Lower Neches	Channel of Neches	95	30.01394	-93.97050	1
12030203	Lower Trinity	Long Island Bayou	103	29.79040	-94.74110	1
12030203	Lower Trinity	Old River/ Lost Lake Fork	104	29.80455	-94.74078	1
12030203	Lower Trinity	Kings Pass	105	29.76484	-94.70509	1
12030203	Lower Trinity	Anahuac Channel	106	29.75391	-94.69353	1
12040104	Buffalo-San Jacinto	Goose Creek	33	29.71257	-94.99318	1
12040104	Buffalo-San Jacinto	Goose Creek	74	29.71490	-94.99196	2
12040104	Buffalo-San Jacinto	Goose Creek	81	29.78741	-95.04282	1
12040104	Buffalo-San Jacinto	Slap Out Gully	80	29.78741	-95.04262	1
12040201	Sabine Lake	Unnamed Tributary to Sabine Pass	25	29.69371	-93.85222	2
12040201	Sabine Lake	Unnamed Tributary to Sabine Pass	76	29.73693	-93.90118	2
12040201	Sabine Lake	Sabine Pass	26	29.70143	-93.85397	1
12040201	Sabine Lake	Texas Bayou	27	29.71037	-93.85940	1
12040201	Sabine Lake	Texas Bayou	70	29.71084	-93.86095	1
12040201	Sabine Lake	Keith Lake	28	29.77370	-93.94292	5
12040201	Sabine Lake	Keith Lake	96	29.77138	-93.95307	1
12040201	Sabine Lake	Keith Lake Above Weir	97	29.77157	-93.94838	1
12040201	Sabine Lake	Keith Lake Point	98	29.75336	-93.97027	1
12040201	Sabine Lake	Old River	47	29.99906	-93.86586	4
12040201	Sabine Lake	Old River Cove	77	29.99018	-93.86797	2
12040201	Sabine Lake	West Crane Bayou	52	29.93434	-93.88589	1
12040201	Sabine Lake	Taylor Bayou	110	29.88302	-94.05046	1
12040201	Sabine Lake	Unnamed Tributary to Taylor Bayou	71	29.87792	-93.97953	1
12040201	Sabine Lake	Unnamed Tributary to Mayhaw Bayou	79	29.82584	-94.25262	1
12040202	East Galveston Bay	Double Bayou	29	29.65583	-94.69034	1
12040202	East Galveston Bay	Unnamed Tributary to Galveston Bay	30	29.66423	-94.69244	1
12040202	East Galveston Bay	Unnamed Tributary to Galveston Bay	57	29.54368	-94.78329	2
12040202	East Galveston Bay	Unnamed Tributary to Galveston Bay	58	29.53618	-94.76449	1
12040202	East Galveston Bay	Lone Oak Bayou	59	29.60231	-94.67567	2
12040202	East Galveston Bay	Lone Oak Bayou	78	29.61111	-94.67701	1

HUC 8	Sub Basin	Waterbody Name	Site	Latitude	Longitude	n
12040202	East Galveston Bay	Onion Bayou	99	29.58517	-94.48905	1
12040202	East Galveston Bay	Oyster Bayou	100	29.58324	-94.49323	1
12040202	East Galveston Bay	Oyster Bayou	101	29.59977	-94.50584	1
12040202	East Galveston Bay	Oyster Upstream	102	29.61030	-94.51193	1
12040203	North Galveston Bay	Ash Lake	60	29.68052	-94.93066	2
12040203	North Galveston Bay	Canal off of Cedar Bayou	73	29.70192	-94.94357	1
12040203	North Galveston Bay	Cedar Bayou	82	29.72094	-94.94290	1
12040204	West Galveston Bay	Little Cedar Bayou	2	29.65033	-95.02644	2
12040204	West Galveston Bay	Boggy Bayou	3	29.61816	-95.01836	3
12040204	West Galveston Bay	Unnamed Tributary to Clear Lake	4	29.57050	-95.03131	2
12040204	West Galveston Bay	Horsepen Bayou	5	29.58537	-95.11050	1
12040204	West Galveston Bay	Horsepen Bayou	6	29.59412	-95.14117	2
12040204	West Galveston Bay	Unnamed Tributary to Highland Bayou	7	29.35055	-94.97177	1
12040204	West Galveston Bay	Dickinson Bayou	8	29.45486	-95.06769	3
12040204	West Galveston Bay	Dickinson Bayou	56	29.46250	-94.97358	2
12040204	West Galveston Bay	Cow Bayou	9	29.54654	-95.10516	1
12040204	West Galveston Bay	Cow Bayou	45	30.02951	-93.76238	1
12040204	West Galveston Bay	Chocolate Bayou	24	29.21204	-95.20873	5
12040204	West Galveston Bay	Factory Bayou	31	29.48553	-94.93224	1
12040204	West Galveston Bay	Highland Bayou	32	29.34295	-94.97475	2
12040204	West Galveston Bay	Highland Bayou	83	29.33158	-94.94631	1
12040204	West Galveston Bay	Highland Bayou	54	29.33500	-94.97230	3
12040204	West Galveston Bay	Highland Bayou Diversion Channel	53	29.30891	-94.98608	3
12040204	West Galveston Bay	Unnamed Tributary to Galveston Bay	34	29.55886	-95.01926	2
12040204	West Galveston Bay	Moses Lake	55	29.42171	-94.96137	2
12040204	West Galveston Bay	Unnamed Tributary to Moses Bayou	1	29.40783	-94.95193	3
12040204	West Galveston Bay	Halls Bayou	91	29.28646	-95.13123	1
12040205	Austin-Oyster	Oyster Creek	21	28.97584	-95.30209	2
12040205	Austin-Oyster	Oyster Creek	44	29.01279	-95.32916	5
12040205	Austin-Oyster	Oyster Creek	68	28.98920	-95.30499	1
12040205	Austin-Oyster	Bastrop Bayou	22	29.09403	-95.28354	5
12040205	Austin-Oyster	Alligator Slough	23	29.12820	-95.24247	1
12040205	Austin-Oyster	Levee Ditch	69	28.99358	-95.30666	3
12070104	Lower Brazos	Brazos River	43	28.94621	-95.38106	2
12090302	Lower Colorado	Colorado River	17	28.68317	-95.97595	1
12090302	Lower Colorado	Colorado River	42	28.66052	-95.96185	1
12090302	Lower Colorado	Colorado River	75	28.61961	-95.97284	3
12090401	San Bernard	San Bernard River	20	28.88416	-95.47672	6
12090402	East Matagorda Bay	Unnamed Tributary to Carancahua Bay	14	28.73845	-96.39988	2
12090402	East Matagorda Bay	Little Boggy Creek	18	28.71048	-95.91928	5
12090402	East Matagorda Bay	Caney Creek	19	28.81076	-95.66691	4
12090402	East Matagorda Bay	Live Oak Bayou	90	28.88962	-95.78584	1
12100101	Lavaca	Lavaca River	88	28.83247	-96.59528	1
12100101	Lavaca	Port Lavaca River	89	28.83181	-96.57827	2
12100204	Lower Guadalupe	Lower Guadalupe	84	28.47863	-96.86266	2

HUC 8	Sub Basin	Waterbody Name	Site	Latitude	Longitude	n
12100401	East Matagorda Bay - W	Keller Creek	13	28.68764	-96.48364	2
12100401	East Matagorda Bay - W	Keller Bay	39	28.63629	-96.45909	1
12100401	East Matagorda Bay - W	Carancahua Bay	109	28.73190	-96.43493	1
12100401	East Matagorda Bay - W	Unnamed Tributary to Carancahua Bay	14	28.73845	-96.39988	1
12100401	East Matagorda Bay - W	Unnamed Tributary to Carancahua Bay	67	28.73624	-96.40894	1
12100401	East Matagorda Bay - W	Unnamed Tributary to Palacios Bay	15	28.70126	-96.23455	2
12100401	East Matagorda Bay - W	Tres Palacios	16	28.76637	-96.14840	4
12100401	East Matagorda Bay - W	Turtle Creek	40	28.72106	-96.27303	2
12100401	East Matagorda Bay - W	Turtle Bay	41	28.71944	-96.25595	1
12100401	East Matagorda Bay - W	Unnamed Tributary to Tres Palacios Bay	61	28.73800	-96.19599	1
12100401	East Matagorda Bay - W	Unnamed Tributary to Tres Palacios Bay	63	28.71779	-96.21054	1
12100401	East Matagorda Bay - W	Cash's Creek	62	28.76384	-96.19344	2
12100401	East Matagorda Bay - W	Evaporation Lake	64	28.68855	-96.52068	1
12100401	East Matagorda Bay - W	Palacios Bayou	107	28.61435	-96.21178	1
12100401	East Matagorda Bay - W	Pilkington Bayou	108	28.71071	-96.16323	1
12100402	West Matagorda Bay	Blind Bayou	10	28.52371	-96.51239	1
12100402	West Matagorda Bay	Little Chocolate Bayou	11	28.59430	-96.63950	1
12100402	West Matagorda Bay	Lynn Bayou	12	28.62471	-96.62987	7
12100402	West Matagorda Bay	Boggy Bayou	35	28.45999	-96.41514	2
12100402	West Matagorda Bay	Powderhorn Lake	36	28.47325	-96.55566	3
12100402	West Matagorda Bay	Old Town Lake	37	28.55980	-96.53803	2
12100402	West Matagorda Bay	Chocolate Bayou	38	28.57846	-96.65005	3
12100402	West Matagorda Bay	Blind Bayou	65	28.51859	-96.50499	2
12100402	West Matagorda Bay	Blind Bayou	66	28.52968	-96.51447	1
12100402	West Matagorda Bay	Hog Bayou	85	28.49656	-96.84341	1
12100402	West Matagorda Bay	Garcita's Creek	87	28.77736	-96.69892	2
12100403	East San Antonio Bay	Goff Bayou	86	28.51179	-96.81661	1
12100405	Aransas Bay	Artesian Creek	B	28.32234	-97.93534	2
12100405	Aransas Bay	Cavasso Creek	C	28.21820	-96.98798	5
12100405	Aransas Bay	McCampbell Slough	D	27.93007	-97.18727	3
12100405	Aransas Bay	Mullens Bayou	E	28.14120	-97.22255	1
12100405	Aransas Bay	Tule Creek	L	28.05029	-97.04230	2
12100405	Aransas Bay	Tule Creek	M	28.04562	-97.03867	2
12100406	Mission	Chocolate Swale	I	28.20423	-97.29584	2
12100406	Mission	Mission River	K	28.18396	-97.21381	4
12100407	Aransas	Aransas River	A	28.12291	-97.31038	6
12100407	Aransas	Unnamed Tributary to Copano Bay	F	27.65667	-97.40207	2
12110111	Lower Nueces	Nueces River	J	27.88906	-97.60886	5
12110111	Lower Nueces	Nueces River	N	28.03811	-97.86088	2
12110201	North Corpus Christi Bay	Rincon Bayou	G	27.89695	-97.61612	6
12110202	South Corpus Christi Bay	Oso Creek	H	27.65700	-97.40210	6
					Total:	**250**

Appendix 2 Phase two study sites by Hydrological Unit Code (HUC) 8 and corresponding sub-basin name. n = total number of events sampled at that site. Coordinates in WGS84.

HUC 8	**Sub Basin**	**Waterbody Name**	**Site**	**Latitude**	**Longitude**	**n**
12020003	Lower Neches	Old River	72	30.00100	-93.86655	10
12040104	Buffalo-San Jacinto	San Jacinto River	114	29.91492	-95.12615	3
12040201	Sabine Lake	Keith Lake	28	29.77384	-93.94267	10
12040201	Sabine Lake	Texas Bayou	70	29.71086	-93.86098	10
12040203	North Galveston Bay	Cedar Bayou	82	29.72073	-94.94300	9
12040204	West Galveston Bay	Horsepen Bayou	6	29.56414	-95.14114	9
12040204	West Galveston Bay	Highland Bayou	83	29.33161	-94.94619	10
12040204	West Galveston Bay	Highland Bayou	113	29.37704	-95.07365	9
12040205	Austin-Oyster	Oyster Creek	112	29.05362	-95.46325	10
					Total:	**80**

Appendix 3. Complete list of fish caught in the cod end of the fyke nets during phase one. Species are listed in order of highest to lowest relative abundance.

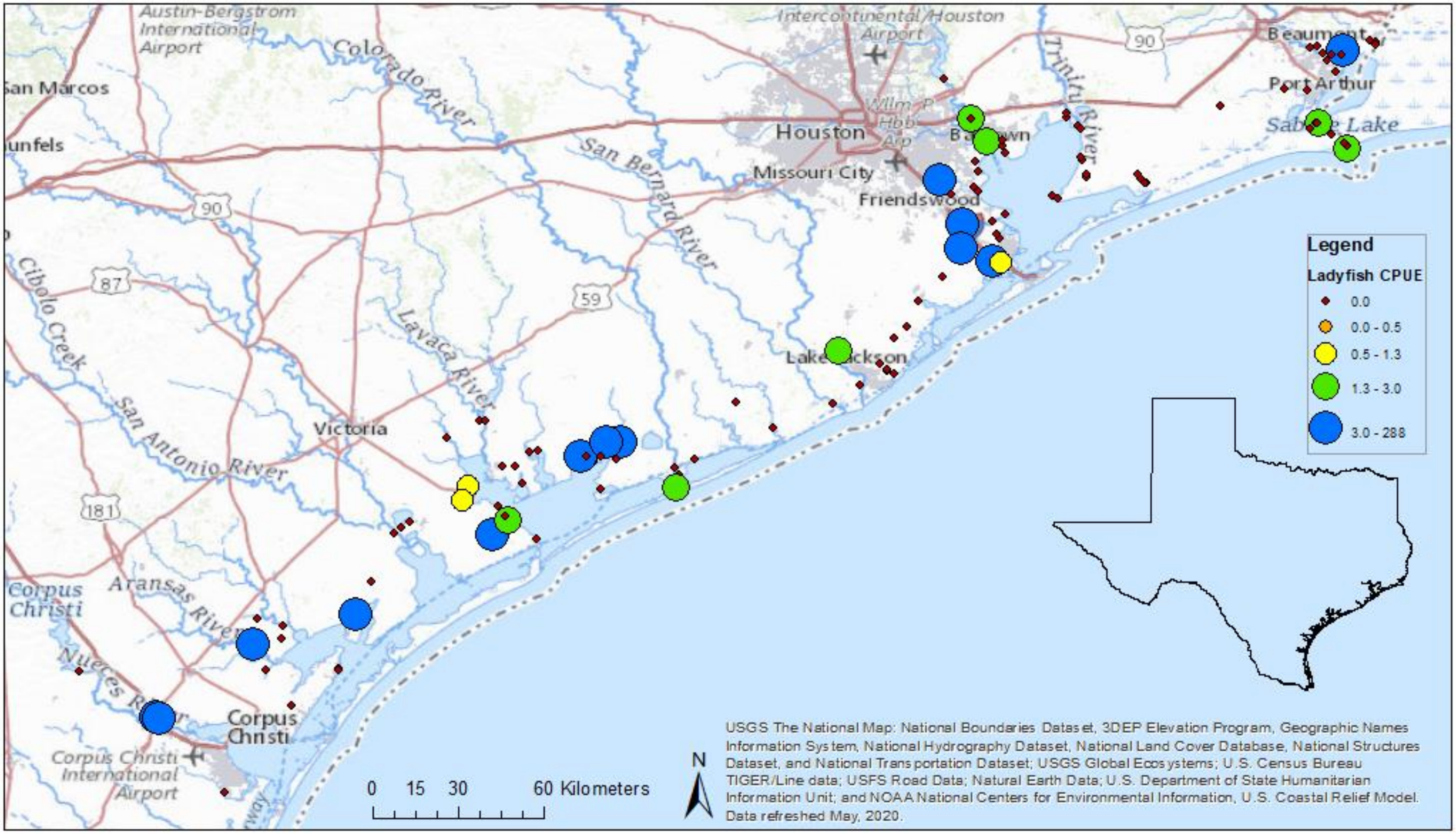
Family	**Scientific Name**	**Common Name**	**Count**	**Relative Abundance**	**CPUE**
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	39,795	31.52	7.82
Engraulidae	*Anchoa mitchilli*	Bay Anchovy	23,880	18.91	4.69
Elopidae	*Elops saurus*	Ladyfish	18,115	14.35	3.56
Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	12,501	9.90	2.46
Sciaenidae	*Micropogonias undulatus*	Atlantic Croaker	6,624	5.25	1.30
Fundulidae	*Lucania parva*	Rainwater Killifish	4,802	3.80	0.94
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	2,484	1.97	0.49
Ophichthidae	*Myrophis punctatus*	Speckled Worm eel	2,272	1.80	0.45
Poeciliidae	*Poecilia latipinna*	Sailfin Molly	2,096	1.66	0.41
Clupeidae	*Dorosoma petenense*	Threadfin Shad	1,877	1.49	0.37
Mugilidae	*Mugil cephalus*	Striped Mullet	1,829	1.45	0.36
Sciaenidae	*Leostomus xanthurus*	Spot	1,719	1.36	0.34
Atherinopsidae	*Menidia beryllina*	Inland Silverside	1,543	1.22	0.30
Sciaenidae	*Cynoscion nebulosus*	Spotted Seatrout	931	0.74	0.18
Sparidae	*Lagodon rhomboides*	Pinfish	833	0.66	0.16
Fundulidae	*Fundulus grandis*	Gulf Killifish	766	0.61	0.15
Fundulidae	*Adinia xenica*	Diamond Killifish	761	0.60	0.15
Fundulidae	*Fundulus pulvereus*	Bayou Killifish	723	0.57	0.14
Gobiidae	*Gobiosoma bosc*	Naked Goby	545	0.43	0.11
Fundulidae	*Fundulus jenkinsi*	Saltmarsh Topminnow	312	0.25	0.06
Gobiidae	*Ctenogobius boleosoma*	Darter Goby	291	0.23	0.06
Poeciliidae	*Peocilia formosa*	Amazon molly	250	0.20	0.05
Cynoglossidae	*Symphurus plagiusa*	Blackcheek Tonguefish	229	0.18	0.04
Gerreidae	*Eucinostomus melanopterus*	Flagfin Mojarra	180	0.14	0.04
Gobiidae	*Gobiosoma robustrum*	Code Goby	125	0.10	0.02
Gobiidae	*Microgobius gulosus*	Clown Goby	115	0.09	0.02
Poeciliidae	*Heterandria formosa*	Least Killifish	78	0.06	0.02
Sciaenidae	*Sciaenops ocellatus*	Red Drum	72	0.06	0.01
Eleotridae	*Dormitator maculatus*	Fat sleeper	68	0.05	0.01
Poeciliidae	*Jordanella floridae*	Flagfish	65	0.05	0.01
Syngnathidae	*Syngnathus scovelli*	Gulf Pipefish	58	0.05	0.01
Achiridae	*Trinectes maculatus*	Hogchoker	56	0.04	0.01
Centrarchidae	*Lepomis macrochirus*	Bluegill	36	0.03	0.01
Sciaenidae	*Cynoscion arenarius*	Sand Sea Trout	23	0.02	<0.01
Sciaenidae	*Stellifer lanceolatus*	Star Drum	22	0.02	<0.01
Gobiidae	*Gobioides broussonnetii*	Violet Goby	20	0.02	<0.01
Syngnathidae	*Syngnathus louisianae*	Chain Pipefish	17	0.01	<0.01
Centrarchidae	*Lepomis symmeritcus*	Bantam Sunfish	15	0.01	<0.01
Cyprinidae	*Cyprinella venusta*	Blacktail Shiner	14	0.01	<0.01
Sciaenidae	*Bairdiella chysoura*	Silver Perch	14	0.01	<0.01
Gerreidae	*Eucinostomus argenteus*	Spotfin Mojarra	13	0.01	<0.01
Cichlidae	*Herichthys cyanoguttatus*	Rio Grande Cichlid	12	0.01	<0.01
Fundulidae	*Fundulus chrysotus*	Golden Topminnow	9	0.01	<0.01
Fundulidae	*Fundulus similis*	Longnose Killifish	9	0.01	<0.01
Centrarchidae	*Micropterus punctulatus*	Spotted Bass	9	0.01	<0.01
Carangidae	*Oligoplites saurus*	Leatherjack	6	<0.01	<0.01
Cyprinidae	*Pimephales vigilax*	Bullhead Minnow	4	<0.01	<0.01

Family	**Scientific Name**	**Common Name**	**Count**	**Relative Abundance**	**CPUE**
Esocidae	*Esox americanus*	Red finned Pickerel	4	<0.01	<0.01
Achiropsettidae	*Paralichthys lethostigma*	Southern Flounder	4	<0.01	<0.01
Elotridae	*Erotelis smaragdus*	Emerald Sleeper	3	<0.01	<0.01
Characidae	*Astyanax mexicanus*	Mexican Tetra	3	<0.01	<0.01
Centrarchidae	*Lepomis gulosus*	Warmouth	3	<0.01	<0.01
Gobiidae	*Microgobius thalassinus*	Green Goby	2	<0.01	<0.01
Centrarchidae	*Micropterus salmoides*	Largemouth Bass	2	<0.01	<0.01
Cyprinidae	*Cyprinella lutrensis*	Red Shiner	2	<0.01	<0.01
Unconfirmed	Unconfirmed	Unconfirmed	2	<0.01	<0.01
Eleotridae	*Gobiomorus dormitor*	Bigmouth Sleeper	1	<0.01	<0.01
Catostomidae	*Ictiobus niger*	Black Buffalo	1	<0.01	<0.01
Ictaluridae	*Ictalurus furcatus*	Blue Catfish	1	<0.01	<0.01
Cichlidae	*Oreochromis aureus*	Blue Tilapia	1	<0.01	<0.01
Clupeidae	*Dorosoma cepedianum*	Gizzard Shad	1	<0.01	<0.01
Lutjanidae	*Lutjanus griseus*	Grey Snapper	1	<0.01	<0.01
Centrarchidae	*Lepomis megalotis*	Longear Sunfish	1	<0.01	<0.01
Cyprinidae	*Opsopoeodus emiliae*	Pugnose Minnow	1	<0.01	<0.01
Gobiesocidae	*Gobiesox strumosus*	Skilletfish	1	<0.01	<0.01
Eleotridae	*Eleotris pisonis*	Spiny-cheek Sleeper	1	<0.01	<0.01
Ictaluridae	*Notorus gyrinus*	Tadpole Madtom	1	<0.01	<0.01
Centrarchidae	*Pomoxis annularis*	White Crappie	1	<0.01	<0.01
		Grand Total	**126,255**	**100.00**	**24.81**

Appendix 4. Complete list of fish caught in the cod end of the fyke nets during phase two. Species are listed in order of highest to lowest relative abundance.

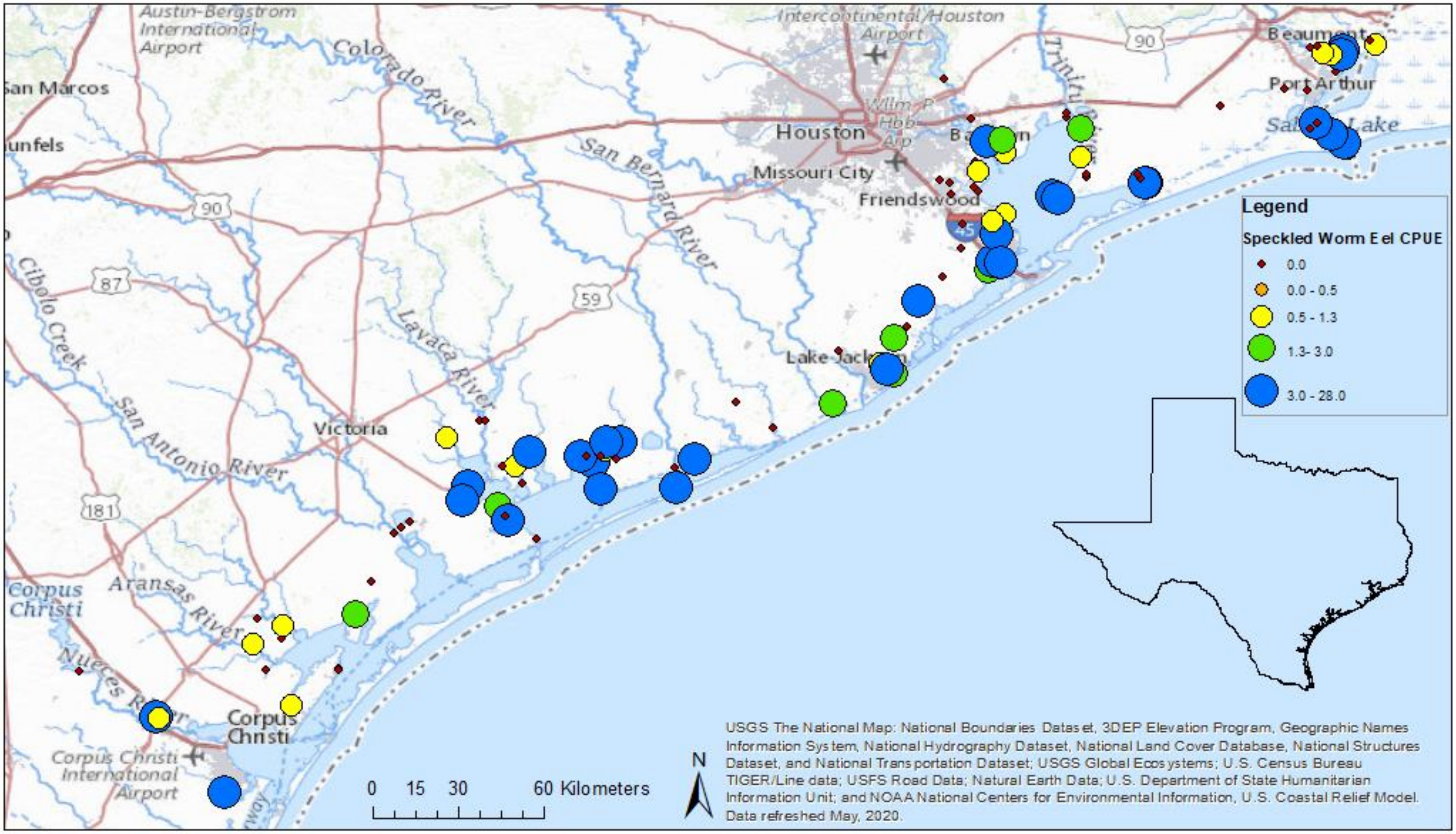
Family	**Genus Species**	**Common Name**	**Count**	**Relative Abundance**	**CPUE**
Clupeidae	*Brevoortia patronus*	Gulf Menhaden	2,282	49.75	1.29
Fundulidae	*Lucania parva*	Rainwater Killifish	949	20.69	0.54
Engraulidae	*Anchoa mitchilli*	Bay Anchovy	257	5.60	0.15
Atherinopsidae	*Menidia beryllina*	Inland Silverside	178	3.88	0.10
Mugilidae	*Mugil cephalus*	Striped Mullet	163	3.55	0.09
Gobiidae	*Ctenogobius boleosoma*	Darter Goby	116	2.53	0.07
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	92	2.01	0.05
Elopidae	*Elops saurus*	Ladyfish	55	1.20	0.03
Fundulidae	*Fundulus grandis*	Gulf Killifish	54	1.18	0.03
Cyprinodontidae	*Cyprinodon variegatus*	Sheepshead Minnow	46	1.00	0.03
Loricariidae	*Pterygoplichthys sp*	Armored Catfish	39	0.85	0.02
Syngnathidae	*Syngnathus scovelli*	Gulf Pipefish	39	0.85	0.02
Sparidae	*Lagodon rhomboides*	Pinfish	36	0.78	0.02
Poeciliidae	*Poecilia latipinna*	Sailfin Molly	36	0.78	0.02
Gobiidae	*Gobiosoma bosc*	Naked Goby	33	0.72	0.02
Eleotridae	*Dormitator maculatus*	Fat sleeper	22	0.48	0.01
Ophichthidae	*Myrophis punctatus*	Speckled Worm eel	22	0.48	0.01
Gobiidae	*Gobiosoma robustrum*	Code Goby	21	0.46	0.01
Sciaenidae	*Sciaenops ocellatus*	Red Drum	19	0.41	0.01
Unidentified	*Unidentified*	Unidentified	16	0.35	0.01
Fundulidae	*Adinia xenica*	Diamond Killifish	15	0.33	0.01
Poeciliidae	*Heterandria formosa*	Least Killifish	13	0.28	0.01
Sciaenidae	*Micropogonias undulatus*	Atlantic Croaker	10	0.22	0.01
Centrarchidae	*Micropterus punctulatus*	Spotted Bass	9	0.20	0.01
Sciaenidae	*Bairdiella chysoura*	Silver Perch	8	0.17	<0.01
Cyprinidae	*Opsopoeodus emiliae*	Pugnose Minnow	7	0.15	<0.01
Cichlidae	*Oreochromis aureus*	Blue Tilapia	6	0.13	<0.01
Cyprinidae	*Pimephales vigilax*	Bullhead Minnow	5	0.11	<0.01
Sciaenidae	*Cynoscion arenarius*	Sand Sea Trout	5	0.11	<0.01
Sciaenidae	*Leostomus xanthurus*	Spot	5	0.11	<0.01
Cyprinidae	*Cyprinella venusta*	Blacktail Shiner	4	0.09	<0.01
Batrachoididae	*Opsanus beta*	Gulf Toadfish	4	0.09	<0.01
Centrarchidae	*Lepomis macrochirus*	Bluegill	3	0.07	<0.01
Syngnathidae	*Syngnathus louisianae*	Chain Pipefish	3	0.07	<0.01
Sciaenidae	*Cynoscion nebulosus*	Spotted Seatrout	3	0.07	<0.01
Elassomatidae	*Elassoma zonatum*	Banded Pygmy sunfish	2	0.04	<0.01
Fundulidae	*Fundulus pulvereus*	Bayou Killifish	2	0.04	<0.01
Fundulidae	*Fundulus chrysotus*	Golden Topminnow	2	0.04	<0.01
Paralichthyidae	*Citharichthys spilopterus*	Bay Whiff	1	0.02	<0.01
Cynoglossidae	*Symphurus plagiusa*	Blackcheek Tonguefish	1	0.02	<0.01
Gerreidae	*Eucinostomus melanopterus*	Flagfin Mojarra	1	0.02	<0.01
Cyprinidae	*Notropis buchanani*	Ghost Shiner	1	0.02	<0.01
Fundulidae	*Fundulus similis*	Longnose Killifish	1	0.02	<0.01
Unconfirmed	Unconfirmed	Unconfirmed	1	0.02	<0.01
		Grand Total	**4,587**	**100.00**	**2.60**

Appendix 5 Map of all study sites from phases one and two. Size and color of the points represent the total Ladyfish (Elops saurus) catch per unit effort (CPUE; number of fish per trap-hour) for each site.



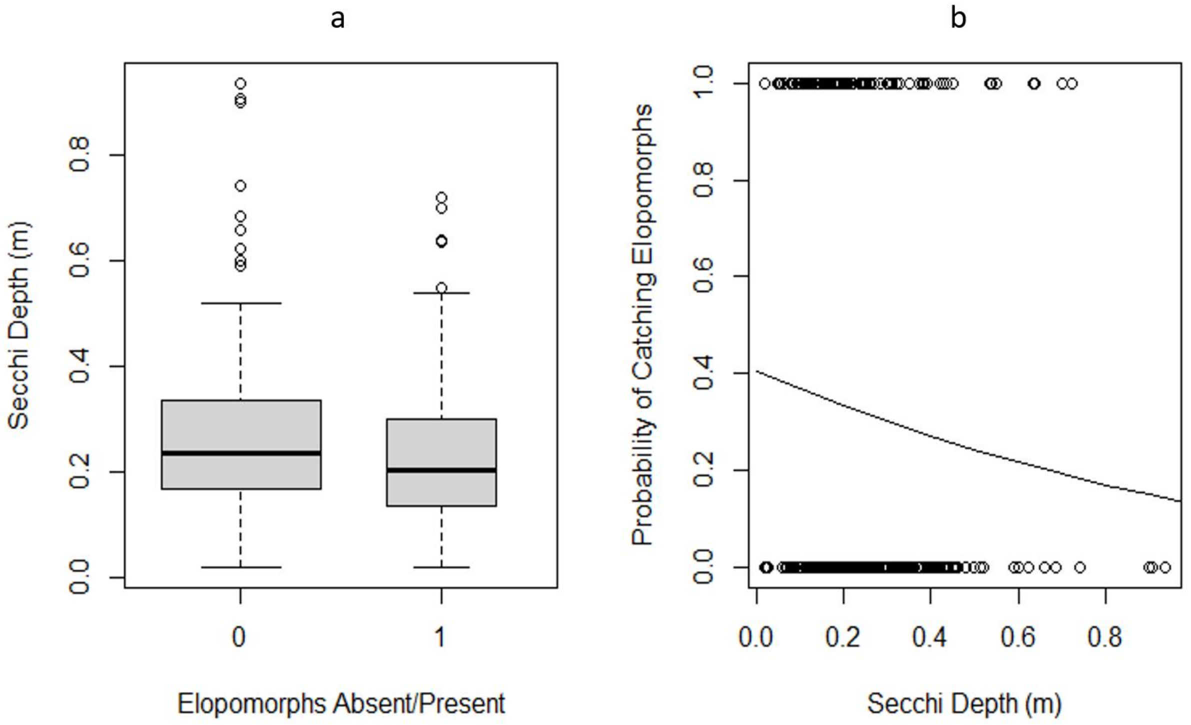
USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed May, 2020.

Appendix 6 Map of all study sites from phases one and two, Size and color of the points represent the total Speckled Worm Eel (Myrophis punctatus) catch per unit effort (CPUE; number of fish per trap-hour) for each site.

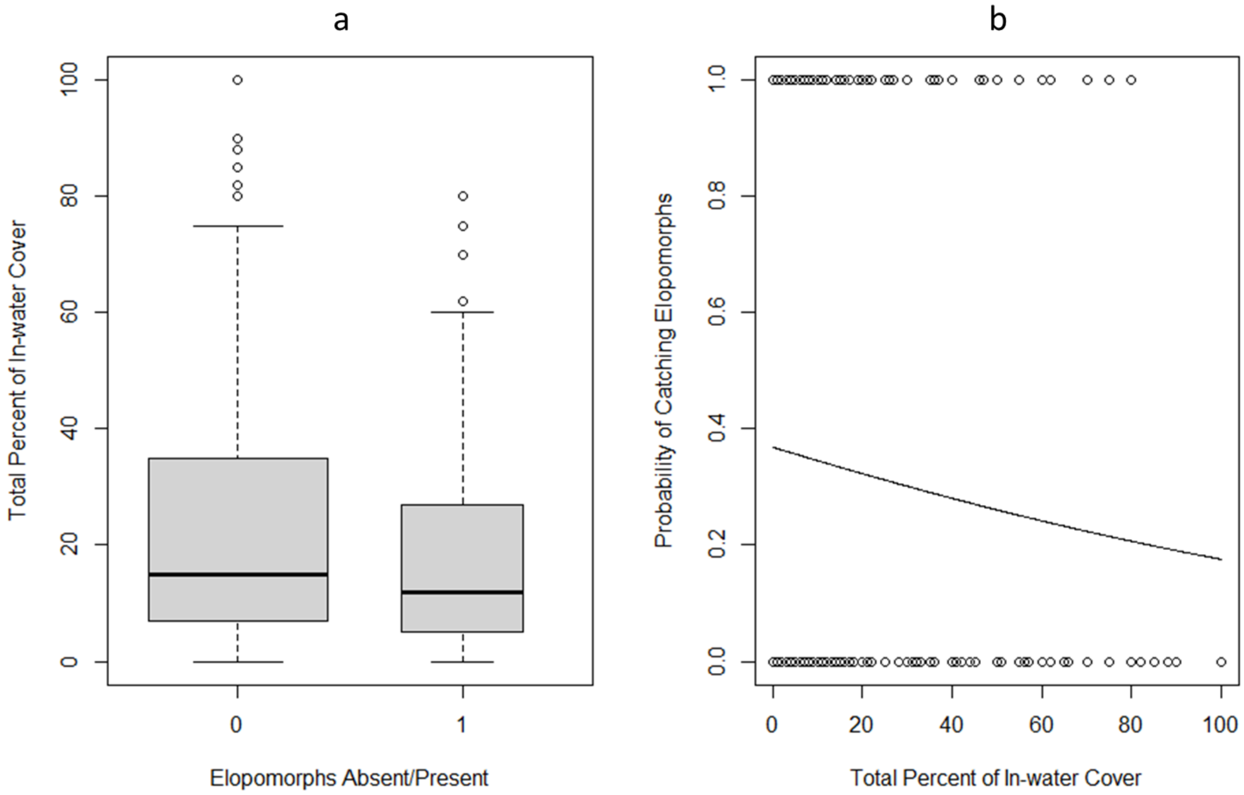


USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed May, 2020.

Appendix 7 a) Boxplot of Secchi depth (m) at sites where elopomorphs were captured versus not captured and b) fitted binomial Generalized Linear Model applied to the presence/absence of elopomorphs by Secchi depth.



Appendix 8 a) Boxplot of total percent cover of in-water cover in the 10 meters in front of the fyke net at sites where elopomorphs were captured versus not captured and b) fitted binomial Generalized Linear Model applied to the presence/absence of elopomorphs by total percent in-water cover.



Reviewed by:

Stephen Curtis ____________________ Date: 03/08/2022 ______________

Stephen Curtis, TPWD Project Coordinator

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______________________________________ Date:__________________________

Megan Bean, Inland Fisheries SWG Coordinator

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