COASTAL RECREATIONAL FISHING LICENSE
FINAL PERFORMANCE REPORT

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Grant Title: Acoustic tracking of adult red drum and black drum to evaluate restored habitat function, resident versus migratory life histories, and post-capture mortality

Grant Award Period: 07/01/2012 – 6/30/2014 (extended to 12/31/2015)

Performance Reporting Period: Final Report

Project Costs:

Expenditures for the Period:

Category	**Expenditures**
Personnel	$404.24
Fringe	$36.33
Travel	$1,616.20
Equipment	
Supplies	$80.47
Construction	
Participant Stipend	$0
Other	$0
Total Direct	$2,137.24
Indirect	$320.61
TOTAL	$2,457.85

Total Cumulative Expenditures:
Total Cumulative Expenditures: $2,457.85 (direct and indirect)
Total Remaining Balance: $324.16 (direct and indirect)

INTRO/BACKGROUND:

As scientist continue to incorporate ecosystem-based approaches for management of coastal resources, researchers are tasked with understanding how species interact with their environment. Fisheries managers, specifically, must incorporate information on the quality and quantity of essential habitat used by fishes as it relates to the production and success of fish populations. This is further complicated as trends in habitat degradation continue to show drastic losses in these habitats that fish use as juveniles and adults. Habitat restoration (including artificial reefs) and augmentation have become major tools in efforts to conserve coastal fishery resources (Christensen and Maclean 2011). Without detailed information on how fishes utilize and rely on these habitats (and conversely, degraded habitats too) over multiple temporal and spatial scales, we lack rigorous quantitative data on how to allocate limited financial and material resources to maximize ecosystem services (i.e., fishery production) within our coastal oceans

Particularly in NC, hundreds of thousands of dollars are spent each year restoring/enhancing reef habitat to help maintain eastern oyster (*Crassostrea virginica*) fisheries (2008 commercial landings valued at over $2,000,000). Calculating the cost/benefit ratio of these restoration efforts should account for both the economic value of oysters harvested from these sites, as well as the ecosystem services provided by this foundation species, such as enhanced water quality, stabilized shorelines, and provision of habitat for fishes and invertebrates. Certainly, understanding how oyster habitat enhancement affects the production of other recreationally/commercially important species could significantly alter the perceived (and realized) ecological/economic benefits or costs associated with these enhancement efforts. A key requisite for addressing this issue would be knowledge of how fish are distributed in relation to restored/enhanced reefs.

For many estuarine species, tracking seasonal movements/migrations of fish capable of large migrations is critical for defining stock concepts and quantifying stage-specific vital rates. For example, recent otolith based studies of weakfish (*Cynoscion regalis*) revealed that even through individual fish have seasonal migratory routes > 100 km, they are capable of homing to their natal estuary year after year (Thorrold et al. 2001). As a result, the researchers have suggested that this species is less demographically connected with stocks from adjacent states over ecologically meaningful timescales than previously realized. Moreover, historical and current work demonstrates that even for species characterized by seasonal migrations, such as striped bass (*Morone saxatilis*), some individuals may forego cycles of emigration from and immigration to estuaries (Secor 1999). This is not without significant management implications. Considering species which typically emigrate from estuaries into nearshore coastal ocean waters or undergoing large migrations to warmer southern waters, individuals choosing to remain may experience alternative pressures such as increased susceptibility to fishing and exposure to extreme environmental conditions (i.e. wintertime cold-stun). Stock-wide estimates of life history may be flawed if these alternative life history decisions alter vital abundance assessments (i.e. natural and fishing mortality). Therefore, the value of movement/migration data across multiple scales should once again be highlighted.

Red drum and Black drum, two frequent inhabitants of NC coastal habitats, are highly targeted by recreational anglers. Red drum have been under stringent regulations for several decades resulting in an efficient recovery from severe depletion of the population. In NC, a long-term Division of Marine Fisheries (DMF) tagging program and recent biotelemetry work based out of North Carolina State University has significantly advanced what is known regarding the movements and mortality of sub-adult and adult red drum (e.g., Bacheler et al. 2008, 2009 a,b,c).

For instance, these researchers observed that local habitat selection of age-2 fish is driven by a suite of abiotic (e.g., salinity, dissolved oxygen) and biotic (e.g., biogenic habitat, prey availability) factors, with the relative importance of these factors changing across spatial scales. While these studies in NC as well as other states demonstrate the wealth of information that can be gathered by quantifying movement data, the authors do stress the temporal and spatial variations that are apparent in movement behavior thus highlighting the remaining need to study red drum behaviors to improve coastal resource management.

Juvenile black drum are reported to inhabit coastal waters from Delaware Bay to Florida along the east coast of the US as well as throughout the Gulf of Mexico. Research in the Gulf of Mexico has suggested that black drum utilize structured habitats (George 2007) and forage within subtidal oyster reefs and hard structure (Brown et al. 2008, George and Brown 2008). The limited research on black drum movement and habitat use has been restricted to locations in the Gulf of Mexico and to our knowledge no research has examined movement patterns of this species within North Carolina's coastal habitats. Anglers often catch black drum while fishing near subtidal structure including oyster reefs and artificial reefs. Catches of black drum appear to be increasing among anglers within NC (personal communication). Fisheries managers implemented minimum length and bag limits on black drum in 2014 likely reflecting the increase in landings of this species within NC. Given the life history characteristics and foraging habitat preferences of these two fish, they serve as good model species for addressing the objectives of this study.

The New River Estuary (NRE), located within Onslow County, NC, is a broad shallow, periodically vertically stratified estuary, covering an area of approximately 34 mi^2 (Fig. 1) (Ensign et al. 2004). Water quality (Salinity, Temperature, and Dissolved Oxygen (DO)) in the

estuary fluctuates seasonally, however due to the relatively small size of the NRE watershed, water quality can fluctuate over short time spans as a result of local meteorologically conditions. Pulses of fresh, low salinity water into the system over short time frames has the potential to dictate fish distributions within the estuary. The NRE connects with the ocean via a narrow inlet and the Intracoastal Waterway. As mentioned previously, since the early 1980's, the NC Division of Marine Fisheries (NC DMF) has been deploying roughly 500,000 bushels of cultch material annually throughout the state. In the NRE alone, from 2001 through 2013, NC DMF has deposited roughly 210,803 bushels of cultch at 47 different locations. After enhancement, cultch oyster reefs are monitored briefly for oyster production; however, there is a lack of empirical based knowledge of how higher order species, specifically fish, use the new habitat. Our overarching goal is to quantify the movements and habitat use of adult red drum and black drum over spatially and temporally relevant scales within the New River Estuary (NRE).

OBJECTIVES

1) To determine, within the NRE, do adult red drum and black drum utilize artificial reef (AR-398) or enhanced (DMF cultch sites) sites/habitats more than non-augmented (i.e., soft-bottom) reference sites?
2) More broadly, how is estuary-scale movement and habitat selection of adult fishes affected by pulsed or seasonal changes in water quality (dissolved oxygen) or abiotic conditions (temperature, salinity)?
3) Are adult red drum and black drum year-round residents in the NRE, or do fishes emigrate from the system (seasonally or permanently)?
4) Can both life-history strategies (resident/migrant) be observed within adult red drum or black drum populations of the NRE?

5) If fishes do emigrate from the NRE seasonally do they return to the NRE in the following year?

6) Does survivorship or movement patterns appear to differ between fishes captured via hook-and-line versus gillnetting?

METHODS

Fish Collection:

Starting in the Fall of 2012, and through 2014, we collected and tagged 55 red drum (mean total length ± S.E, 517.35 ± 14.27mm) and 36 black drum (mean total length ± S.E, 454.75 ± 5.59mm) within the NRE. We collected fish via hook and line as well as gill net from a variety of resources. During the fall of 2012 we conducted the bulk of our collections in conjunction with the monthly DMF fishery independent survey in the NRE as well as with a group from the University of North Carolina Wilmington (UNCW) conducting a similar tracking study on southern flounder. During this first tagging season, the DMF survey contributed 13 fish towards the project (11 red drum and 2 black drum) and the UNCW efforts contributed three red drum. Additionally we received collection assistance from local fisherman through a collaboration with a local chapter of the Coastal Conservation Association North Carolina (CCANC) and two separate red drum fishing tournaments. During two weekends in the fall of 2013 members of the Onslow chapter of the CCANC organized a fishing day and all fish caught were transferred to our tagging team on the water for tagging. Anglers from this group contributed 13 red drum towards the study. Additionally, during the fall of 2014 we attended one red drum fishing tournament in Jacksonville, NC (Reelin to Heal Inshore Slam) and another in Swansboro, NC (Carolina Redfish Series) tagging and releasing 8 red drum. Although the Swansboro tournament was not held directly within the NRE, anglers were questioned about the

catch location of each fish weighed in and only fish caught within the NRE were kept for this study. Upon collection of the fish at this tournament, we administered external ID tags in order to maintain knowledge of of capture location for each individual fish (based on anglers best description). Fish were transported to the UNC IMS lab where they were held for a day before surgically implanitng the transmitters. After a day of recovery fish were transported back to the NRE and released in the area where they were captured. Overall, of the 55 red drum tagged, twenty-six were collected via hook and line and twenty-nine via gill net. All black drum were collected via gill net.

Acoustic array and tagging:

We collaborated closely with the research team from UNCW to establish a hydrophone array within the NRE that was able to monitor use of oyster cultch sites as well as monitor larger scale movement and habitat use within the NRE. We chose to use the widely applied Vemco acoustic tracking technology to monitor movement of fish in this study. The high popularity (particularly along the east coast of the US) of this company allowed us to collaborate closely with the UNCW research team as well as receive contributions of data from other groups in South Carolina, Virginia, and Deleware whom detected several of our fish in their hydrophone arrays. Initially, a total of thirty-eight hydrophones were deployed covering the entire NRE from Jackonsville, NC, to the exit points at the inlet and Intracoastal Waterways (Fig. 1). During the spring of 2013, the UNCW team added seven additional hydrophones to Northeast Creek in the norther region of the estuary.

We monitored the cultch sites by placing one hydrophone at each of six chosen cultch sites and cooresponding reference site. At sites where only one oyster cultch planting occurred, we placed the hydrophone in the center of the restored site. In circumstances where multiple

cultch reefs were established in different years, we placed the hydrophone inbetween individual reefs so that the greatest cultch area and number of reefs fell within the detection range of the hydrophone. At the artificial reef site we placed two hydrophones to miximize ability to detect fish. The artifical reef rubble mounds rise off the sediment surface about a meter and therefore create line of sight blockage between hydrophones and fish within the area. The material was placed in a grid pattern thus leaving 80 m wide runways of empty space spanning both the length and width of the restoration site. We placed the hydrophones in saparate runways within the site. The refereence site was located on the opposite side of the river in an open, primairly mudddy sediment, habitat at the same distance from the nearest shoreline as the Artifiical Reef.

The remaining hydrophones were placed at pinch points or narrow locations where we could cover the entire width of the river with few hydrophones and have a high probablity of detecting a fish moving by. In the lower portion of the river these points were located near the NRE exit points at the inlet and Intracoastal waterways north and south (stations 32-38) as well as at the Hwy 172 bridge crossing (stations 22-23). In the central region of the river the main pinch point was located between hospital point and town point (stations 9-13). In the upper part of the river, the narrow distance across southwest creek (stations 5-7), northeast creek (stations 3,4, and NE1 – NE8), and the channel at the Hwy 17 bridge (station 1-2) permit uninterrupted detection from shore to shore. Finally, the remaining sites where chosen to monitor use of two main creek systems (station 17: Frenches Creek; station 8: Wallace Creek).

Restoration/enhancement sites:

In addressing our first objective of this study we identified 6 cultch reef sites to target in this study. The bulk of cultch planting within the NRE has occurred in the lower half of the estuary in Stones Bay and below the Hwy 172 bridge near Sneads Ferry. Our six target sites

were chosen to cover the spatial extent of cultch plantings within the NRE. Although a variety of material (oyster shell, clam shell, scallop shell, and marl) have been used in these resoration projects, we chose sites that were constructed with oyster shell. Theses sites were constructed on various dates from 2003 through 2010 and contained a range of material from as little as 950 bushells up to 23,575 bushells (Table 1). Several of our sites were located in an area where cultch was planted multiple years in the same general loaction and thus we considered total cultch material at those sites as the combination of multiple plantings. For each of the six cultch sites we monitored, we also chose a cooresponding non-augumented reference site. Each reference site was chosen to closely represent the spatial and environmental characteristics of its cooresponding cultch site (i.e. depth, temperature salinity, geographic features, etc) while being far enough away from structured habitat so that detection at these sites will be synonymous with use of unrestored soft-bottom benthic habitat. For example the Courthouse Bay cultch site was paired with a Trapps Bay reference due to the similarities in sediment composition, location within a semi-enclosed bay, region within the NRE, and proximity to each other. Station pairings for cultch sites with reference sites are (cultch – reference): 18-19, 21-20, 27-24, 26-29, 25-28, 31-30.

To compare the total amount of time fish spent at the cultch sites versus the reference sites, we calculated a standardized number of detections at each site. Due to the periodic loss of hydrophones at various stations over the course of the study and time lapse before replacements were added, sites could be defined by different number of days which hydrophones were present and listening for fish transmitters. Thus we standardized detection data by comparing the detections per unit effort (DPUE) among the stations. DPUE was calculated by dividing the

number of detections at an individual site by the number of days in which a hydrophone was present at that site during the study.

Each cultch site and reference site were treated as replicates of restored and non-restored habitats respectively for comparisons. DPUE at cultch versus reference was analyzed using a student's t-test. We also looked at the differences in DPUE for each individual cultch and reference site. To accomplish this we treated each fish as a replicate for calculations of mean DPUE at individual sites. The sites were compared using analysis of variance (ANOVA) on log transformed data. Data for comparison of individual cultch and reference sites was log transformed due to the large number zeros in the data set. For the artificial reef, since there was only one site, we again treated each individual fish as a replicate for determining mean DPUE. Additionally since there were two hydrophones at the artificial reef, we used the average DPUE between the two hydrophones for each fish. We compared DPUE between the artificial reef and reference sites using a student's t-test on log transformed data. Data for comparison of artificial reef versus reference site was log transformed due to the large number zeros in the data set.

In addition to the cultch sites in the lower portion of the estuary, we also monitored red drum and black drum use of an artificial reef located in the middle part of the estuary (Fig. 1). During 2010-2011, RIVERWORKS received funding (>$550K) from the CRFL program to construct a large artificial reef complex within the NRE. The project utilized bridge demolition material from the NC Route 17 Bridge (Buddy Phillips Bridge) in Jacksonville, NC. Using combined RIVERWORKS and DMF resources, ~1900 bridge rubble mounds (each ~ 2m3) were deployed to create AR-398 southeast of Town Point in 6-8 feet of water, over seafloor that was historically hard bottom (i.e., attempting to restore structured habitat in the NRE). The entire site covers an area approximately 450 m long and 275 m wide. Similar to the cultch oyster reefs, this

artificial reef was monitored for biogenic habitat development (oyster, muscles, barnacles, soft corals, etc.) however limited data is collected on how higher-order organisms, specifically fishes, are using the structurally complex habitat.

Previous research has characterized subtidal oyster reefs as valuable foraging habitat for both red drum and black drum. As a tool to better understand patterns in cultch site use, we quantified the biotic characteristics of the restored and control habitats. During the spring of 2013 we sampeled each cultch and reference site to quantify the density of live adult oysters, live oyster spat, non-oyster bivalves, crustaceans, and soft body infauna. First, we collected all material to a depth of ~5cm within a .25m^2 quadrat to quantify each metric listed above. Quadrat samples were only collected at the cultch sites. Additionally at each cultch and reference site we we took core (10cm dia.) samples. We did not differentiate between adult and spat oysters in the core data and grouped them together; however, for the quadradats we counted adult and spat separately. Quadrat samples were used to compare the metrics between individual cultch sites while the cores were used for general comparissons between cultch and reference sites. For the quadrat samples, analysis of variance was run on raw data for adult oysters and log transformed data for oyster spat, bivalves, crustaceans, and soft body infauna. Due to the high variability in the core data, we compared differences among individual sites using a non-parametric Kruskal-Wallis test and between restoration status (cultch vs refreence) using a non-parametric Wilcoxon test. Due to sampling error, we do not have data for non-oyster species at station 29. While this station remains in the graphs, it does not indicate that zero animals were found at that station. For statistical analysis, this station was removed. Finally we compared DPUE at each cultch site based on the total amount of shell that has been deposited per site. Total amount of shell was obtained from the NC DMF cultch planting project website.

Environmental monitoring:

In addition to monitoring fish use of cultch and artificial reef habitats, we wanted to evaluate how local and estuarine-scale water quality conditions affect the movement patterns and habitat use of these two species of fish. Through Department of Defense funding, the Coastal Environmental and Microbial Process Lab (Paerl Lab – UNC IMS) conducts monthly water quality monitoring at six stations througout the NRE (Fig). At each station, vertical profiles of salinity, temperature, and dissolved oxygen (DO) are conducted. The data for these three metrics was provided to us for the time span of our study. For our analysis we utilized the measurements from the deepest point in the profile for or analysis.

During thie study there were differences in the number of fish known to be in the system each month based on when we tagged fish, individuals knowlingly exited the NRE, individuals were harvested, and individuals knowingly returned to the NRE. Based on these known dates, we calculated the number of fish in the estuary for each month (Fig. 2). We used the middle of each month as a cuttoff for determining which month fish were applied to. For example, if a fish was tagged after the 15th of the month, it was considered in the system starting the following month. Similarly if a fish knowlingly exited before the 15th of the month, it was not considered to be in the system during that month. When calculating monthly detection values for comparisons with water quality metrics, we further standardized detection data by dividing the DPUE values at each hydrophone by the number of fish present in the system.

For each fish species, we created monthly DPUE/fish density images across the entire estuary. Additionally, we used the environmental data collected by the Paerl lab to create monthly density images for salinity, temperature, and dissolved oxygen. Visual representations

of fish positions and water quality metrics were examined for temporal and spatial relationships within the river. Additionally, as a quantitative measure of the relationships between fish detections and water quality we analyzed coorelations between the factors. Since the waterquality monitoring stations and hydrophones are not perfectly alligned spatially within the estuary, we divided the estuary into six zones cooresponding with each water quality monitoring station (see Fig. 1). Hydrophone stations were then grouped within these zones and matched with water quality monitoring stations. Hydrophone detection data was further simplified by averaging monthly DPUE/fish at each hydrophone within each respective zone resulting in a single detection value paired with a single water quality value each (for each water quality metric) per month. In a best-case scenario this would result in 40 pairs of detection/water quality data points in each zone over the course of the study for a total of 240 points. However, due to temporary loss of hydrophones and some months when water quality was not measured, the number of points do not add to this perfect scenario value. Data were analyzed seperately for each season during the year (Spring: Mar-May, Summer: Jun – Aug, Fall (Sep. – Nov).

We also explored seasonal patterns of fish detections within the estuary excluding the water quality metrics. To accomplish this we calculated seasonal DPUE/fish for each region of the estuary according to the delta density method, further refered to as “delta DPUE”. This approach has been used for comparing densities of fish among spatially separate regions when zeros are prevalent in survey data. The delta density approach requires the establishment of two data sets: occurrence (the proportion of hydrophones detecting fish per region for each season pooled over the entire study) and concentration (monthly DPUE/fish when fish are actually detected) (Serafy et al. 2007). Seasonal delta DPUE is calculated as the product of occurrence

(O) and mean seasonal concentration values (C) for each region. Seasonal concentration values are calculated for seasons within each year.

Residency status:

Both red drum and black drum are known occupy estuaries for the first 3-5 years of their life-cycle before recruiting to the adult populaiton that resides primarly in nearshore shelf waters. During the colder winter months in North Carolina, a number of these sub-adult fish will exit the estuary and either occupy nearshore habitats or migrate south while other individuals will remain in the the estuary. Furthermore, some of those fish exiting the system may return the following year to the NRE. Understanding the annual and seasonal movement along with the residency patterns of these two species is inextricably linked to a greater understanding of their population ecology and fisheries dynamics. We categorized each fish as either a) exiting the estuary and never coming back, b) exiting the estuary and returning the following season, or c) staying in the estuary continuously before leaving permanently. We analyzed each group above for differences in fish length, capture method, and capture location using analysis of variance. Capture method was either hook and line or gill net and capture location was either upper river (up river from the Hwy 172 bridge) or lower river (down river from the Hwy 172 bridge).

RESULTS/DISCUSSION

We tagged a total of fifety-five red drum and thirty-six black drum (Table 2 and Table 3). Of the 55 red drum, we successfully collected detection data on all but five individuals, and for black drum there was only one out of 36 individuals that were not detected in the array. On average, red drum were detected 3,341.18 ± 829 times (mean ± SE) at 10.94 ± 1 (mean ± SE) stations and 197.19 ± 24.48 (mean ± SE) days at liberty. Black drum were detected more often with an average of 13,766.80 ± 2,255(mean ± SE) detections at 12.71 ± 1 (mean ± SE) stations

and 140.16 ± 20.39 (mean ± SE) days at liberty. Of the fish that were detected for red drum, there were no significant differences in days at liberty, total number of detections, and stations visited between fish collected via hook and line and those captured by gillnet. All black drum were captured with gillnets and thus comparing methods is not atainable. Movement parameters (days at liberty, numbe of stations visited, and total detections) for red drum that were detected indicate that there is no difference in the impacts of capture method on the fish. Four of the five red drum that were never detected were captured using gillnets; however, all four of these fish were captured and released in the marsh systems near the inlet where there are numerous small creeks and avenues where fish have the potential to "sneak" out of the system undetected. We feel that based on the observations made during this study, there are no major post capture impacts on fish behavior between hook and line caught fish and gillnet caught fish.

Restored Habitat Use

Red drum used the reference sites slightly more than the cultch reefs however this difference was not significant (t_5 = -0.560, P = 0.5994)(Fig. 3). The average DPUE for black drum at the reference sites was also greater than the cultch, however this difference was not significant (t_5 = -1.189, P = 0.2879). Although black drum DPUE at references sites was drastically higher than at cultch reef sites, there was a large amount of variability in the detection data at these locations. Similar to the cultch reef sites, red drum showed no signfiicant preference for the artificial reef over the natural reference site (t_{16} = -0.352, P = 0.729)(Fig. 4). Black drum however showed a strong preference for the artificial reef over the unmodified reference site ($t2_6$ = 2.783, P = 0.009)(Fig. 5).

Looking closer at individual cultch and natural reference sites there is no significant difference in the red drum DPUE at individual sites ($F_{11,564}$ = 1.6335, P = 0.085) (Fig. 6). Black

drum however did show several significant differences between individual sites ($F_{11, 396}$ = 3.8234, P < 0.001) (Fig. 7). Individual comparisons show that the DPUE at reference site 18 was only significantly similar to the cultch site 19 and reference site 21 and significantly greater than all other sites.

Results from the core samples indicate that there were no significant differences in the density of bivalves (Fig. 8) and crustaceans (Fig. 9) between cultch and reference sites (bivalves: χ^2 (2, N = 61) = 1.17, p = 0.279; crustaceans: χ^2 (2, N = 61) = 3.205, p = 0.073). There was a significantly greater density of soft-body infauna at the references sites compared to the cultch sites χ^2 (2, N = 61) = 5.313, p = 0.021) (Fig 10). The lack of differences in bivalve densities was mostly due to the substantial abundance of hard clams (*Mercenaria mercenaria*) and dwarf surf clam (*Mulinia lateralis*) found at reference sites in the NRE, particularly in stones bay. Abundance of crustaceans was generally low in the core sampling. The size of the core used was not efficient in collecting crabs and shrimp which are two likely crustacean species to make a substantial difference between cultch reefs and reference sites. Although the core samples were useful for comparing cultch and reference sites, due to their size, they do not fully represent the greater diversity of organisms within the cultch reefs. Quadrat samples were more efficient in identifying the organisms within the reefs. The results indicate that there are no differences in the density of adult oysters at the cultch sites ($F_{5, 47}$ = 2.317, P = 0.058) (Fig. 11); however, there were significant differences in the number of spat. Stations 28 and 29 had a significantly greater number of oyster spat than all other cultch sites ($F_{5, 47}$ = 10.5048, P < 0.0001) (Fig. 12). There was a significant difference in the density of bivalves. Stations 19 and 20 in stones bay contained significantly greater densities of non-oyster bivalves ($F_{4, 40}$ = 10.2991, P < 0.0001) (Fig. 13). Crustacean densities varied among the sites however the differences were only moderately

significant ($F_{5, 40}$ = 2.8553, P = 0.0358) (Fig. 14). Only stations twenty-eight and twenty-four were statically different from each other. There was also a significant difference among the sites when comparing soft body infauna ($F_{5, 40}$ = 5.0858, P = 0.0021) (Fig. 15). Similar to crustaceans, densities of soft body infauna were greater at stations twenty-eight and twenty-four.

The lack of differences in DPUE between cultch oyster reef sites and corresponding reference sites was a surprising result in this study. With the extent of previous research indicating how much these two species use oyster habitats there was evidence to suggest that the restored sites in the NRE would have served as highly valuable habitat. It was difficult to identify any direct linkages between the habitat metrics and DPUE for red drum. The greatest individual site use was at stations 24 and 27. The only standout habitat metric that could suggest a correlation with DPUE, and this is stretched as is, would be the abundance of soft body infauna. Soft body infauna have been shown to be negligible in red drum diets in the New River (Facendola and Scharf 2012), thus we suspect this is more coincidence than causality. Crustaceans are a significant component of red drum diets in the New River, however site 24 had the lowest density of this category from quadrat data. In addition to crustaceans, in the new river, diets of age 1-2 red drum are also dominated by a variety of fish species (Atlantic menhaden, pinfish, Atlantic croakers, spot, mullets, snake eels, and flounders (Facendola and Scharf 2012). Our detection data from this study shows that red drum have the potential to utilize the entire estuary but these cultch sites are located in the farthest down river portion of the estuary. This spatial component along with the extremely low spatial coverage of cultch reefs (specifically in relation to the total are of the NRE) mean that the habitat which red drum utilize to in the new river are dominated primarily by shallow soft bottom habitat and smaller creek systems, not subtidal hard bottom or shell habitats. Unlike intertidal oyster reefs and flooded salt

marshes, individuals in the NRE likely do not necessarily need to target these locations to search for potential prey since all habitats are readily available to fish. It is more likely that factors which result in aggregates of potential food items such as creek systems (i.e. Frenchs Creek and Wallace Creek), small bays (i.e. Courthouse Bay (station 24) and Traps Bay (station 27)), and tidal boundaries (Stones Bay stations 18-21) are more influential on where red drum go and what habitats they use.

Black drum DPUE is a little easier to track since these individuals predominantly used only the sites located in Stones Bay and more specifically occupied the reference sites over the cultch sites. Given the reported magnitude of impact that black drum can impose on oyster reefs, specifically oyster survival, we were surprised to see the patterns we did in this study. Although these studies have reported heavy predation on oysters, black drum are not solely dependent on oysters as prey and have been reported to maintain diets dominated by other small bivalves such as Venus clams (*Anomal ocaridia*) and amphipods (Street et al. 1997). Documentation of nekton in the diets of black drum are rare. Sampling of cultch and reference sites revealed a high density of juvenile hard clams and juvenile dwarf surf clams at the stones bay sites, specifically the reference sites. Although we do not have diet data for black drum in this system, the abundance of these small bivalves suggests that black drum are potentially feeding on these small infauna in addition to or as a substitute for oysters. Similar to the argument made for red drum, given the small ratio of oyster cultch habitat to the rest of the sandy/muddy substrate habitat in the NRE and few detections on cultch sites, black drum are likely obtaining food resources from other habitats (i.e. small bivalves living in muddy substrate). Comparing black drum DPUE versus size of cultch reef does suggest that larger size reefs could enhance the value of this habitat for this species (Fig. 16). Although detection data was low for black drum in the

lower river, of the two sites in Stones Bay, these individuals used the larger site significantly more. This pattern was not true for red drum as they actually showed less preference for the larger cultch sites in the river.

Although the artificial reef did not appear to be a preferred habitat for red drum, there was no evidence that the individuals in this study preferred the alternative reference site either. Contrary to this observation, black drum expressed a high degree of preference for this structure. Comparable to the habitat sites monitored in Stones Bay, the artificial reef contained a large quantity of small bivalves. Although clams were present in small numbers, the reef mounds were dominated by mussels. We sampled only the large marl rock pieces and therefore the surrounding substrate may have contained the same hard clams and dwarf surf clams that we observed in other locations of the NRE as well and were simply not captured in our collection efforts at this site. Additionally, it was noted in our sampling (however not quantified) that there was a large number of amphipods in our samples at the artificial reef. As reported by Street et al. (1997), amphipods may be an important prey item in juvenile black drum. The presence of large quantities of small bivalves (mussels) and amphipods at the artificial reef may be a plausible explanation of why black drum occupied this habitat often.

Water Quality

We plotted monthly images of detections, salinity, temperature, and dissolved oxygen with the goal of relating fish locations with water quality. In Fig. 17 and Fig. 18 there appears that there are no strong relationships between the parameters of interest for both black drum and red drum. Upon examining the plots, there are only a few instances where it appears that the fish respond to the changing water condition. From July through September 2014 it appears that there is a pulse of fresher water into the system that lowers the salinity in the middle part of the

estuary. Coincidently, the distribution of black drum positions within the estuary also moved slightly down river during the low salinity in august and then starts to redistribution farther up river during September and October as salinity rises. However in two other circumstances in October 2012 and October 2015, black drum were not responsive to changing salinity as they were observed remaining farther up river even when a pulse of fresher water lowered salinity in the middle part of the river. Similar results were observed for red drum. For example, during July 2013, a pulse of fresh water lowered the salinities around NE Creek, and the fish appear to respond to this. However, during May 2014, red drum are detected frequently in the upper part of the river despite the lower salinities measured in this region during April and carrying over into May.

Temperatures in the river typically were uniform throughout the system when sampling occurred. There is little evidence for significant changes over the time scale of a month in the temperatures to indicate that they have an influence on fish detections in this study. Dissolved oxygen did show some changes between months during the study however there was no apparent correlation with fish detections for either species. We would expect to see fish respond to low oxygen levels and move out of this area, however on multiple occasions both red drum and black drum were detected frequently in areas of low DO (Oct 2012, Aug 2013, Aug 2014, Jul 2015).

We plotted the mean monthly DPUE per fish against the monthly salinities, temperature, and dissolved oxygen levels for both species and there appeared to be little correlation between these values for all metrics and both species. We did see some trends, however it is difficult to interpret these results due to the low R-squared values associated by these comparisons. For salinity there appears to be a trend of the highest DPUE values to occur at moderate levels between 15 and 25 ppt (Fig. 19 and 20). For both species, this suggested pattern is more evident

in the summer, fall, and winter months. Similar to the heat map temperature plots, there does not appear to be any identifiable correlative patterns between DPUE and temperature for both species (Fig. 21 and 22). Temperature ranges varied by season and fish appear to use locations within the full temperature range during all seasons. For dissolved oxygen, although there are outliers, we could argue that typically the cluster of higher DPUE points fall between 4 and 10 mg/L (Fig. 23 and 24).

Outliers for red drum DPUE during several summer months was high in areas with less than 2 mg/L dissolved oxygen (Fig. 23B). This was also the case for a monthly observation during the fall for black drum (Fig. 24C). Water quality sampling protocol through the Paerl Lab takes samples in the middle of the river. Although we can track events of substantial changes in water quality parameters, the conditions in the deeper parts of the river may not directly reflect conditions in the shallower regions where most of our hydrophones are located. Brief pulses of low oxygen may displace red drum prey (sensu Craig et al. 2013) to areas of moderate oxygen levels (i.e. the shallow edges) which are then targeted in higher volume by red drum.

Fish DPUE seems to be best described by looking at the seasonal trends between the different regions of the river (Fig. 25). During the spring, red drum are fairly evenly distributed through the estuary however in the spring they appear to show a preference for the NE Creek area. The even distribution and low DPUE in the spring is likely due to the overwintering fish starting to increase their movement as well as returning fish being detected again in the lower portion of the system. During the fall, highest DPUE is observed in the middle region of the river as well as the lower river. We think two factors drive this pattern. In general, during the fall we saw the highest DPUE at all sites throughout the entire NRE. As water temperatures cool, fish appear to be more mobile and occupy a wider range within the system. Given the centralized

location of the Middle River hydrophones, it is not surprising that DPUE was high. Furthermore, slightly higher DPUE in the lower river is likely indicative of fish exiting the system. Finally, during winter month's red drum are almost always observed in the middle river. The detection plots indicate two relative hotspots at Frenches creek and Wallace creek, both located in the middle river. There is evidence in detection data from SW creek and the two upper river stations indicating fish moved farther upstream of these hydrophones during winter months and then re-appeared during late winter or early spring months. These observations along with data from Frenches and Wallace creeks suggest that these habitats are valuable overwintering locations for red drum.

In general, black drum did not show much preference for the upper regions of the NRE. Seasonal patterns identify the lower river as most preferred location during spring, middle river during the summer and fall, and Stones Bay during the winter. Although DPUE data suggest black drum don't appear to prefer the regions in the upper portion of the NRE, we do know that they occupy these habitats since we tagged a couple fish in NE Creek. In general, black drum showed a strong preference for the middle region of the river during both summer and fall. This pattern is driven by the high affinity to Frenches creek and the artificial reef. During the winter, black drum shift to primarily using the stones bay area of the river. There are some detections in SW creek during the winter suggesting that creek systems are valuable overwintering habitats, however this observation was not as definitive for black drum as it was for red drum.

Unfortunately we only had monthly measurements of water quality while our detection data span the entire month. We did investigate patterns in DPUE within several days before and after water quality measurements were taken, however the relationships between DPUE and water quality did not show any significantly different trends. We are trying to obtain water

quality data for the shallow parts of the NRE from another research group that worked in the system during part of our study. We plan to further investigate relationships between DPUE and water quality with more rigorous analysis and inclusion of shallow water data as we move towards publication of this data. We will provide any advancements in this analysis to the NC CRFL grants program as we progress.

Residency Behaviors:

For both red drum and black drum we witnessed all three expected behaviors in relation to residency patterns. For red drum, roughly 40% of the fish exited the system and never returned, 40% stayed in the system over the winter, and the remaining 20% of the fish that left the NRE and returned at some point the following year (Fig. 26). The pattern was similar for black drum however a greater proportion of fish left the system (~55%) with approximately 30% remaining in the system over the winter and 15% leaving and returning the following season. We did observe some size relationships with the different fates of the fish. There were significant differences in size of fish among the three classifications of fish for both red drum ($F_{2, 45}$ = 5.9940, $P < 0.0049$) and black drum ($F_{2, 31}$ = 4.1035, $P < 0.0262$) (Fig. 27). Red drum that stayed in the NRE were significantly smaller than individuals that permanently left the system or returned the following season. For black drum, there was only a significant difference in size between individuals exiting the system for good and those that stayed. Black drum that returned to the NRE were not statistically different from the other two categories. Looking closer at the fate of red drum, we noticed that of the fish that remained over winter in the NRE, a greater proportion of these individuals were tagged and released in the upper part of the river (Fig. 28). Proportions of fish exiting and those that returned were equal for individuals tagged in the upper-river vs lower-river. The size of red drum staying in the system was slightly smaller for upper-

river tagged fish compared to lower-river fish however this relationship was not significant (Fig 29).

It is not novel to observe the given proportions of fish that exhibited each life history behavior in relation to residency within the system. However, in quantifying these patterns, we are able to apply some numbers for more definitive characterization. For example, roughly 60% of fish (returning or staying) tagged in this study were dependent on the NRE for consecutive years of their juvenile life stage (two individuals stayed three years). Bacheler et al. (2009) reported that fish remain in the Pamlico Sound estuary for up to five years of their early life history, however that system is much larger. Comparatively, Reyier et al. (2011) documented adult red drum that utilized estuarine habitats year-round. Both of these examples reflect large estuarine systems, however the majority of coastline along US east coast (specifically in North Carolina) are either small or medium sized riverine estuaries covering a range of biotic and abiotic characteristics. Considering the surging concern for identifying and protecting nursery habitats for fish (sensu Nagelkerken et al. 2015), quantifying the amount of time individual fish occupy different estuarine systems is critical. This theory applies for both species studied. So little is known for juvenile black drum habitat use and movement behavior that there is little to compare our results to. Approximately 45% of black drum in this study utilized the NRE during consecutive years.

Although the red drum that stayed in the system over consecutive seasons were significantly smaller than the fish that exited, the difference in mean size was only 83 mm. The small size range suggest that fish from the same age cohort potentially exhibit both life history behaviors dependent upon their yearly growth patterns. Differences in size among the three categories for black drum were even smaller. The average size difference between fish exiting

the system and those staying in the system was only 30 mm. With such a fine line between staying and going, inter-annual or even seasonal changes in prey availability or environmental conditions such as temperature (given their direct linkage to metabolism and thus growth) could dictate the proportion of individuals that leave the NRE each year.

Migrations

The question always is asked, "Once the fish leave the study system, where do they go?" We were fortunate enough to obtain data from other groups along the east coast conducting acoustic tracking studies providing insight into larger migrations. Eight individuals, six black drum and 2 red drum, were detected in arrays outside of the NRE. The two red drum detected outside the NRE did not travel as far as the black drum did. One fish traveled north to Morehead City, NC while the other traveled south where it was detected near Murrells Inlet, SC. Black drum however have demonstrated even greater migrations along the east coast. One individual, NR46, traveled south after departing the NRE being detected near Charleston and then near Brunswick, GA. Five months later this individual was detected in the Delaware Bay, a total distances of approximately 750 miles. This was not a singular anomaly as another individual was also recaptured by a commercial fisherman in the Delaware Bay.

In total, 17 red drum and eight black drum were recaptured by recreational anglers or commercial fishermen. Out of five red drum that were recaptured outside of the NRE, three individuals traveled south and the other two traveled north. The remaining 12 fish were recaptured in the NRE. All black drum recaptures outside of the NRE occurred north of the NRE in Swansboro, NC; Atlantic Beach, NC; and Delaware Bay, DE.

Bacheler, N.M., Paramore, L.M., Buckel, J.A., and Hightower, J.E. 2009. Abiotic and biotic factors influence the habitat use of an estuarine fish. Mar. Ecol. Prog. Ser. **377**: 263–277. doi: 10.3354/meps07805.

Bacheler, N.M., Paramore, L.M., Burdick, S.M., Buckel, J. a., and Hightower, J.E. 2009. Variation in movement patterns of red drum (Sciaenops ocellatus) inferred from conventional tagging and ultrasonic telemetry. Fish. Bull. **107**: 405–419.

Brown, K.M., George, G.J., Peterson, G.W., Thompson, B.A., and Cowan, J.H. 2008. Oyster predation by black drum varies spatially and seasonally. Estuaries and Coasts **31**(3): 597–604. doi: 10.1007/s12237-008-9045-8.

Christensen, V., and Maclean, J. 2011. No Title. *In* 1st edition. *Edited by*V. Christensen and J. Maclean. Cambridge University Press.

Craig, J.K., Crowder, L.B., Gray, C.D., McDaniel, C.J., Henwood, T.A., and Hanifen, J.G. 2001. Ecological Effects of Hypoxia on Fish and Marine Mammals in the Northwestern Gulf of Mexico. Coast. Hypoxia Consequences Living Resour. Ecosyst.: 269–292.

Ensign, S.H., Halls, J.N., and Mallin, M.A. 2004. Application of digital bathymetry data in an analysis of flushing times of two large estuaries. Comput. Geosci. **30**(5): 501–511. doi: 10.1016/j.cageo.2004.03.015.

Facendola, J.J., and Scharf, F.S. 2012. Seasonal and Ontogenetic Variation in the Diet and Daily Ration of Estuarine Red Drum as Derived from Field-Based Estimates of Gastric Evacuation and Consumption. Mar. Coast. Fish. **4**(1): 546–559. doi: 10.1080/19425120.2012.699018.

George, G.J., Brown, K.M., Peterson, G.W., and Thompson, B.A. 2008. Removal of Black Drum on Louisiana Reefs to Increase Survival of Eastern Oysters Crassostrea virginica. North Am. J. Fish. Manag. **28**(6): 1802–1811. doi: 10.1577/m08-036.1.

George, G.J., and Brown, K.M. 2007. Acoustic tagging of black drum on Louisiana oyster reefs: movements, site fidelity, and habitat use. Biol. Sci. **MS**(May): 71.

Jech, J.M., Bacheler, N.M., Buckel, J. a., Hightower, J.E., Paramore, L.M., and Pollock, K.H. 2009. A combined telemetry – tag return approach to estimate fishing and natural mortality rates of an estuarine fish. Can. J. Fish. Aquat. Sci. **66**(8): 1230–1244. doi: 10.1139/F09-076.

Jech, J.M., Bacheler, N.M., Buckel, J. a., Hightower, J.E., Paramore, L.M., and Pollock, K.H. 2009. A combined telemetry – tag return approach to estimate fishing and natural mortality rates of an estuarine fish. Can. J. Fish. Aquat. Sci. **66**(8): 1230–1244. doi: 10.1139/F09-076.

Mowen, J.C., and Cialdini, R.B. 2016. Linked references are available on JSTOR for this article : On Implementing the Door-in-the-Face Compliance Technique in a Business. **17**(2): 253–258.

Nagelkerken, I., Sheaves, M., Baker, R., and Connolly, R.M. 2015. The seascape nursery: A novel spatial approach to identify and manage nurseries for coastal marine fauna. Fish Fish. **16**(2): 362–371. doi: 10.1111/faf.12057.

Reyier, E. a., Lowers, R.H., Scheidt, D.M., and Adams, D.H. 2011. Movement patterns of adult red drum, Sciaenops ocellatus, in shallow Florida lagoons as inferred through autonomous acoustic telemetry. Environ. Biol. Fishes **90**: 343–360. doi: 10.1007/s10641-010-9745-3.

Secor, D.H. 1999. Specifying divergent migrations in the concept of stock: The contingent hypothesis. Fish. Res. **43**(1–3): 13–34. doi: 10.1016/S0165-7836(99)00064-8.

Serafy, J.E., Valle, M., Faunce, C.H., and Luo, J. 2007. Species-specific patterns of fish abundance and size along a subtropical mangrove shoreline: An application of the delta approach. Bull. Mar. Sci. **80**(3): 609–624.

Street, G.T., Montagna, P.A., and Parker, P.L. 1997. Incorporation of brown tide into an estuarine food web. Mar. Ecol. Prog. Ser. **152**(1–3): 67–78. doi: 10.3354/meps152067.

FIGURES

Figure 1. Map of the New River Estuary (NRE) showing locations of hydrophones, cultch reefs, and water quality stations. Lines indicate section dividers for grouping hydrophones for water quality analysis.

Figure 2. Number of fish in the system per month during the study for A) red drum and B) black drum. Number of fish was calculated based on when new fish were tagged and released, when fish knowingly exited the NRE, when fish were harvested, and when fish knowingly returned.

Figure 3. Mean DPUE for both red drum (dark bars) and black drum (light bars) at the restored cultch sites and the reference sites.

Figure 4. Mean DPUE for red drum at AR-398 and the associated reference site.

Figure 5. Mean DPUE for black drum at AR-398 and the associated reference site.

Figure 6. Mean DPUE for red drum at individual cultch (dark bars) and reference (light bars) sites in the NRE.

Figure 7. Mean DPUE for black drum at individual cultch (dark bars) and reference (light bars) sites in the NRE.

Figure 8. Density of non-oyster bivalves in cores collected from each cultch (light bars) and reference (dark bars) site in the NRE.

Figure 9. Density of crustaceans in cores collected from each cultch (light bars) and reference (dark bars) site in the NRE.

Figure 10. Density of soft-body infauna in cores collected from each cultch (light bars) and reference (dark bars) site in the NRE.

Figure 11. Densities of live adult oysters found in quadrat samples from the six restored cultch sites in the NRE.

Figure 12. Densities of oyster spat found in quadrat samples from the six restored cultch sites in the NRE.

Figure 13. Densities of non-oyster bivalves found in quadrat samples from the six restored cultch sites in the NRE. Due to sampling error, there is no data for non-oyster bivalves from station 29. The station is left in the graph, noted by ND (no data), however it was not included in statistical analysis.

Figure 14. Densities of crustaceans found in quadrat samples from the six restored cultch sites in the NRE. Due to sampling error, there is no data for crustaceans from station 29. The station is left in the graph, noted by ND (no data), however it was not included in statistical analysis.

Figure 15. Densities of soft body infauna found in quadrat samples from the six restored cultch sites in the NRE. Due to sampling error, there is no data for soft body infauna from station 29. The station is left in the graph, noted by ND (no data), however it was not included in statistical analysis.

Figure 16. Scatter plot of mean DPUE versus the size (number of bushels) of reef at each cultch site for red drum (black circles) and black drum (black triangles). Linear trend lines lines are shown for each species with corresponding R-squared values.

Figure 17. Density heat maps showing interpolated data collected in the NRE between September 2012 and November 2015 for DPUE (red drum), salinity, temperature (temp), and dissolved oxygen (DO). Color codes are log scale for detection plots. Blank spaces for water quality indicate that no data was collected for that month. If no fish were detected during a month, the block will indicate "no detections".

Figure 18. Density heat maps showing interpolated data collected in the NRE between September 2012 and November 2015 for DPUE (black drum), salinity, temperature (temp), and dissolved oxygen (DO). Color codes are log scale for detection plots. Blank spaces for water quality indicate that no data was collected for that month. If no fish were detected during a month, the block will indicate "no detections".

Figure 19. Scatterplots for red drum mean DPUE versus salinity during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 20. Scatterplots for black drum mean DPUE versus salinity during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 21. Scatterplots for red drum mean DPUE versus temperature during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 22. Scatterplots for black drum mean DPUE versus salinity during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 23. Scatterplots for red drum mean DPUE versus dissolved oxygen during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 24. Scatterplots for black drum mean DPUE versus dissolved oxygen during spring, summer, fall, and winter. Each data point represents a single month during corresponding seasons of the year.

Figure 25. Seasonal DPUE patterns within the NRE for A) red drum and B) black drum. Sections of the creek on the y-axis reflect actual location in the NRE from north to south.

Figure 26. Patterns of the proportion of individual red drum (dark bars) and black drum (grey bars) identified as either exiting the system and not returning, exiting the system and returning the next season, or staying in the system throughout the winter.

Figure 27. Mean size (total length) of A) red drum and B) black drum for each of the three residency behaviors observed.

Figure 28. Patterns of the proportion of individual red drum tagged and released in the upper river (dark bars) and lower river (grey bars) for each of the three residency behaviors observed.

Figure 29. Mean size (total length) of red drum tagged and released in the upper river (dark bars) and lower river (grey bars) for each of the three residency behaviors observed.

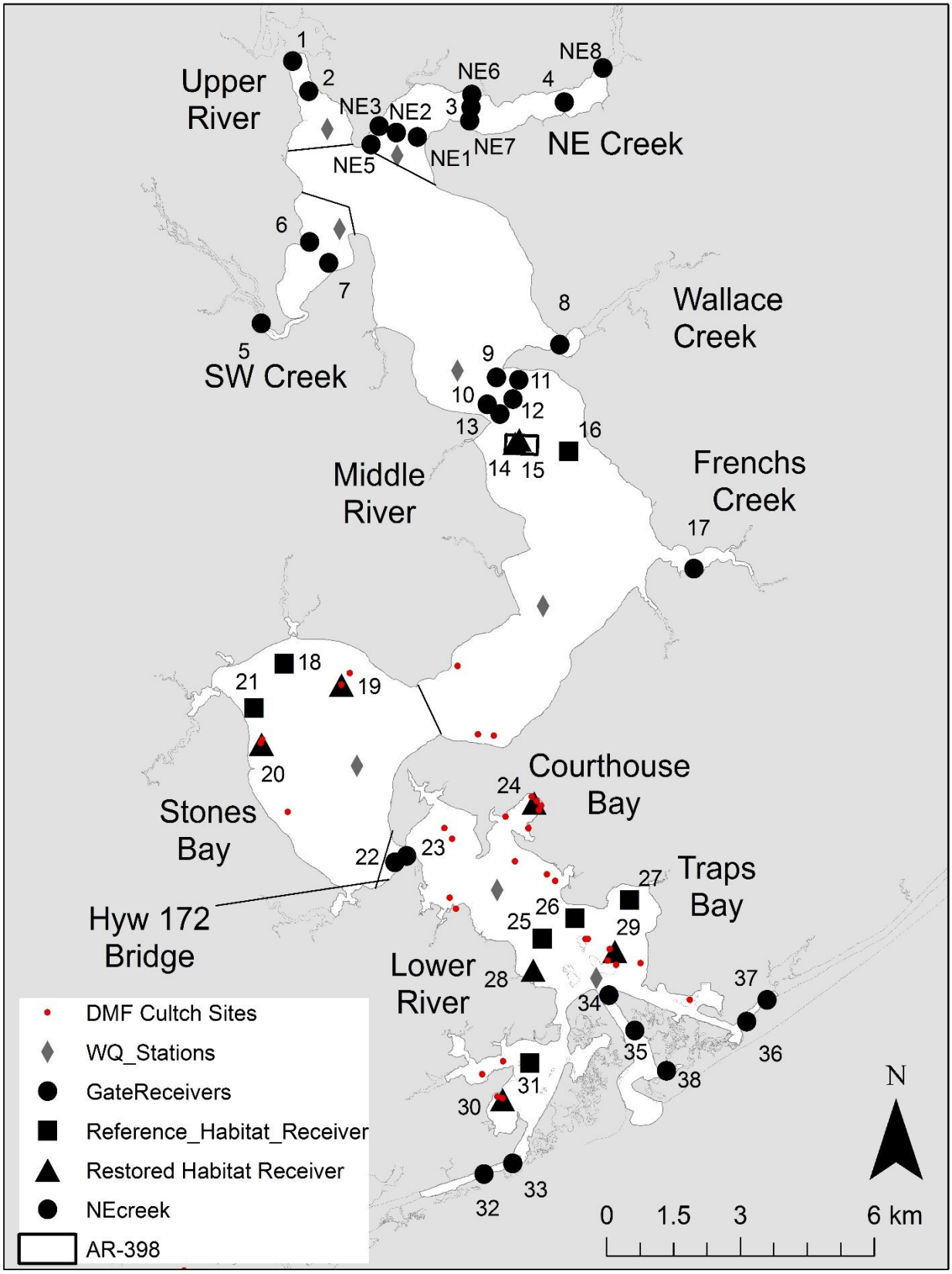
TABLES

Table 1. Details of the six restored cultch stations. Cultch sites listed are those that are within a 500 meter detection range of the hydrophone located at that station.

Table 2. Table of red drum tagged and released in the study. Release location identifies weather the fish was tagged in the upper (north of hwy 172 bridge) or lower (south of hwy 172 bridge). Initials representing recapture locations and other locations detected are: LNRE (lower new river estuary), UNRE (upper new river estuary), WB (Wrightsville Beach, NC), SW (Swansboro, NC), SB (Sunset Beach, SC), MI (Murrell's Inlet, SC), SC (Surf City, NC), MC (Morehead City, NC), CB (Chesapeake Bay), CH (Charleston, SC), GA (Georgia), DB (Delaware Bay), and AB (Atlantic Beach, NC). Fish highlighted in grey bars indicate individuals that were recaptured by fisherman. Fish ID's with an asterisk beside it indicate fish that were caught by anglers and released alive. Entries in bold are fish that were captured via hook and line while all other entries were captured using gillnet.

Table 3. Table of black drum tagged and released in the study. Release location identifies weather the fish was tagged in the upper (north of hwy 172 bridge) or lower (south of hwy 172 bridge). Initials representing recapture locations and other locations detected are: LNRE (lower new river estuary), UNRE (upper new river estuary), WB (Wrightsville Beach, NC), SW (Swansboro, NC), SB (Sunset Beach, SC), MI (Murrell's Inlet, SC), SC (Surf City, NC), MC (Morehead City, NC), CB (Chesapeake Bay), CH (Charleston, SC), GA (Georgia), DB (Delaware Bay), and AB (Atlantic Beach, NC). Fish highlighted in grey bars indicate individuals that were recaptured by fisherman. Fish ID's with an asterisk beside it indicate fish that were caught by fisherman and released alive.

Figure 1


Upper River
NE Creek
Wallace Creek
SW Creek
Middle River
Frenchs Creek
Stones Bay
Courthouse Bay
Traps Bay
Hyw 172 Bridge
Lower River
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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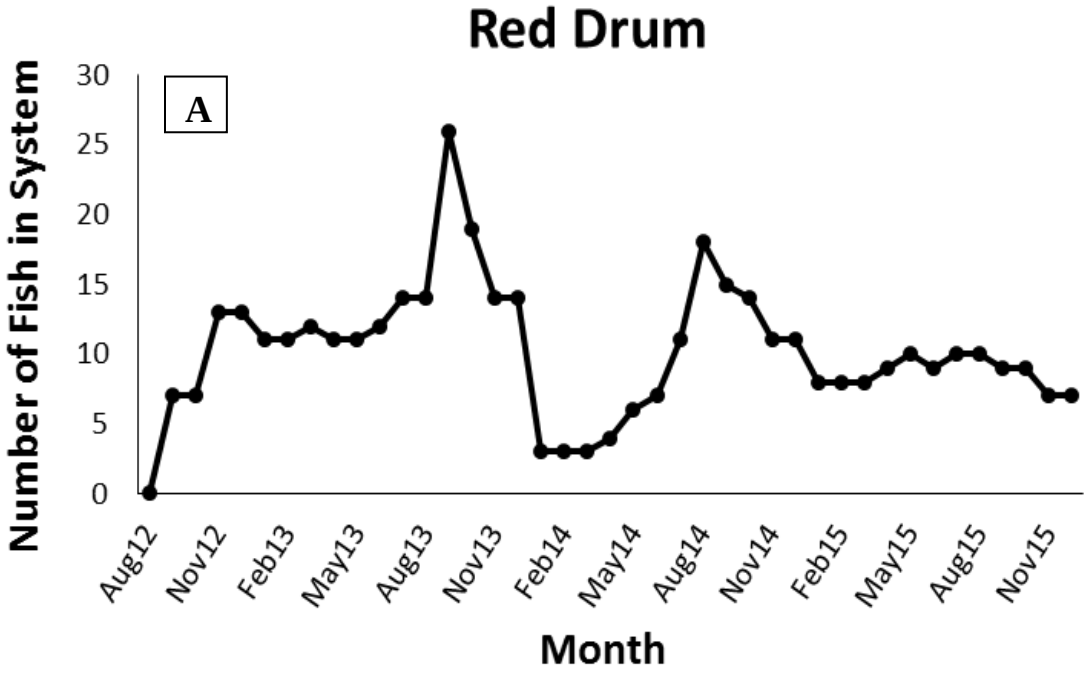
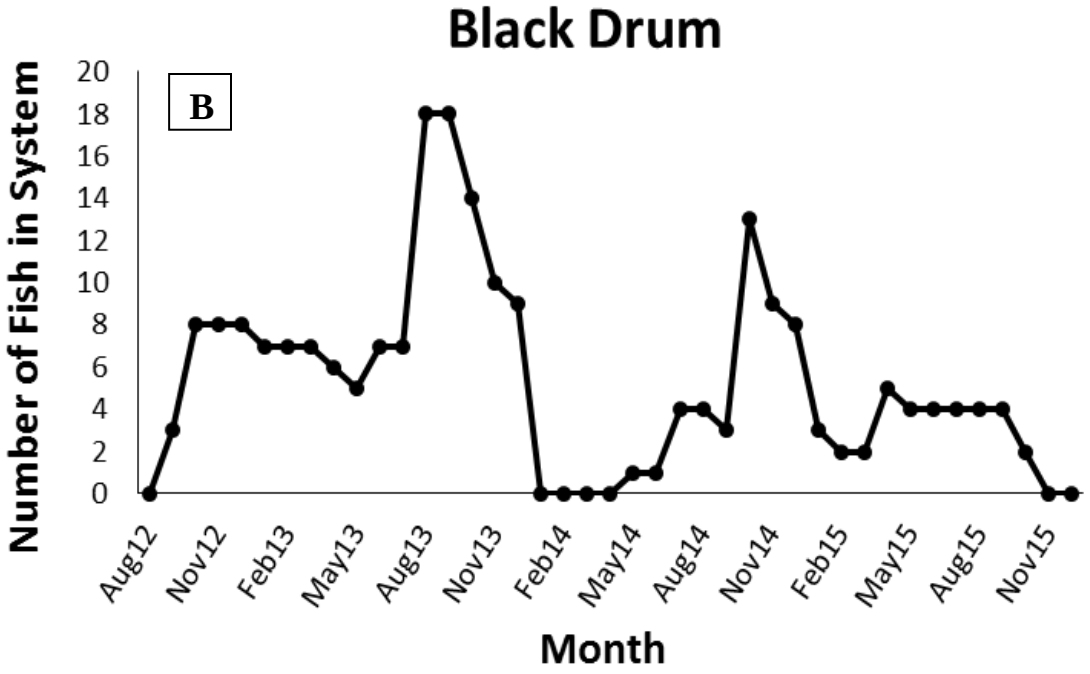
30
31
32
33
34
35
36
37
38
NE1
NE2
NE3
NE5
NE6
NE7
NE8
DMF Cultch Sites
WQ_Stations
GateReceivers
Reference_Habitat_Receiver
Restored Habitat Receiver
NEcreek
AR-398
N
0
1.5
3
6 km

Figure 2


Red Drum
A
Number of Fish in System
30
25
20
15
10
5
0
Aug12
Nov12
Feb13
May13
Aug13
Nov13
Feb14
May14
Aug14
Nov14
Feb15
May15
Aug15
Nov15
Month


Black Drum
B
Number of Fish in System
20
18
16
14
12
10
8
6
4
2
0
Aug12
Nov12
Feb13
May13
Aug13
Nov13
Feb14
May14
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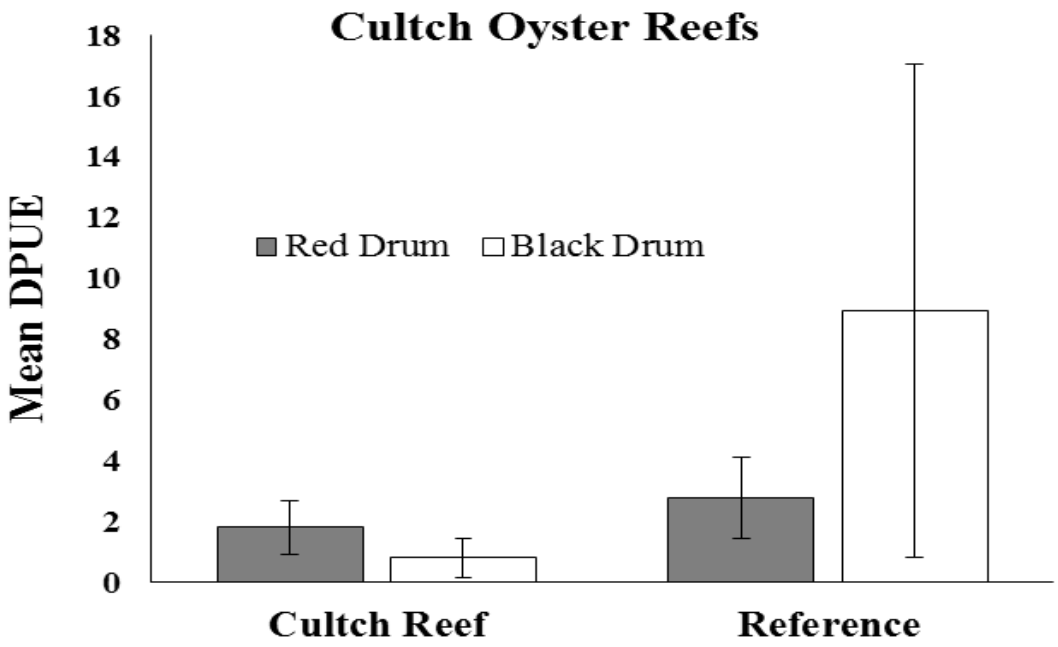
May15
Aug15
Nov15
Month

Figure 3.



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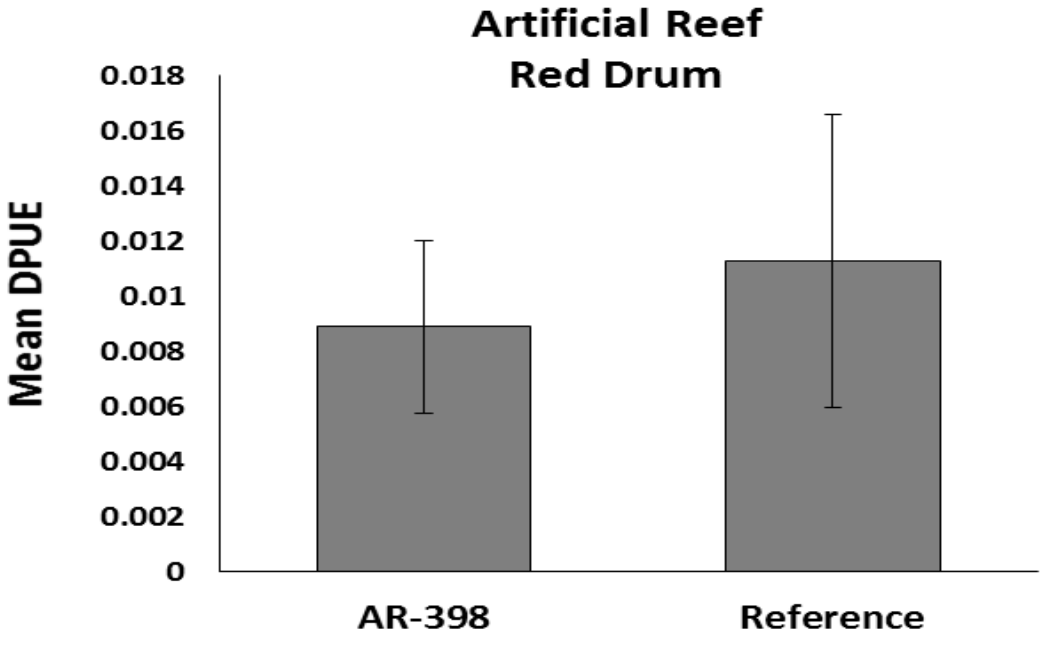

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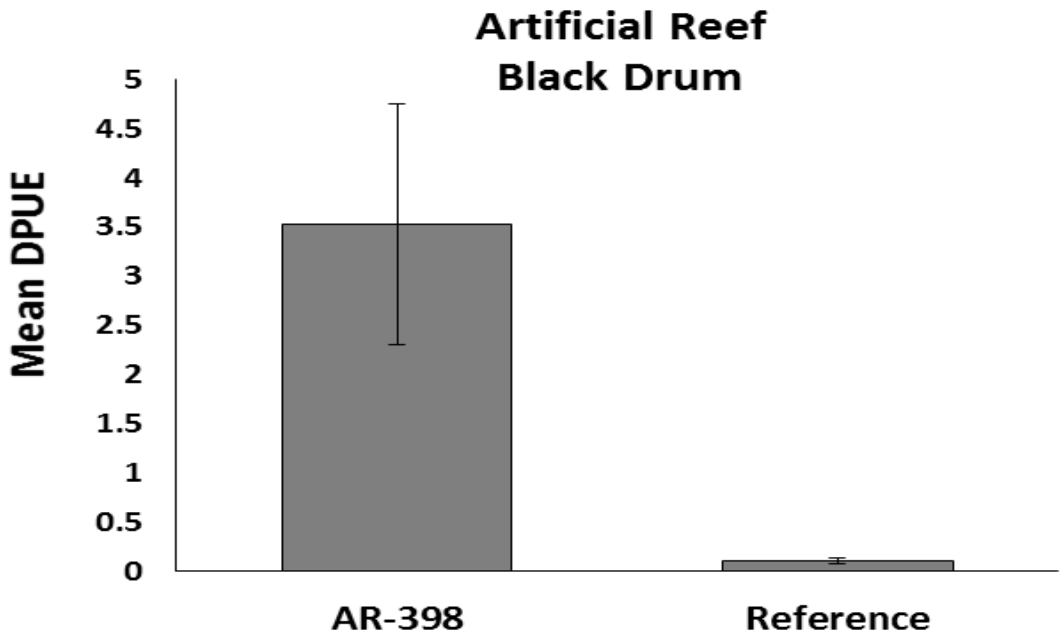

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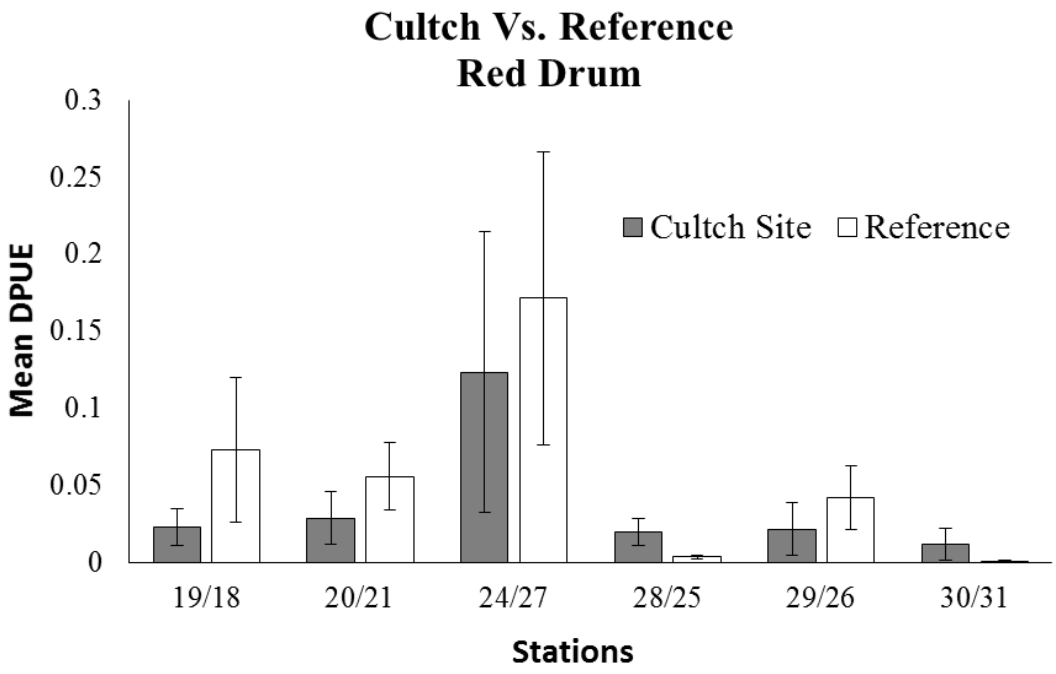

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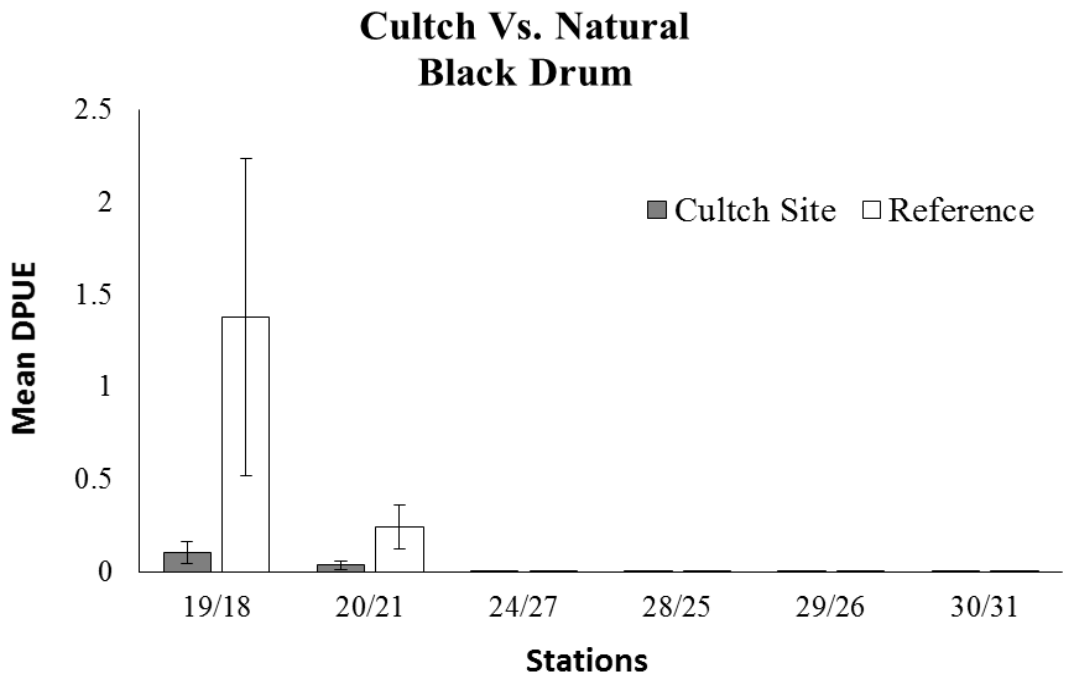

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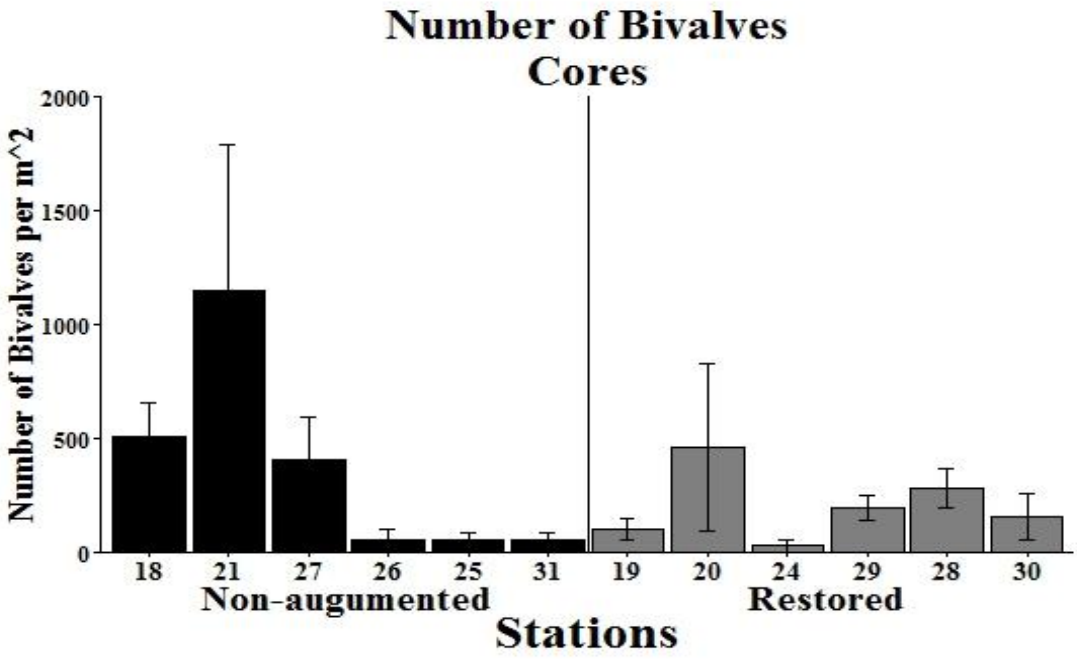

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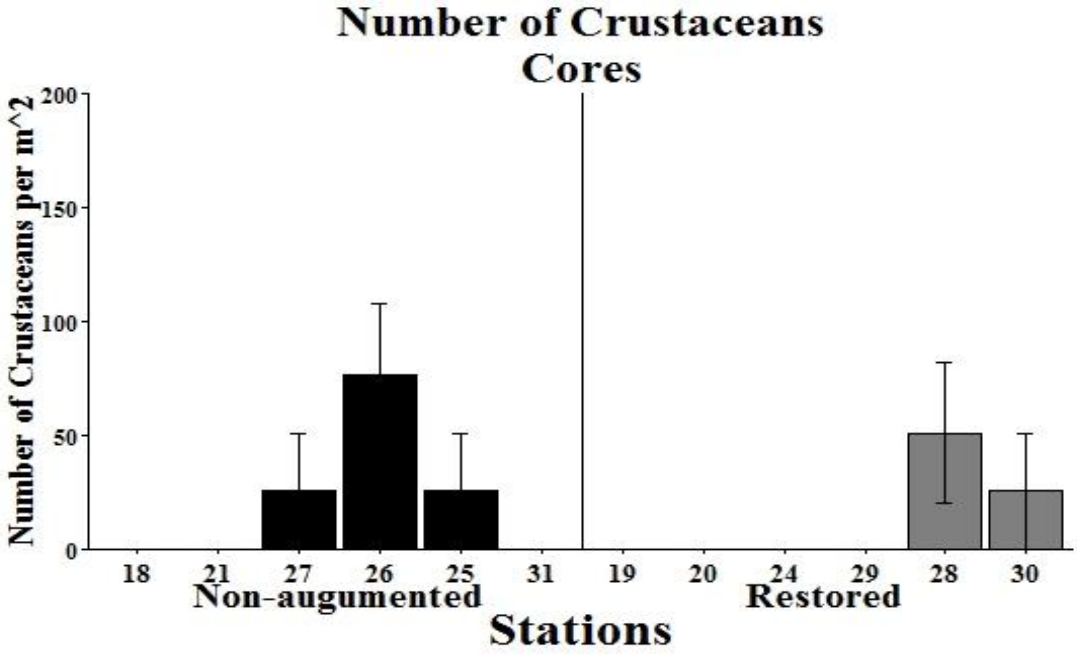
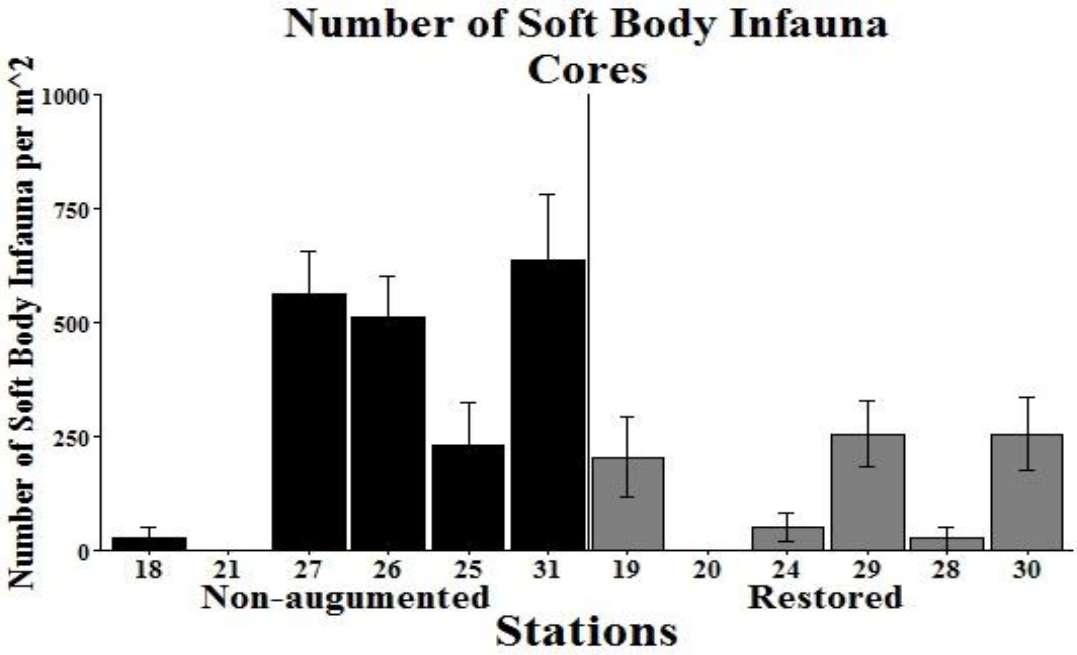


Figure 10



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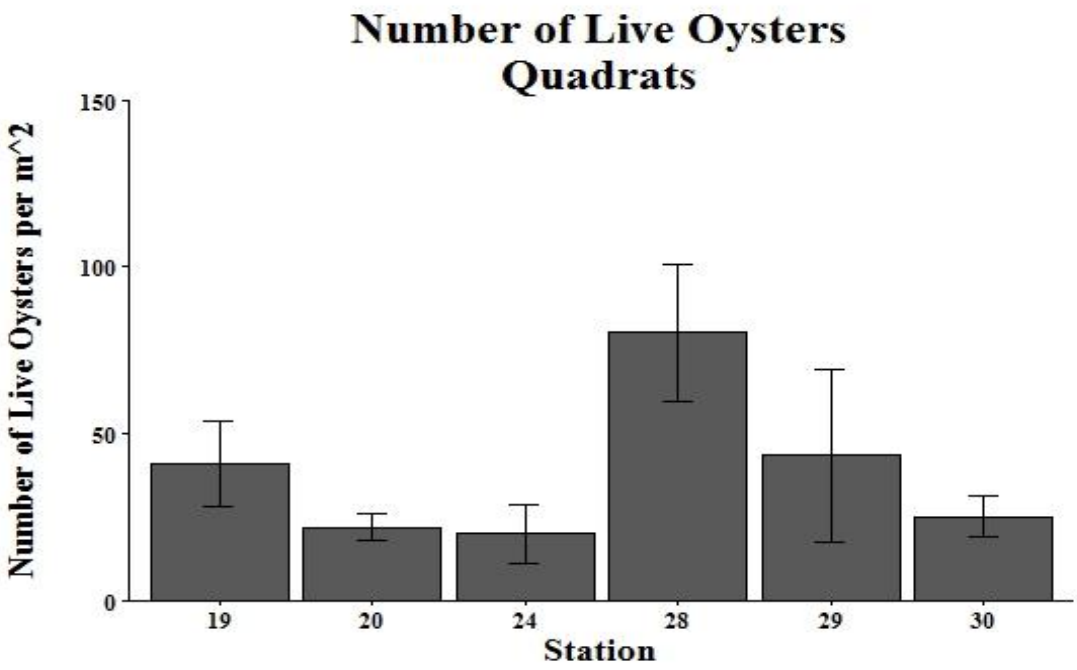


Figure 12

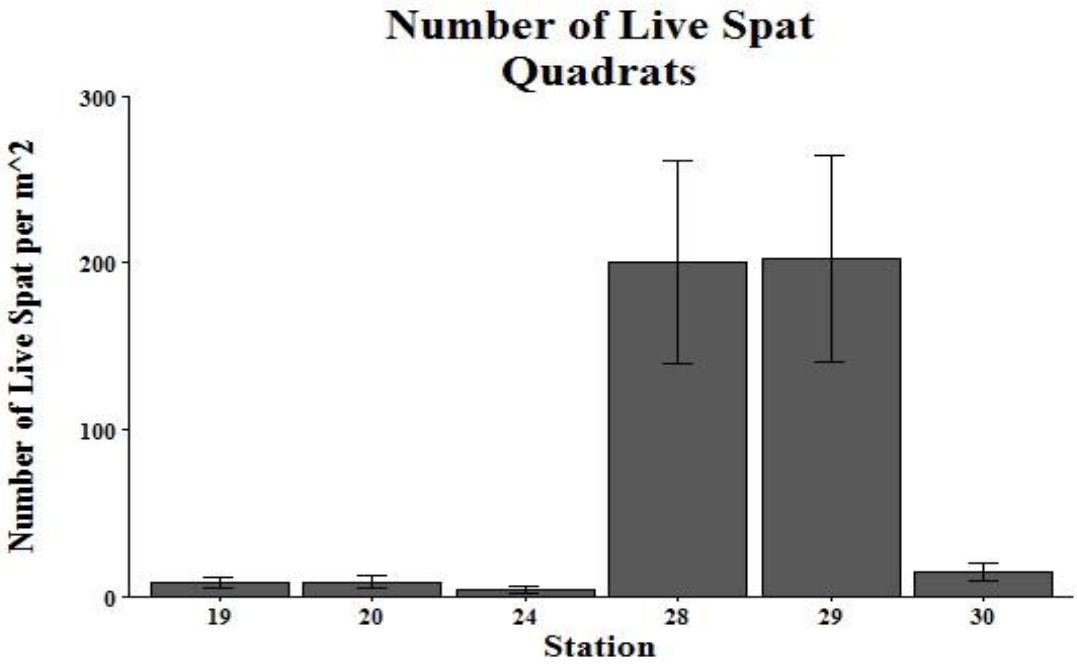


Figure 13

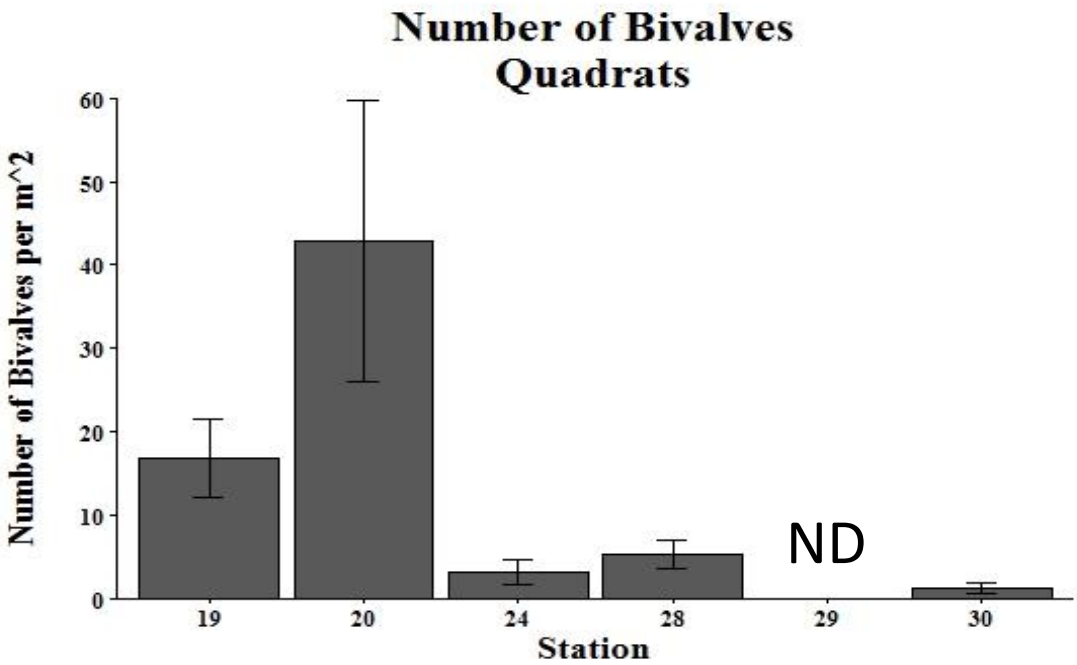


Figure 14

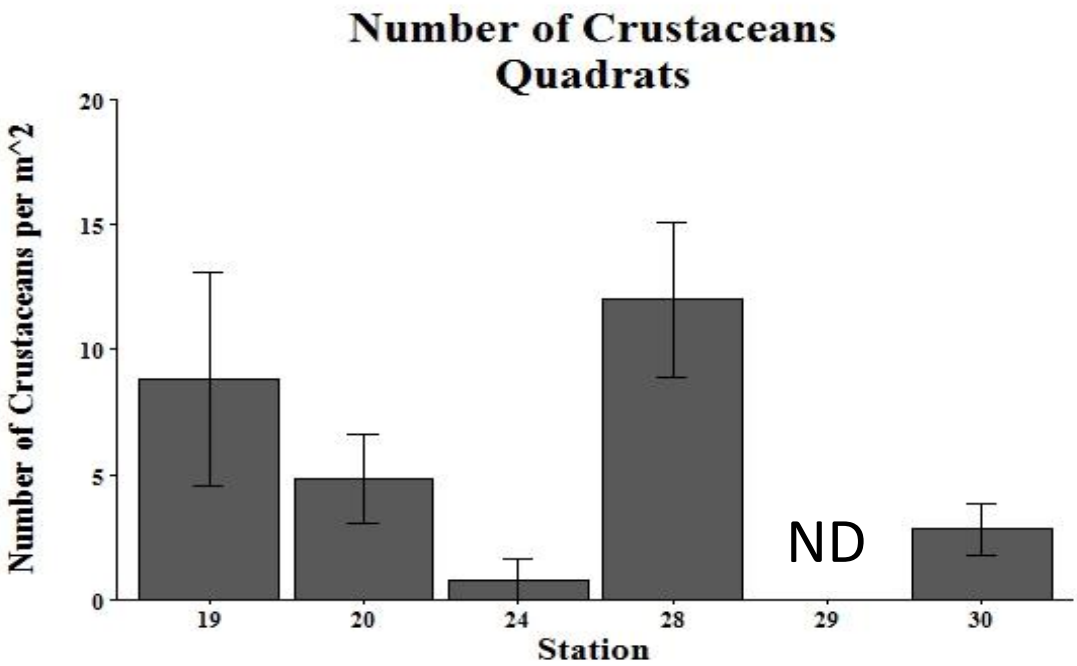


Figure 15

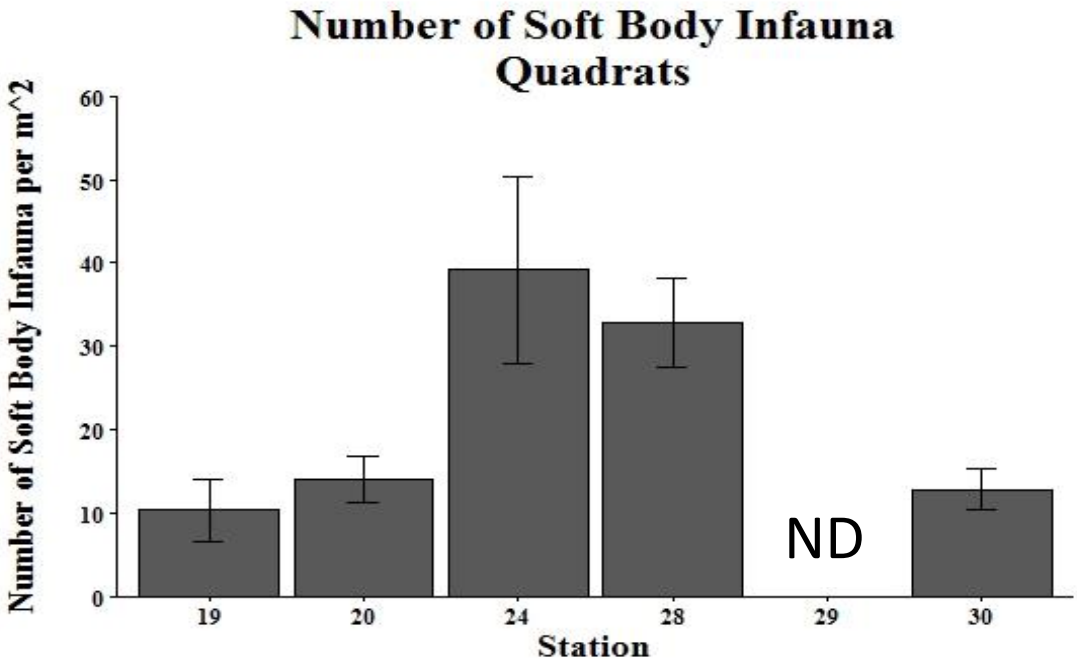


Figure 16

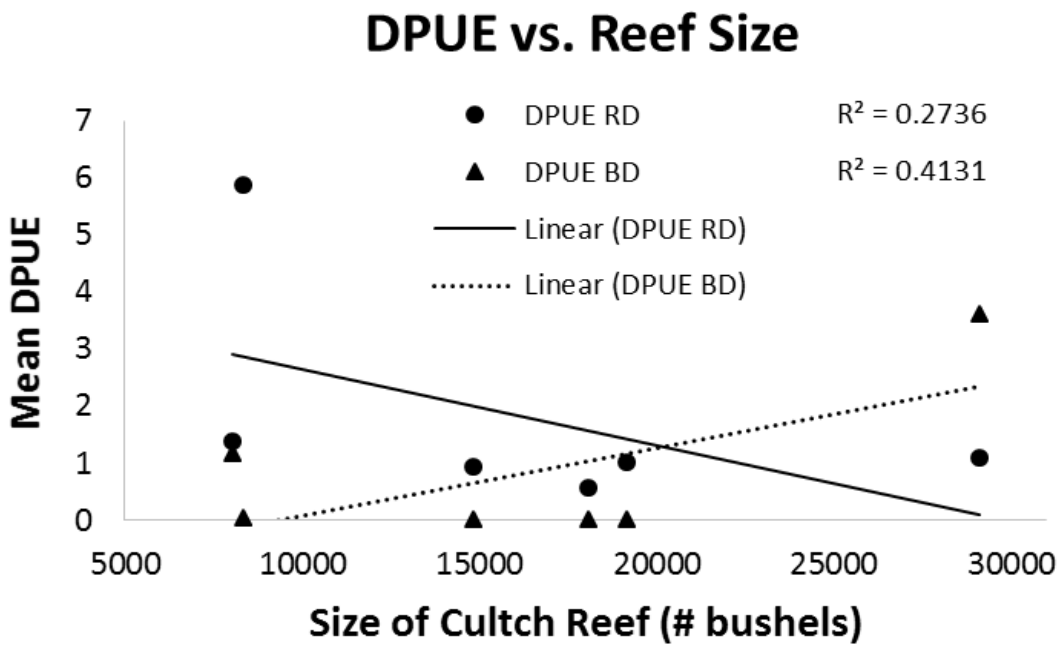
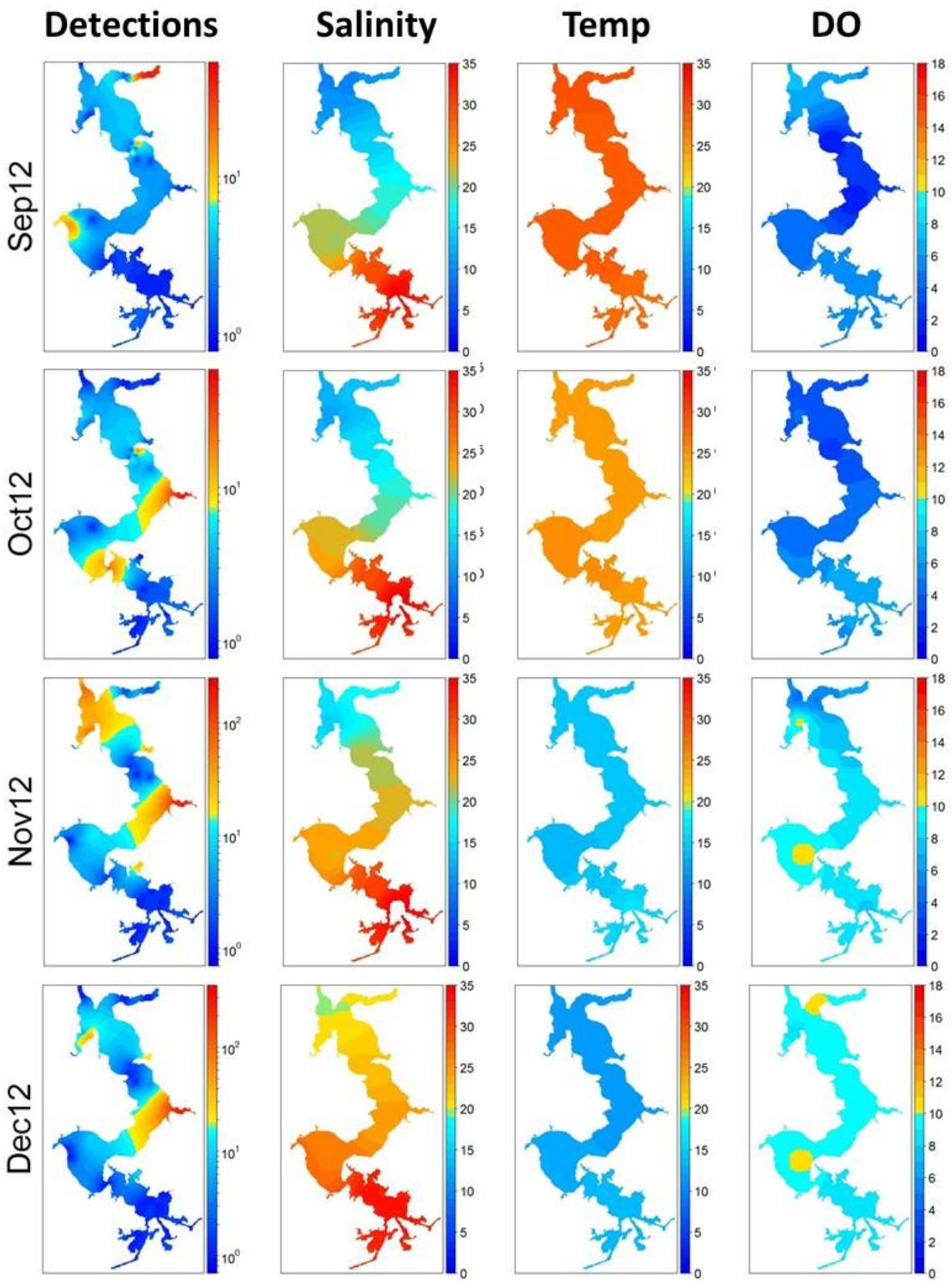
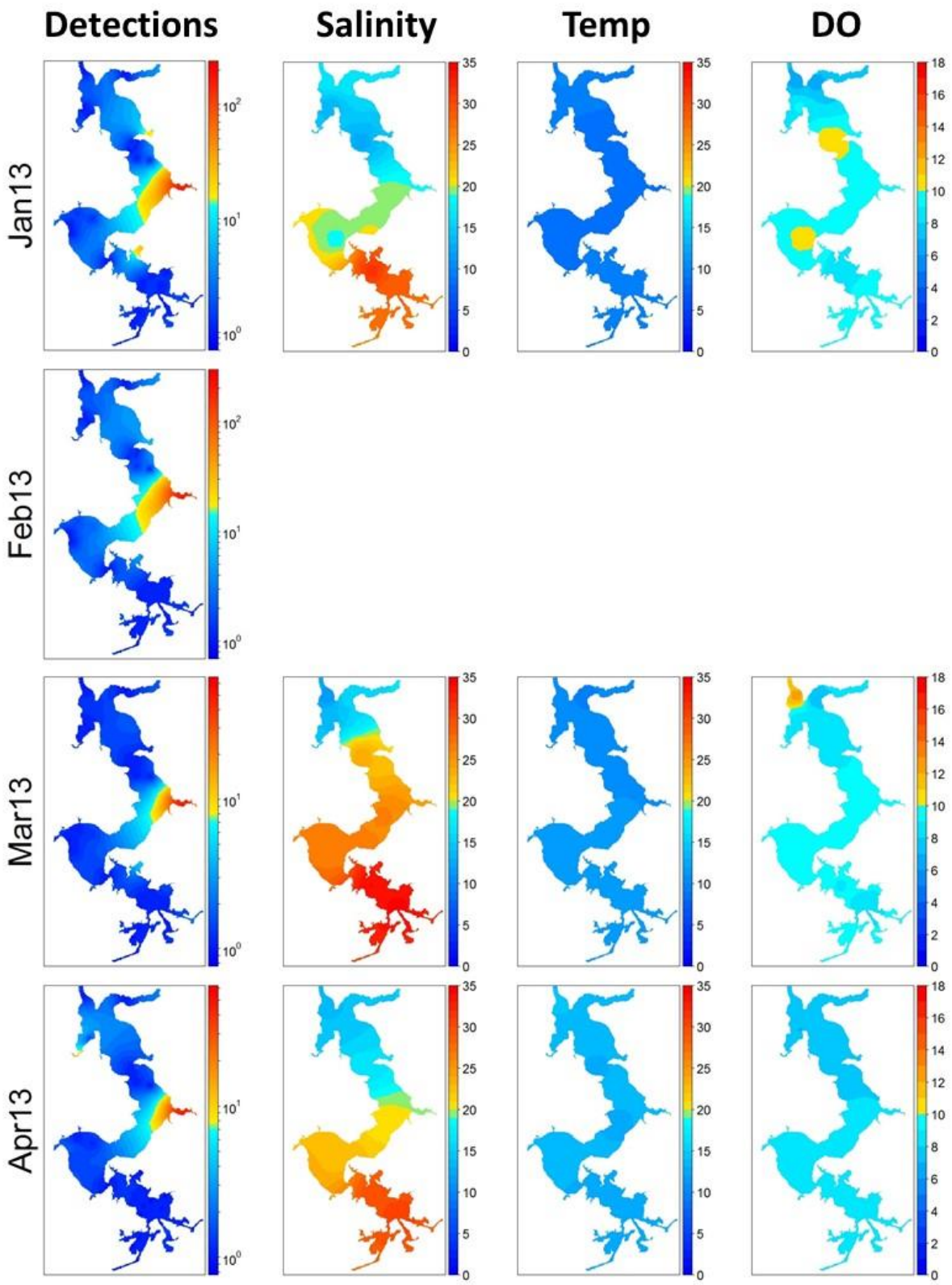
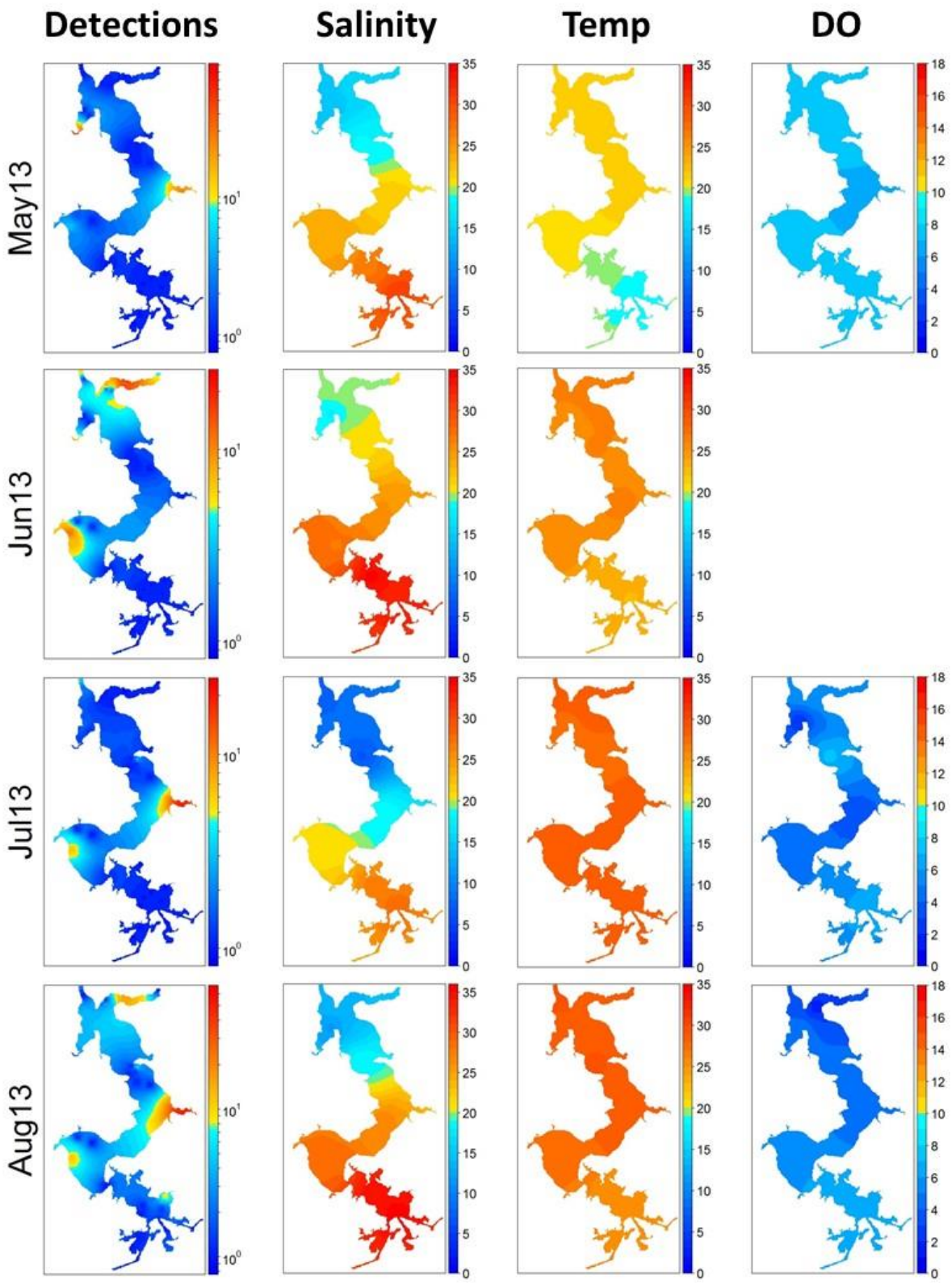


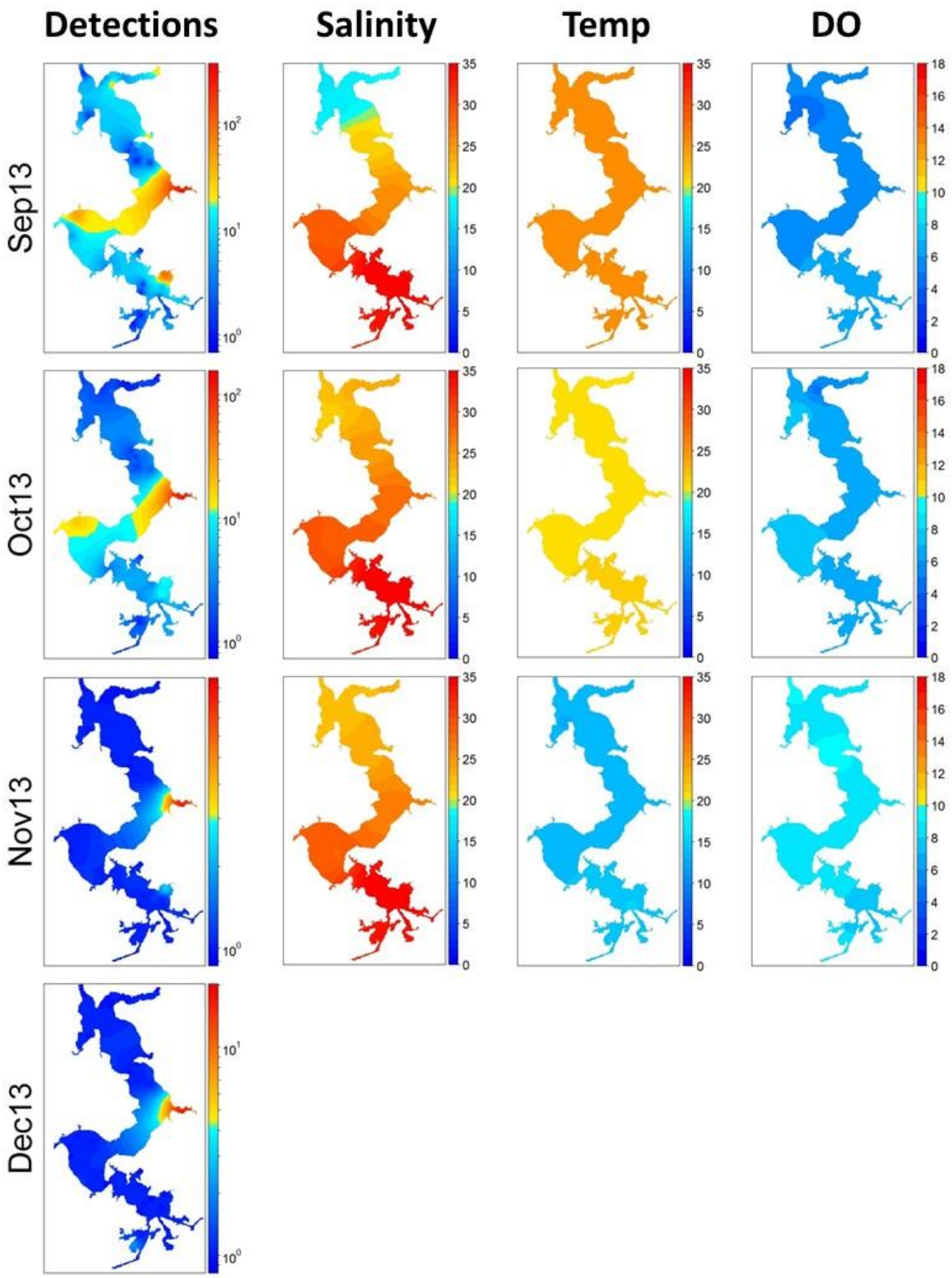
Figure 17

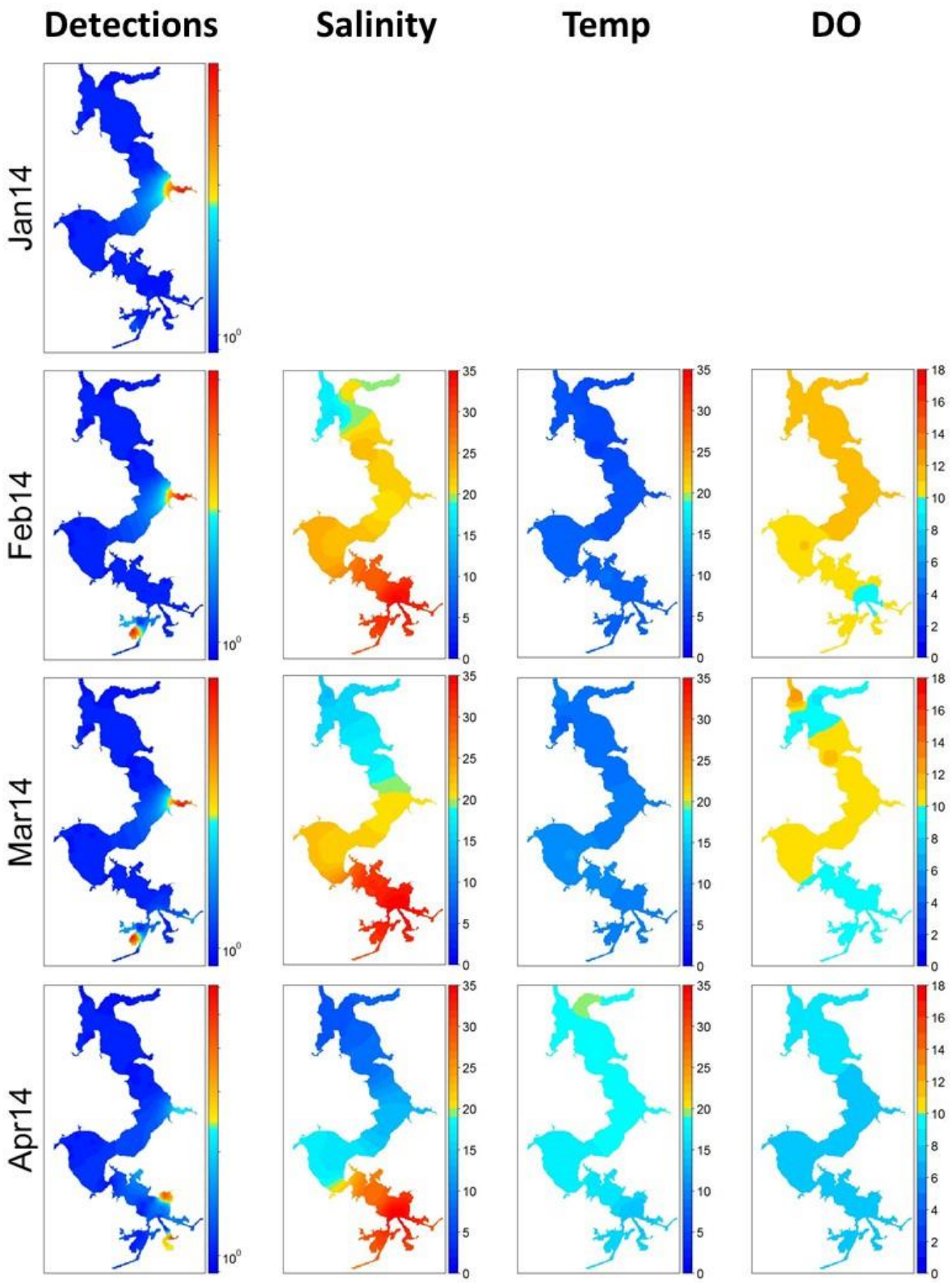
Red Drum

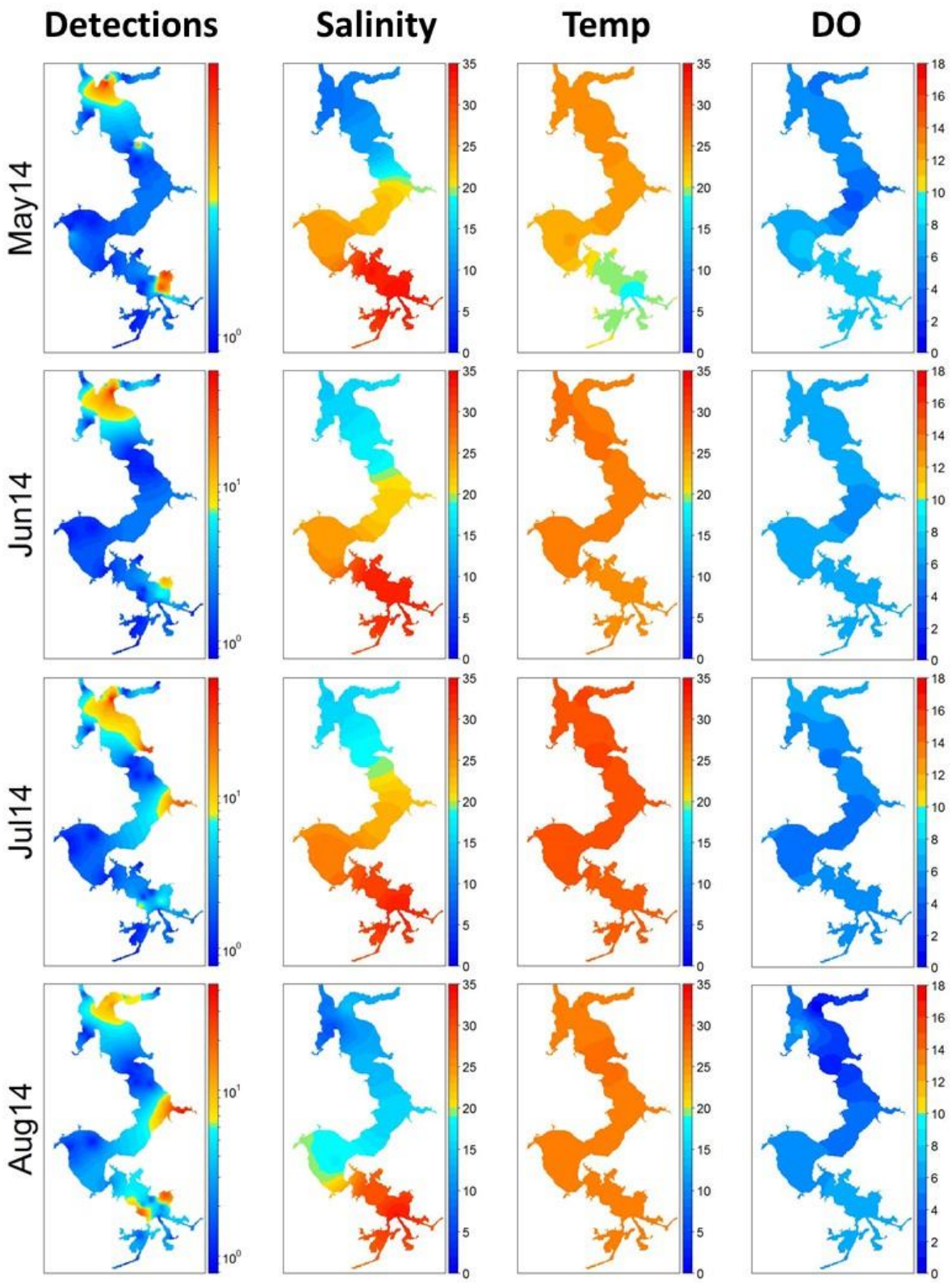

Detections
Salinity
Temp
DO
Sep12
Oct12
Nov12
Dec12

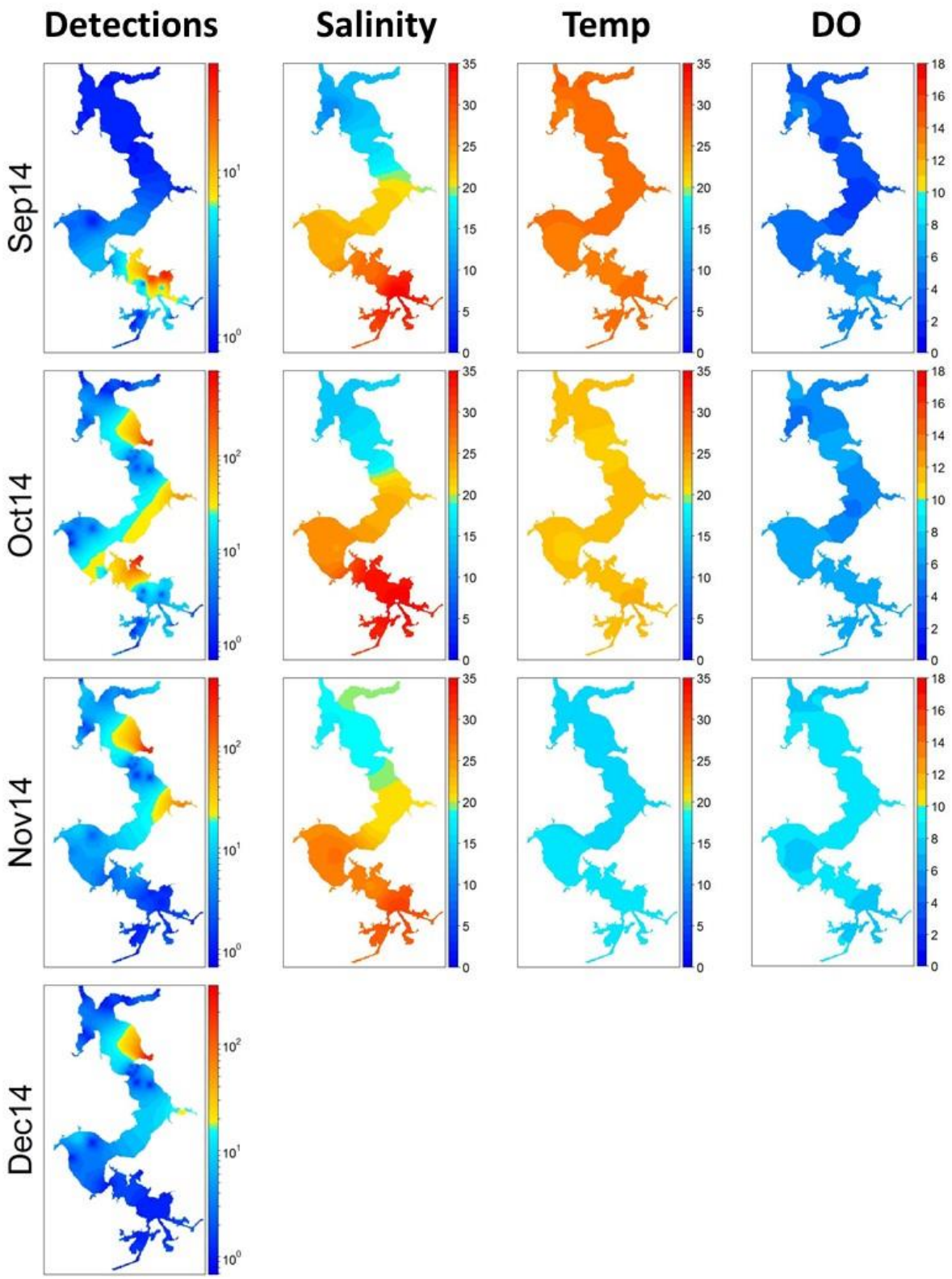

Detections
Salinity
Temp
DO
Jan13
Feb13
Mar13
Apr13

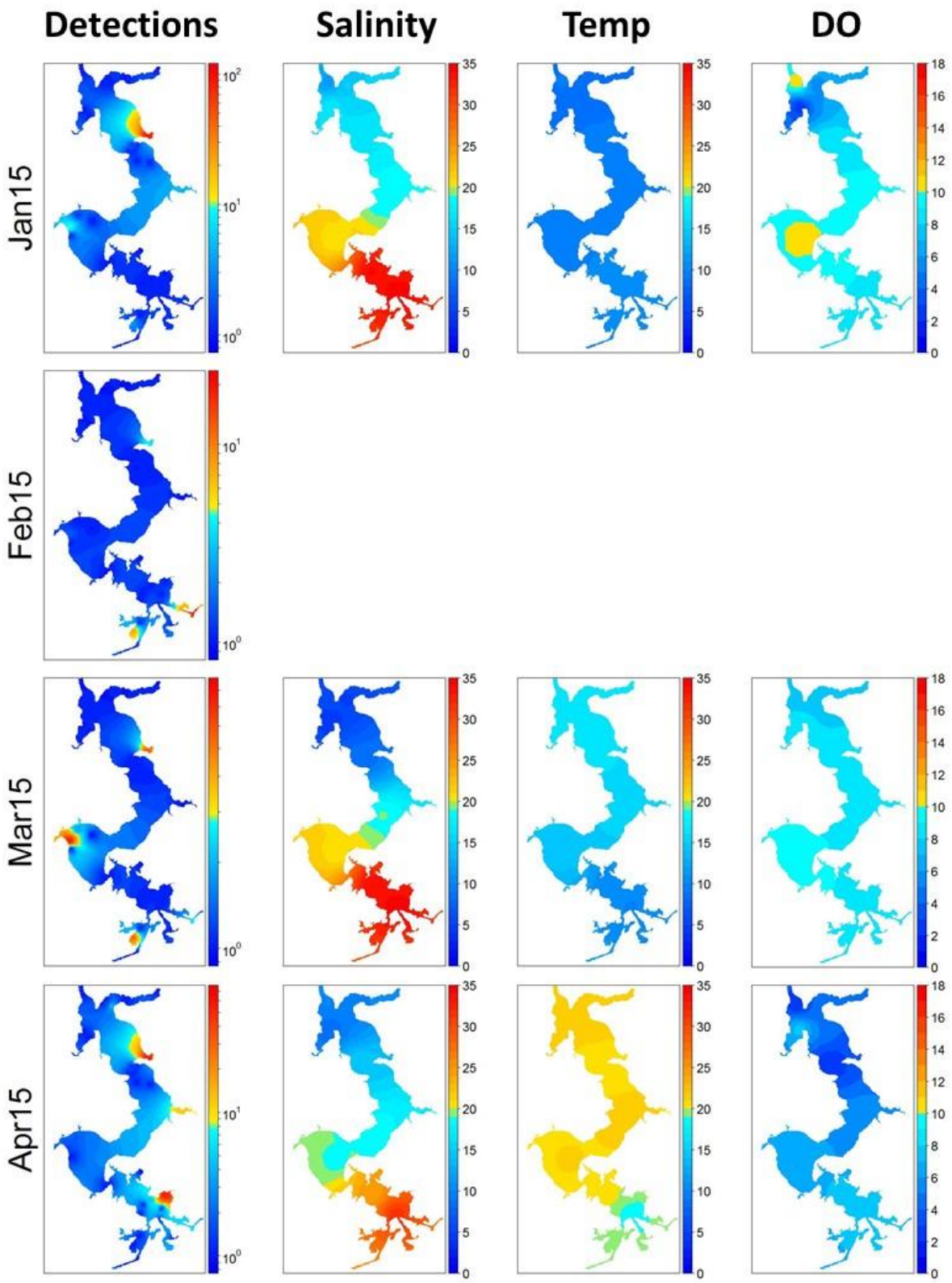

Detections
Salinity
Temp
DO
May13
Jun13
Jul13
Aug13

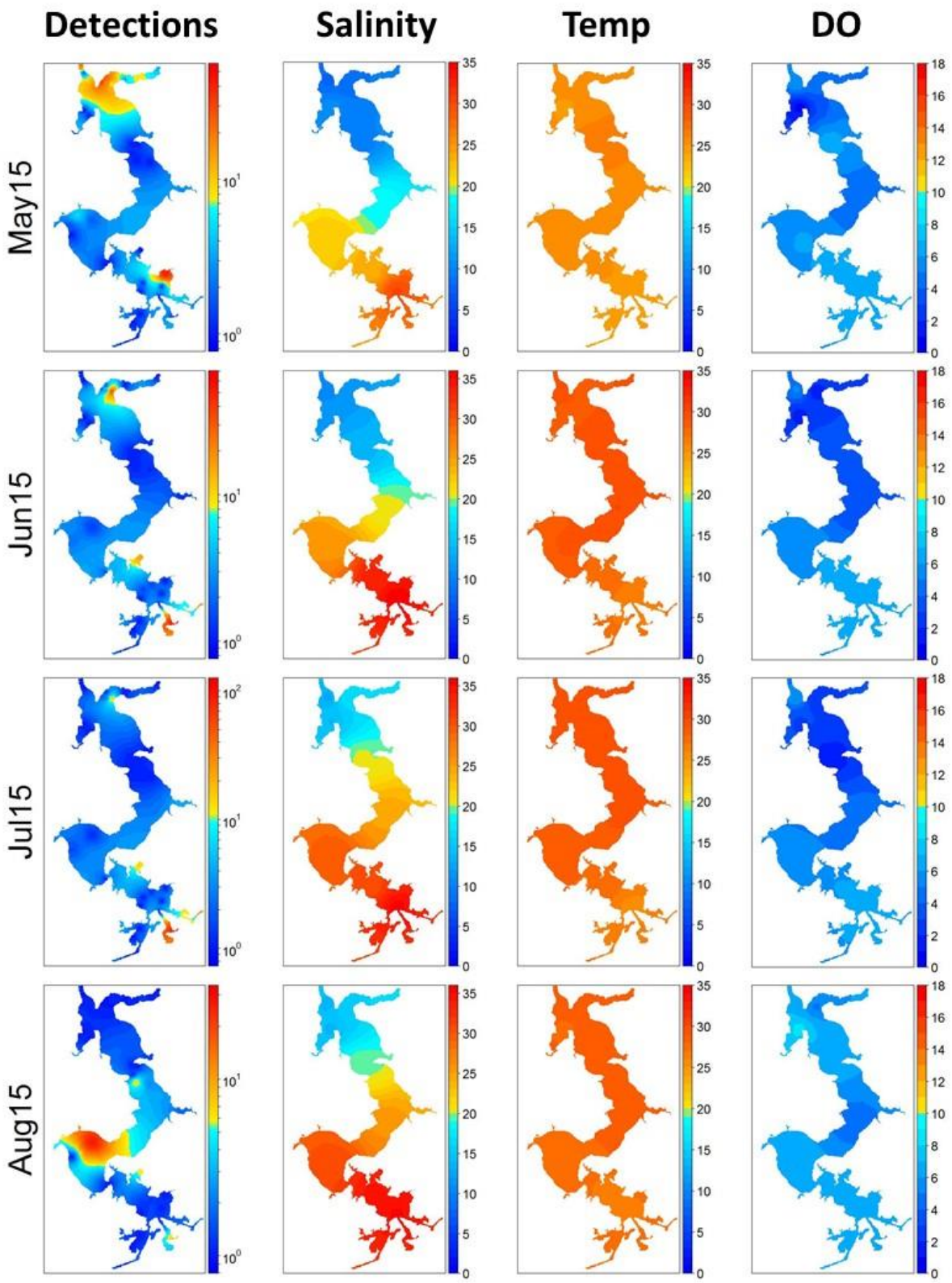

Detections
Salinity
Temp
DO
Sep13
Oct13
Nov13
Dec13


Detections
Salinity
Temp
DO
Jan14
Feb14
Mar14
Apr14
10^0
35
30
25
20
15
10
5
0
18
16
14
12
10
8
6
4
2
0


Detections
Salinity
Temp
DO
May14
Jun14
Jul14
Aug14


Detections
Salinity
Temp
DO
Sep14
Oct14
Nov14
Dec14


Detections
Salinity
Temp
DO
Jan15
Feb15
Mar15
Apr15


Detections
Salinity
Temp
DO
May15
Jun15
Jul15
Aug15

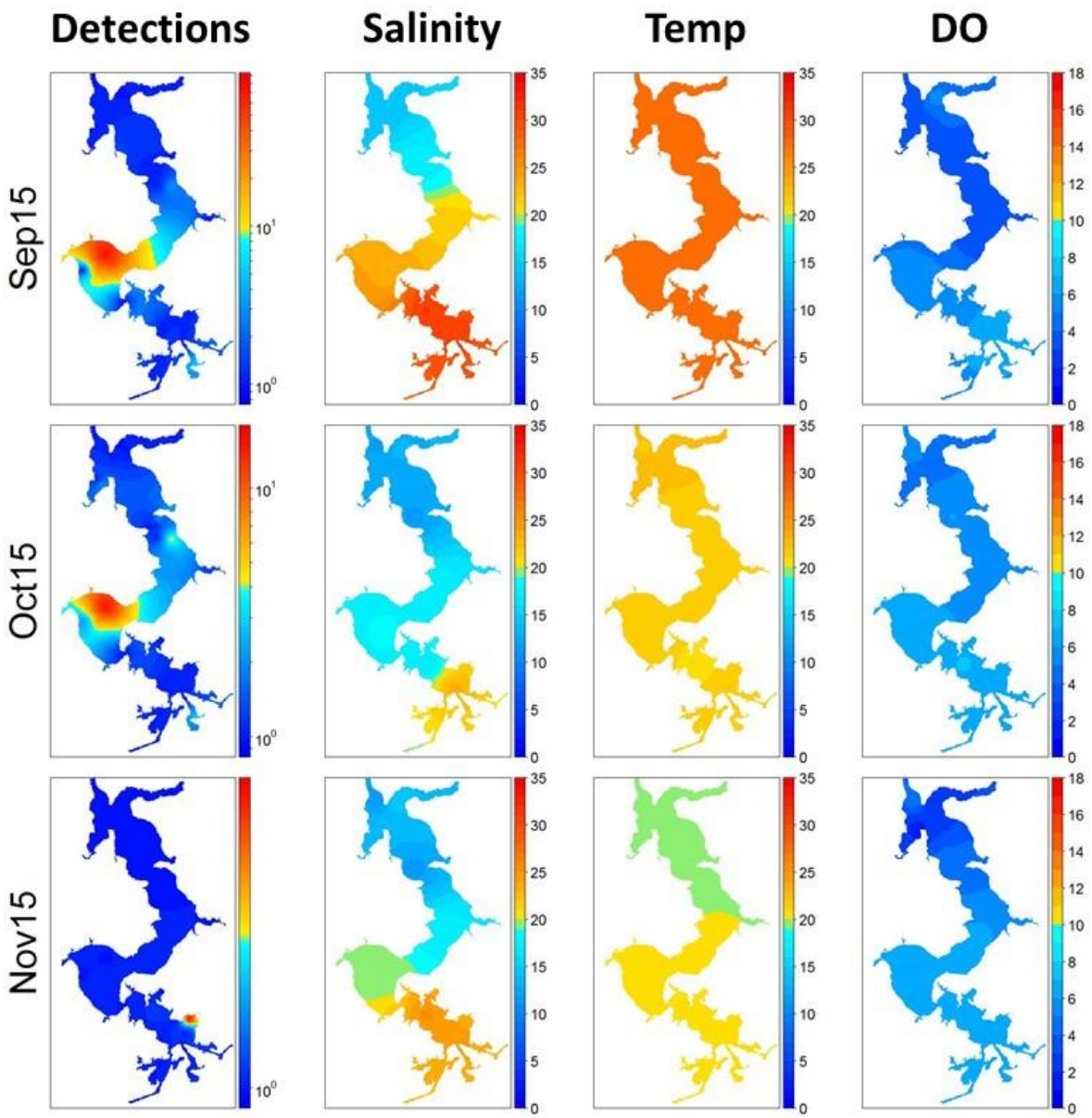
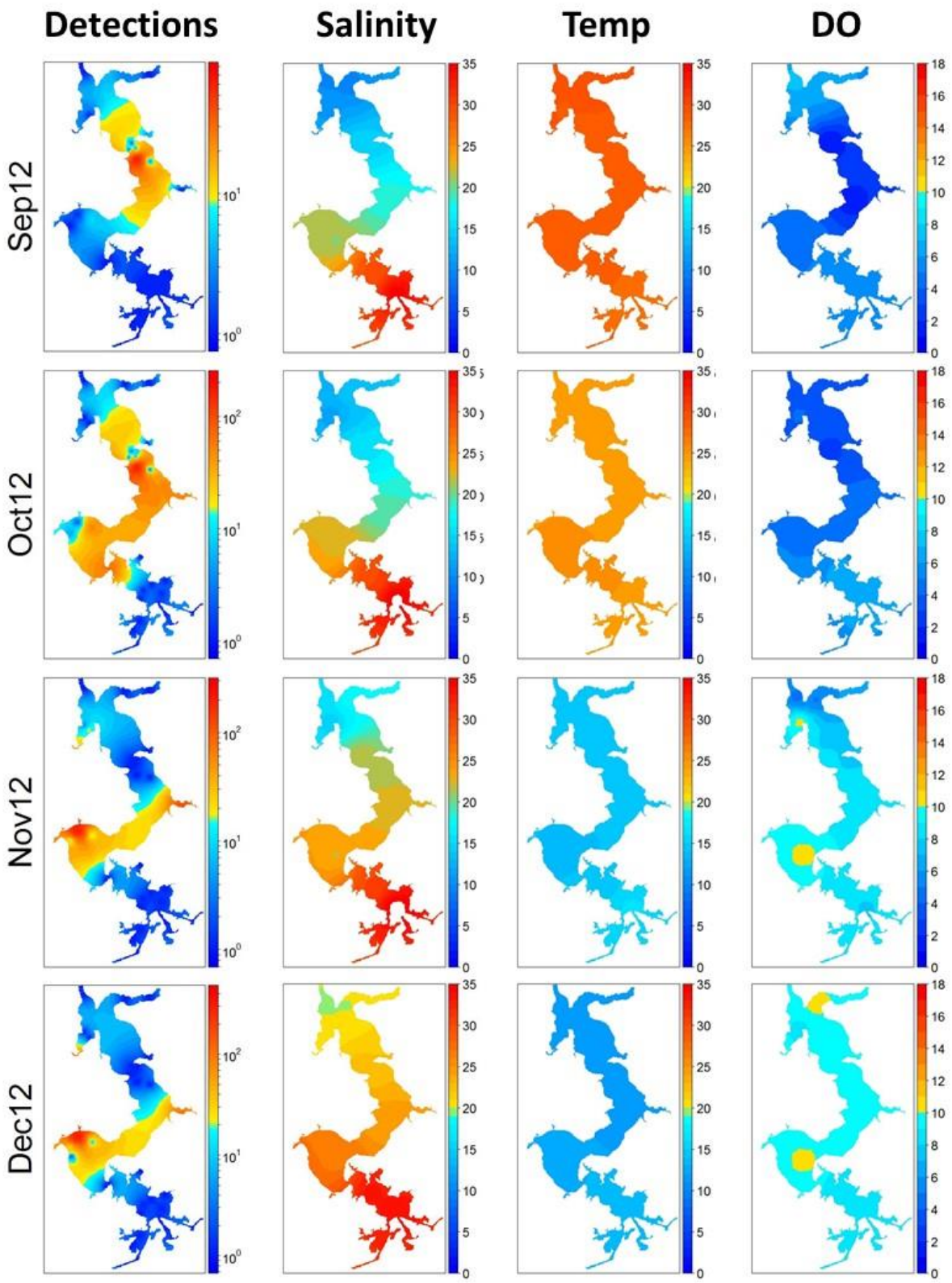
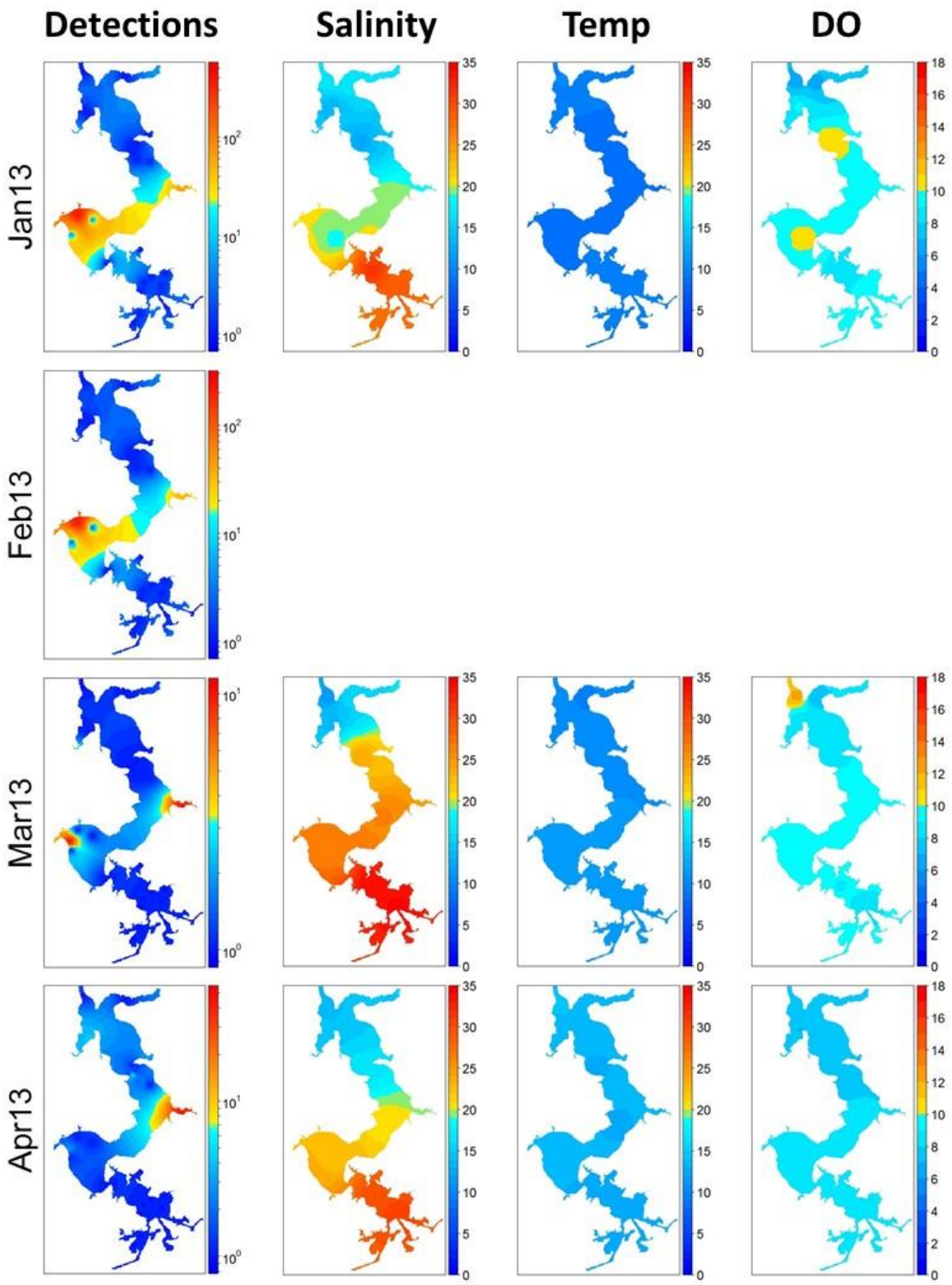
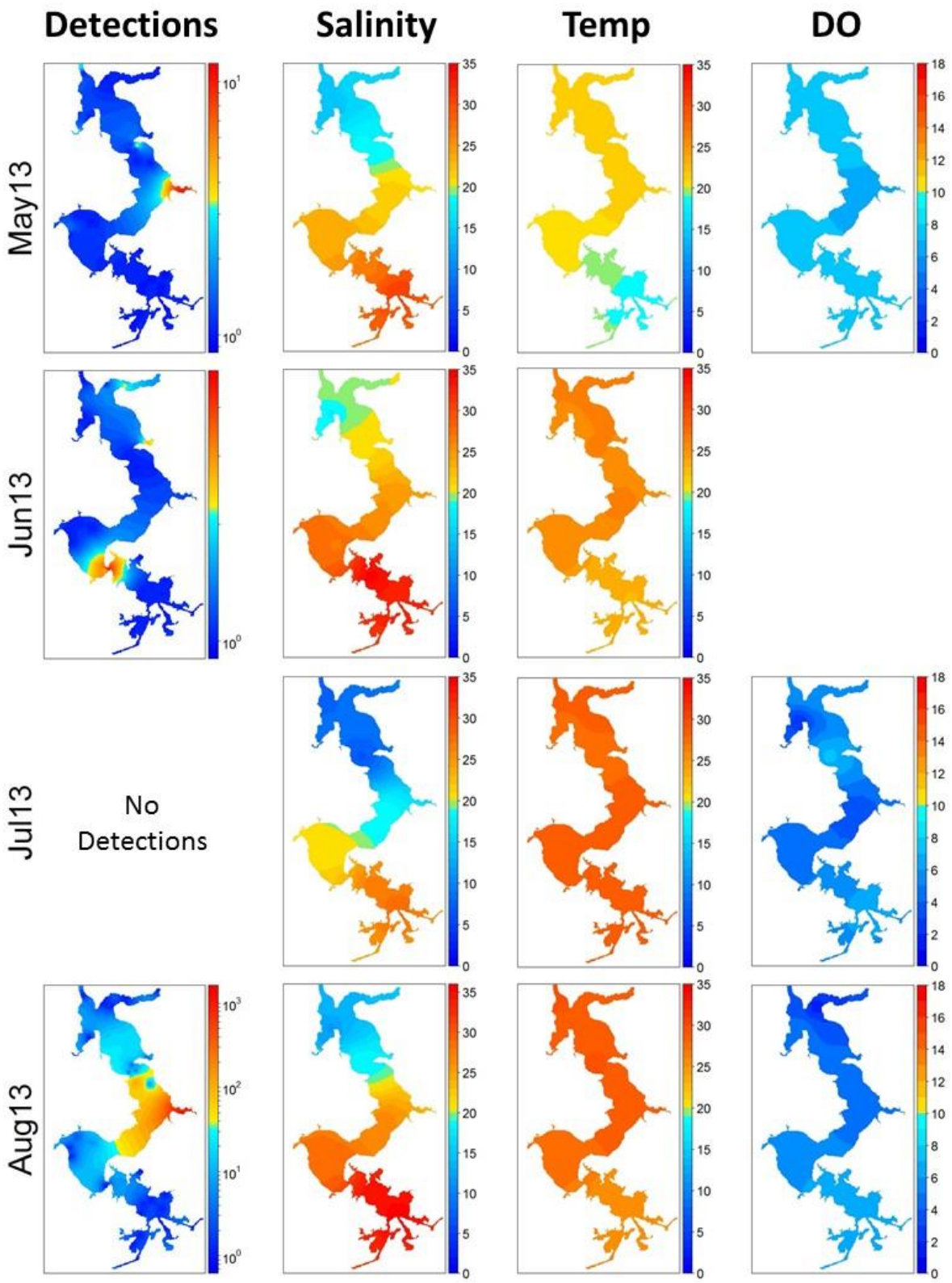

Detections
Salinity
Temp
DO
Sep15
Oct15
Nov15

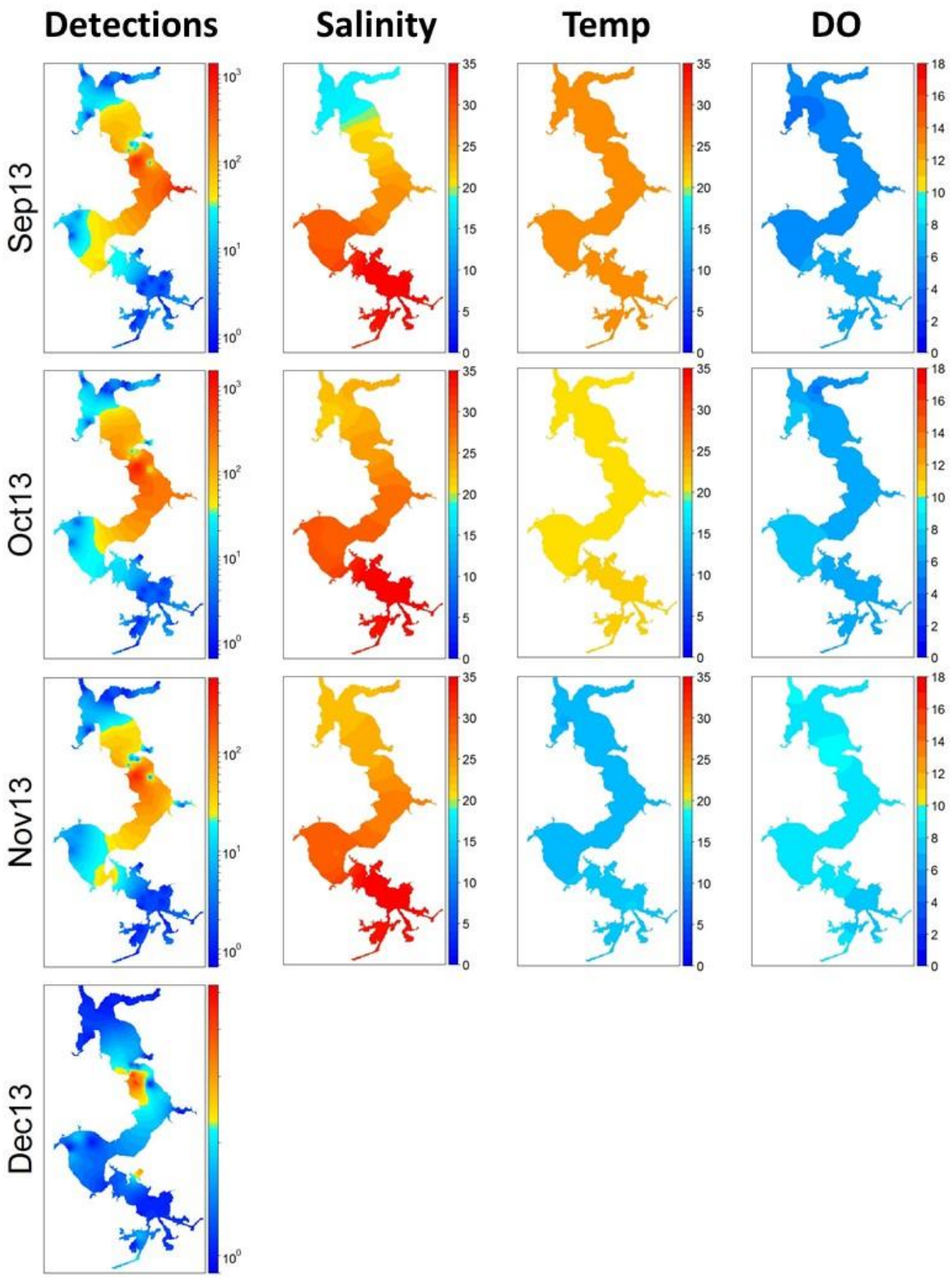
Figure 18

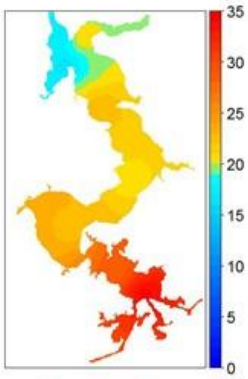
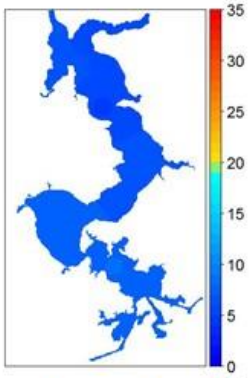
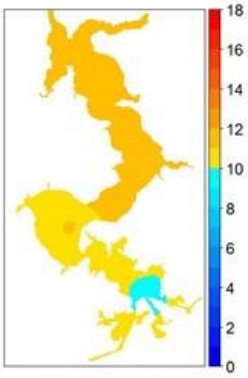
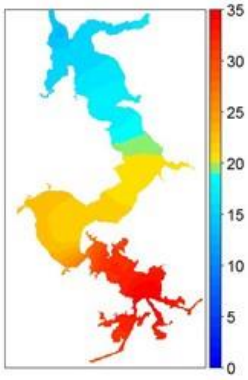
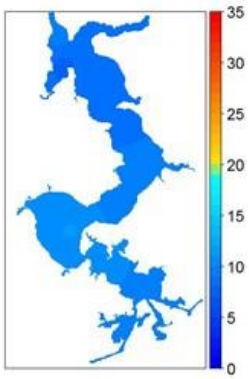
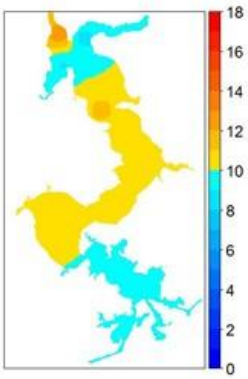
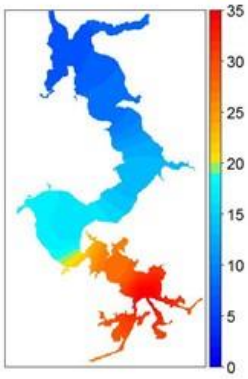
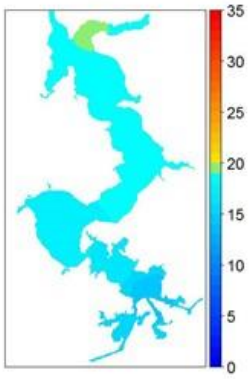
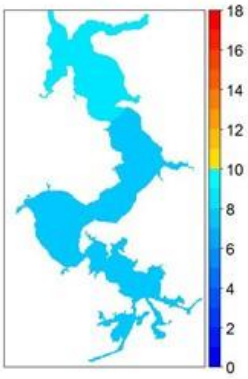
Black Drum

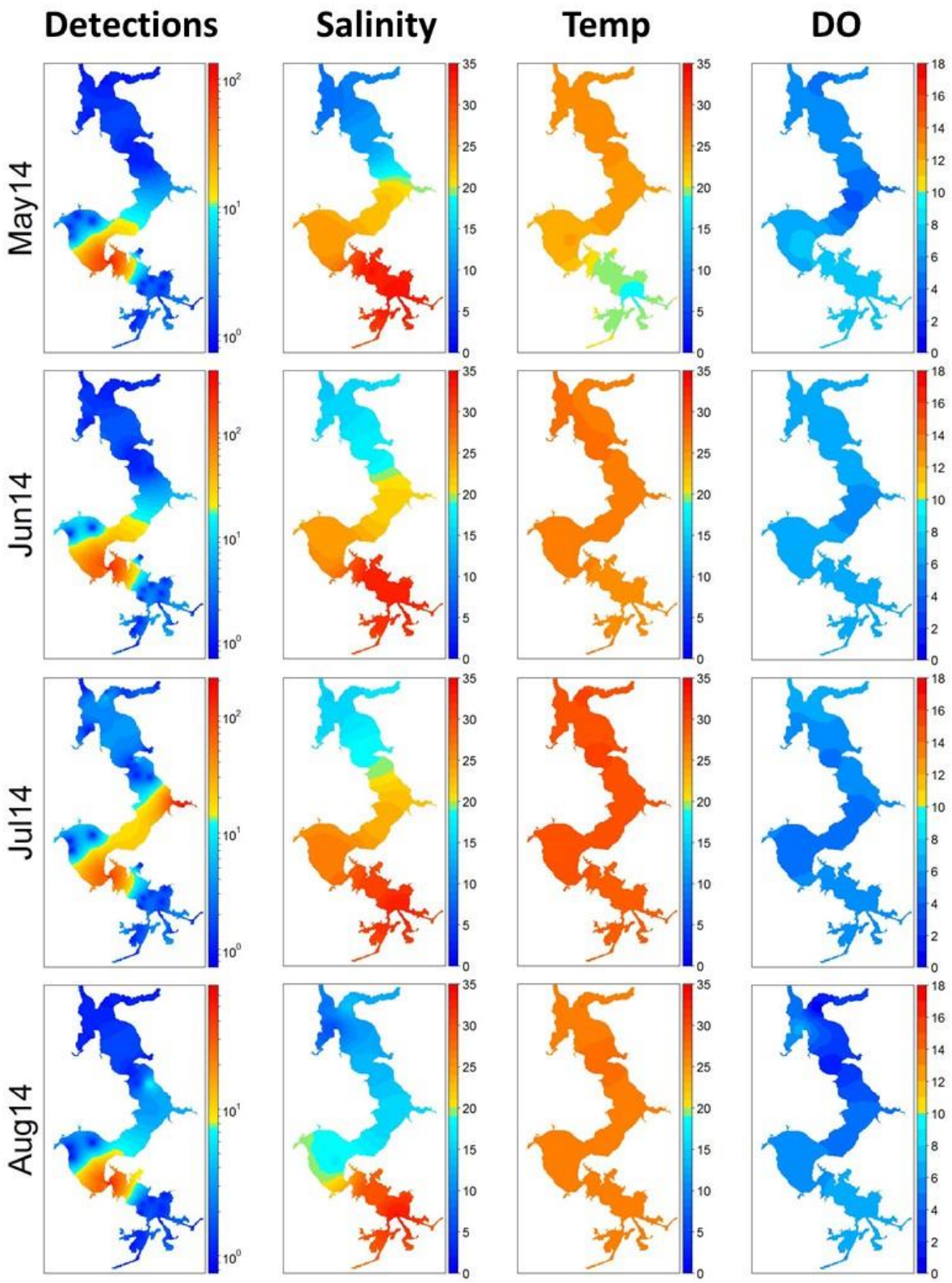

Detections
Salinity
Temp
DO
Sep12
Oct12
Nov12
Dec12

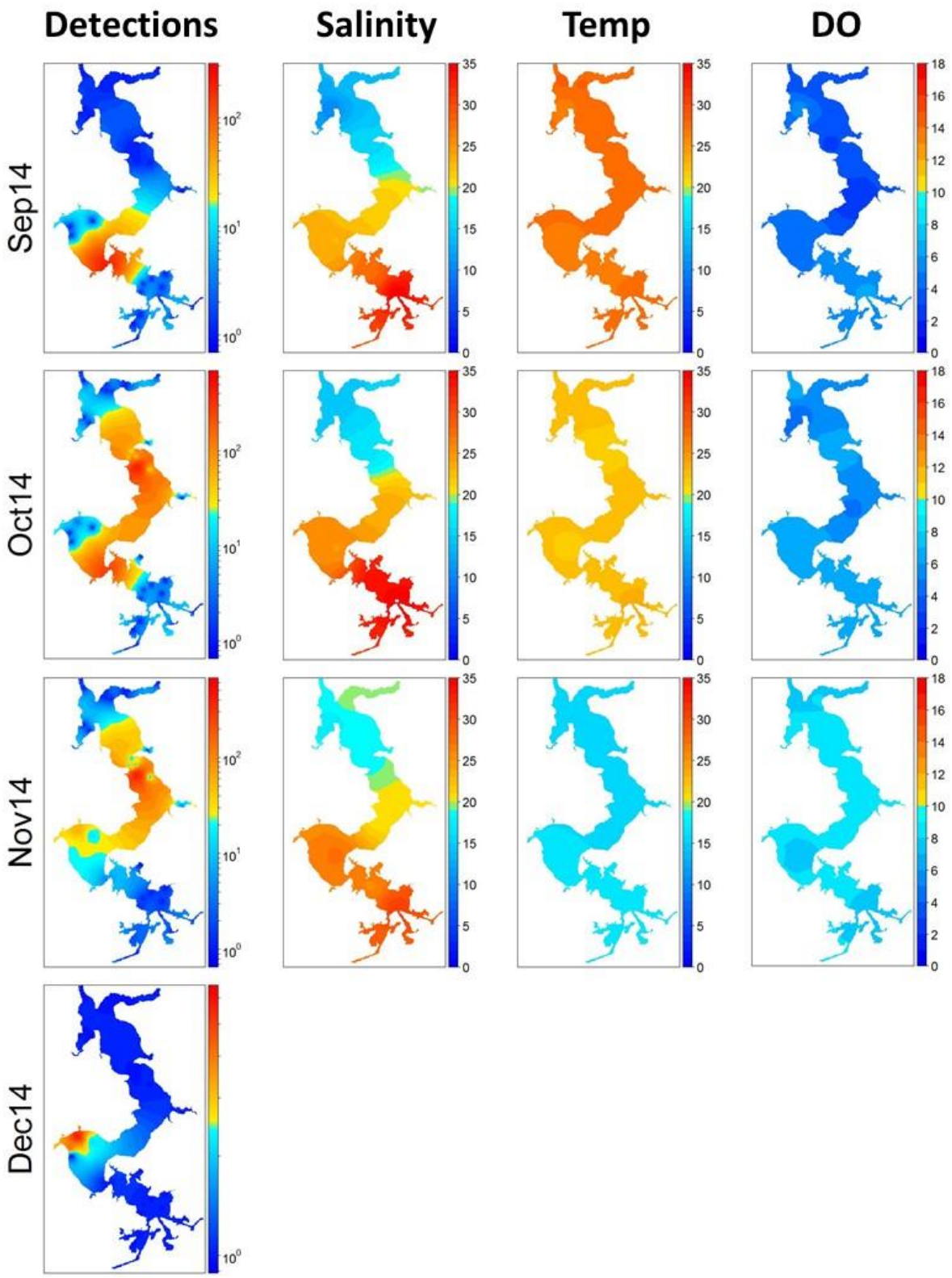

Detections
Salinity
Temp
DO
Jan13
Feb13
Mar13
Apr13

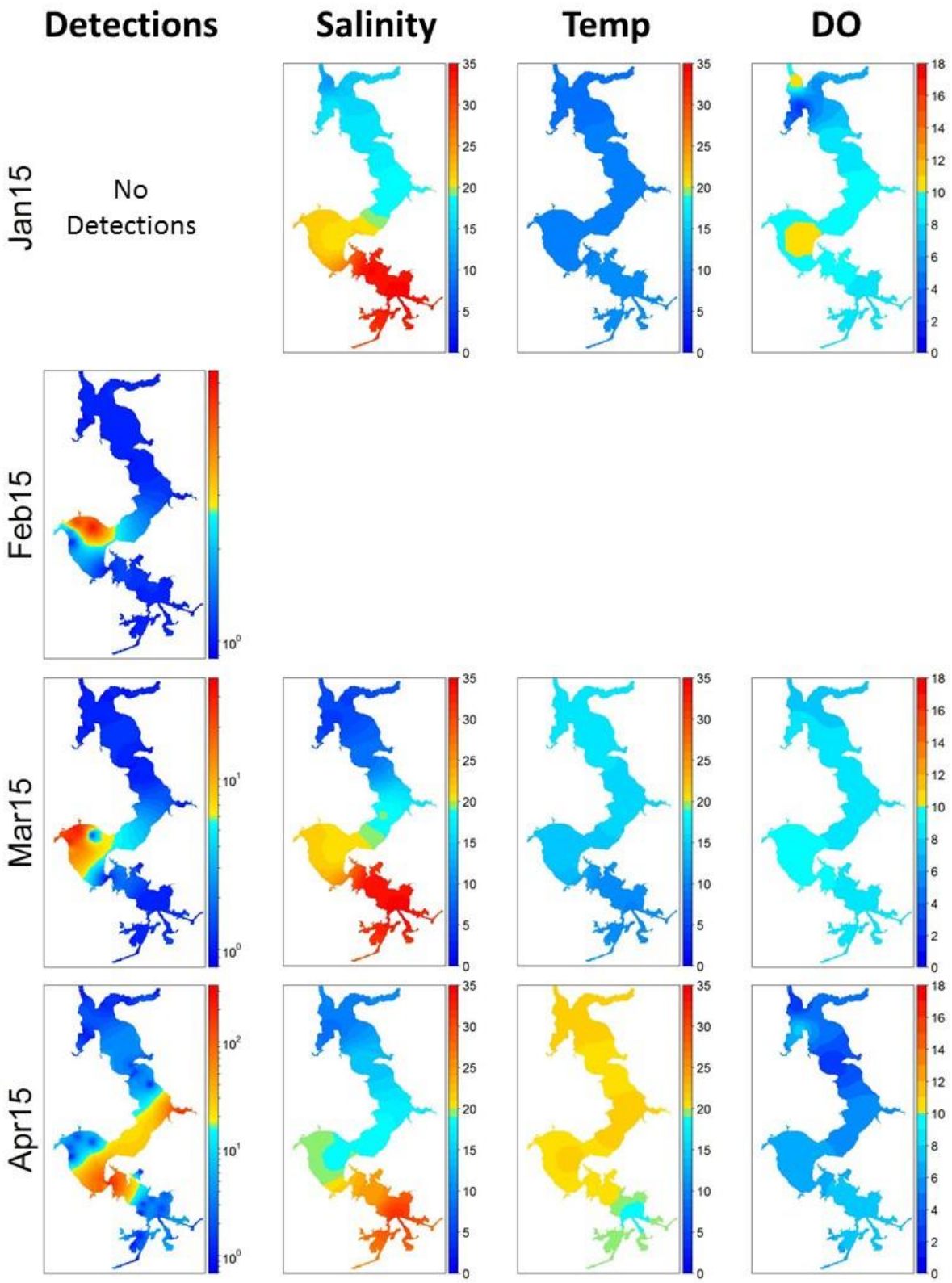

Detections
Salinity
Temp
DO
May13
Jun13
Jul13
Aug13
No Detections

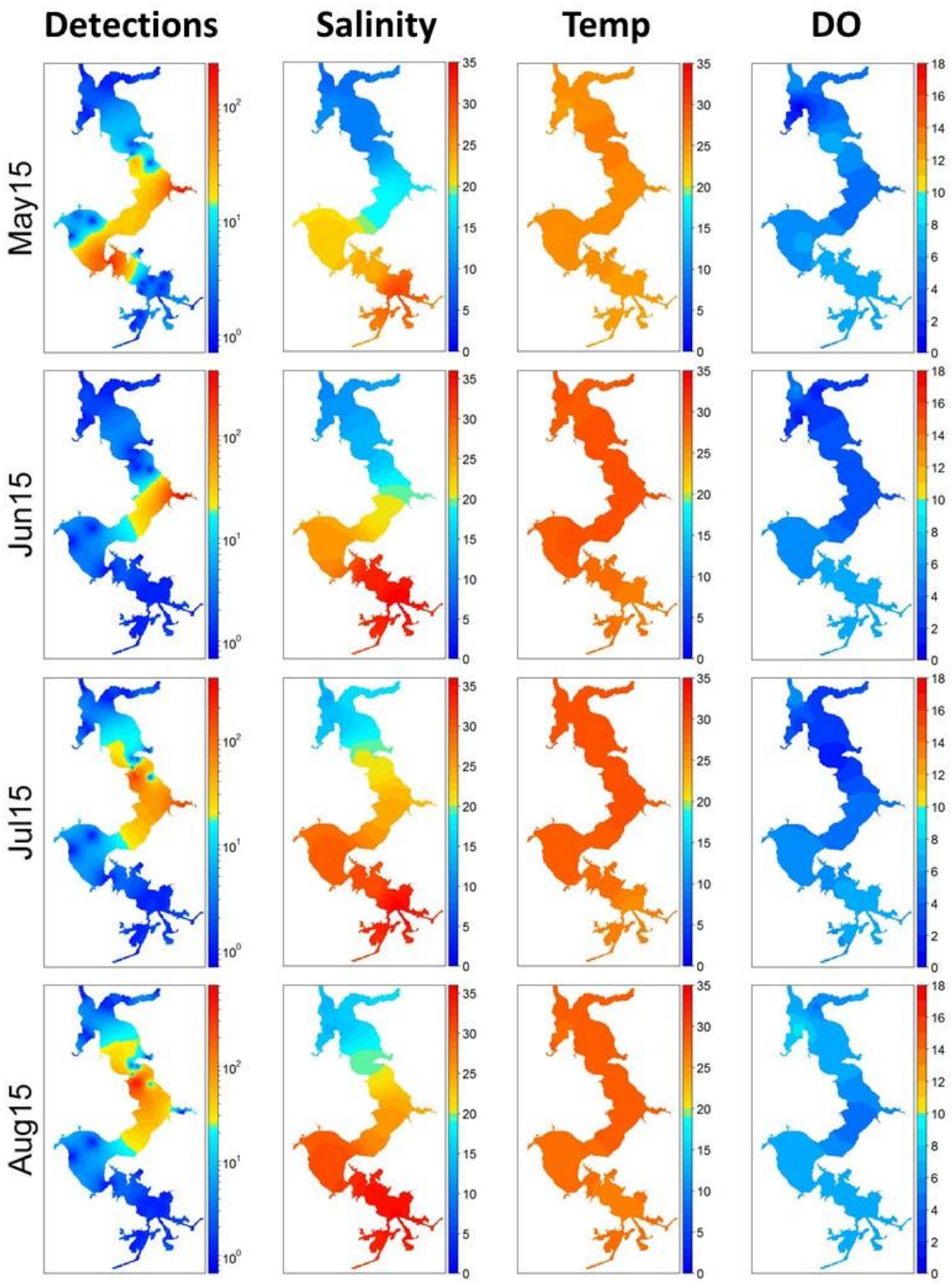

Detections
Salinity
Temp
DO
Sep13
Oct13
Nov13
Dec13

	Detections	Salinity	Temp	DO
Jan14	No Detections			
Feb14	No Detections			
Mar14	No Detections			
Apr14	No Detections			


Detections
Salinity
Temp
DO
May14
Jun14
Jul14
Aug14


Detections
Salinity
Temp
DO
Sep14
Oct14
Nov14
Dec14


Detections
Salinity
Temp
DO
Jan15
No Detections
Feb15
Mar15
Apr15


Detections
Salinity
Temp
DO
May15
Jun15
Jul15
Aug15

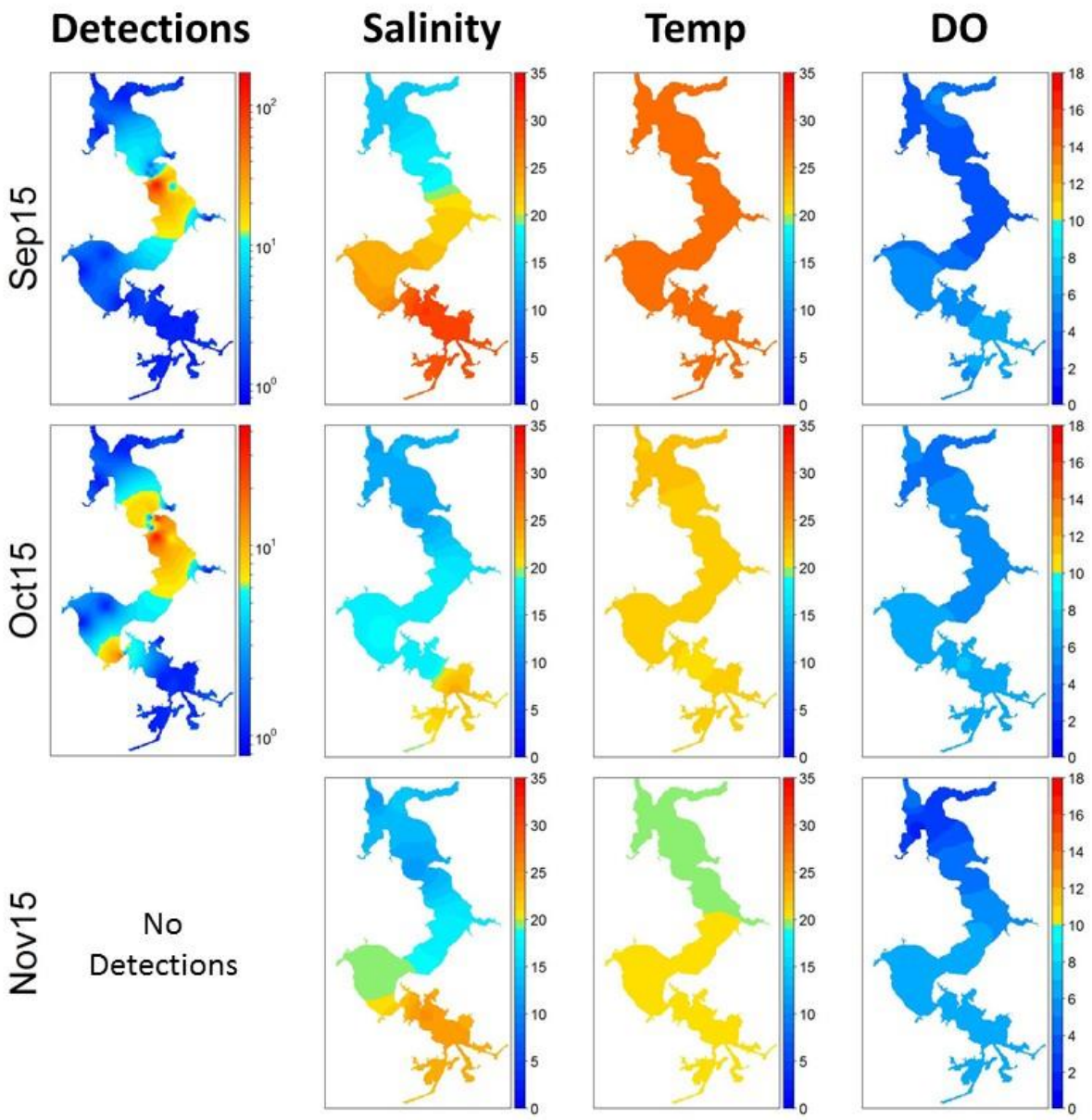

Detections
Salinity
Temp
DO
Sep15
Oct15
Nov15
No Detections

Figure 19

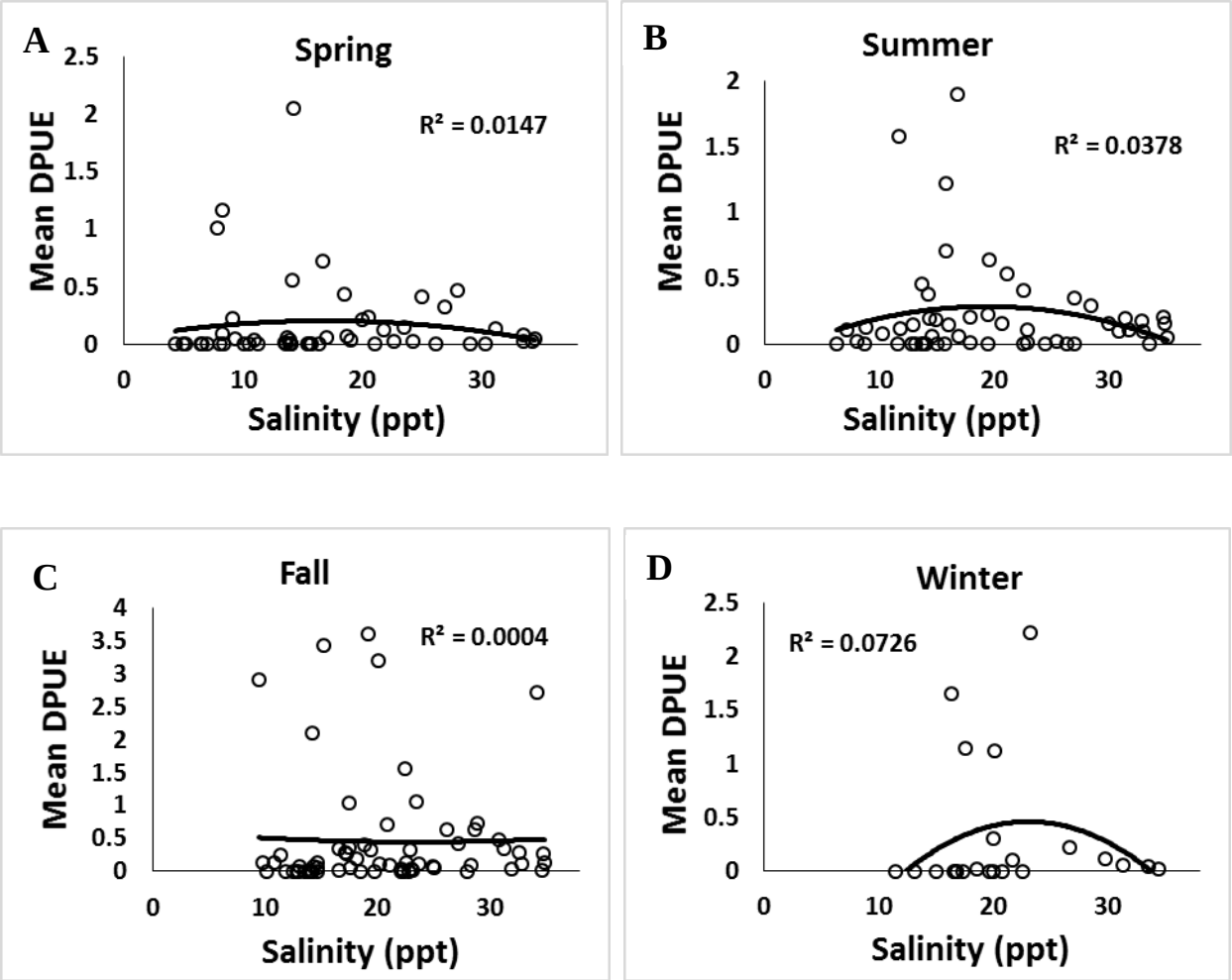

A
Spring
R² = 0.0147
Mean DPUE
Salinity (ppt)
B
Summer
R² = 0.0378
Mean DPUE
Salinity (ppt)
C
Fall
R² = 0.0004
Mean DPUE
Salinity (ppt)
D
Winter
R² = 0.0726
Mean DPUE
Salinity (ppt)

Figure 20

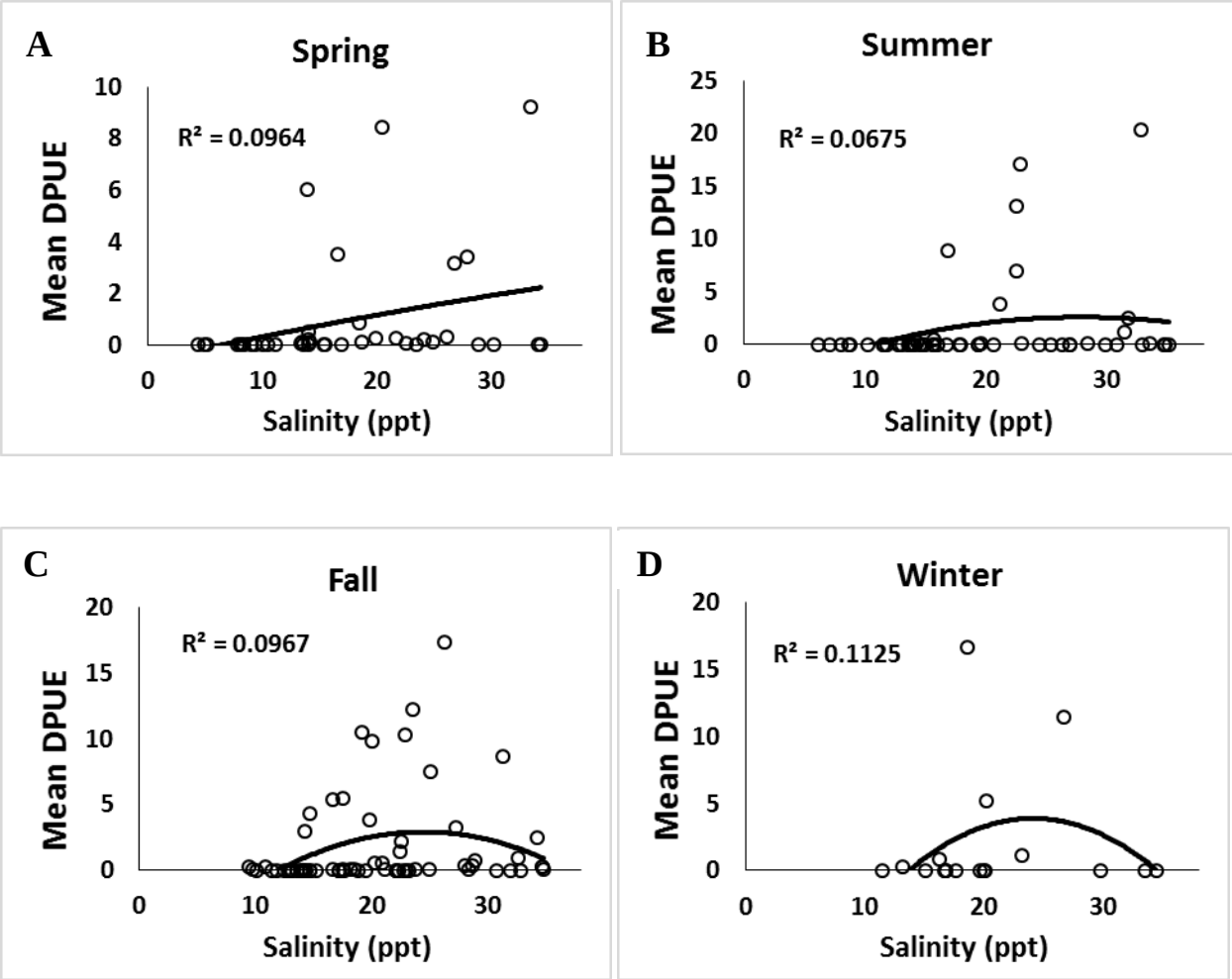

A
Spring
R² = 0.0964
Mean DPUE
Salinity (ppt)
B
Summer
R² = 0.0675
Mean DPUE
Salinity (ppt)
C
Fall
R² = 0.0967
Mean DPUE
Salinity (ppt)
D
Winter
R² = 0.1125
Mean DPUE
Salinity (ppt)

Figure 21

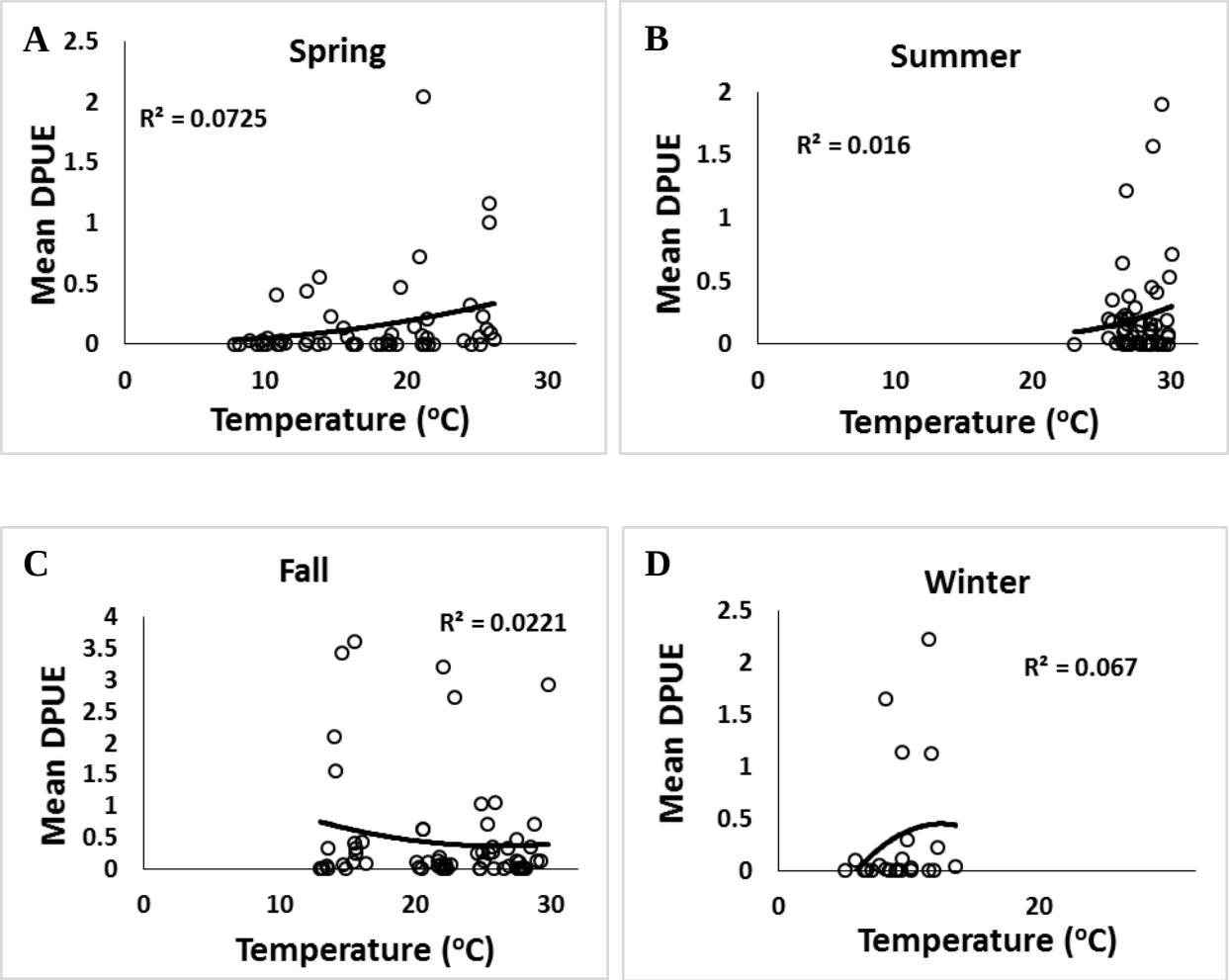

A
Spring
R² = 0.0725
Mean DPUE
Temperature (°C)
B
Summer
R² = 0.016
Mean DPUE
Temperature (°C)
C
Fall
R² = 0.0221
Mean DPUE
Temperature (°C)
D
Winter
R² = 0.067
Mean DPUE
Temperature (°C)

Figure 22

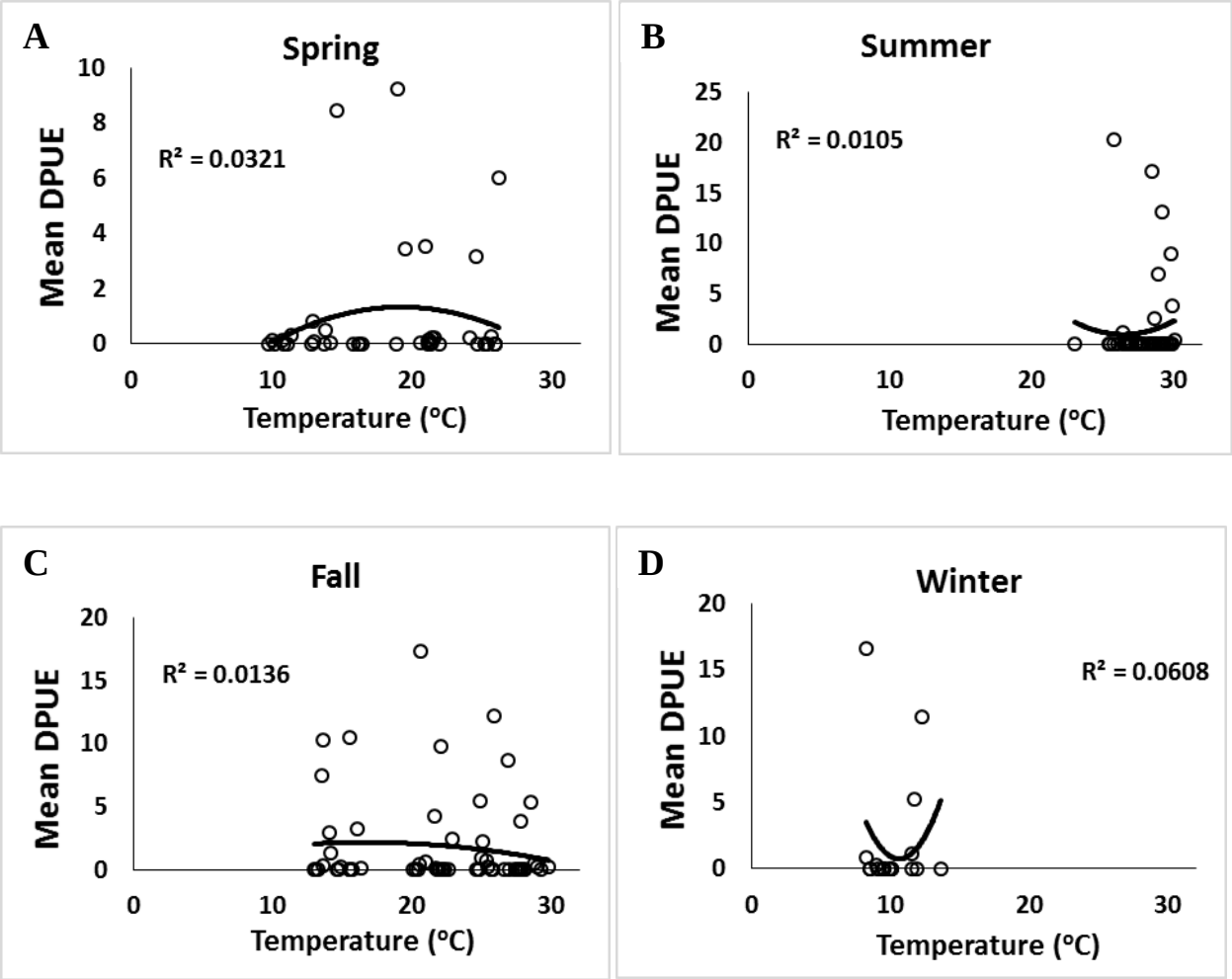

A
Spring
Mean DPUE
R² = 0.0321
Temperature (°C)
B
Summer
Mean DPUE
R² = 0.0105
Temperature (°C)
C
Fall
Mean DPUE
R² = 0.0136
Temperature (°C)
D
Winter
Mean DPUE
R² = 0.0608
Temperature (°C)

Figure 23

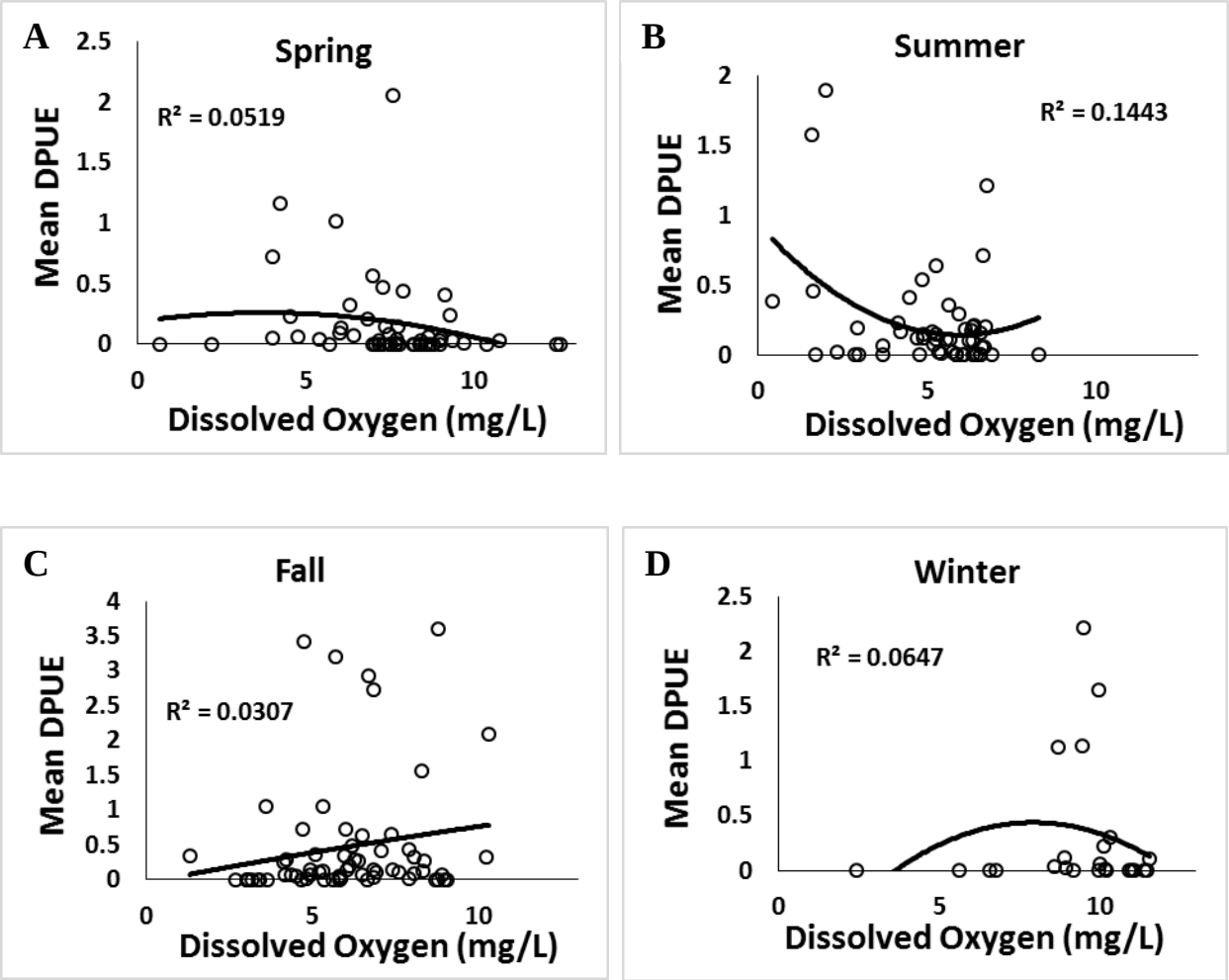

A
Spring
R² = 0.0519
Mean DPUE
Dissolved Oxygen (mg/L)
B
Summer
R² = 0.1443
Mean DPUE
Dissolved Oxygen (mg/L)
C
Fall
R² = 0.0307
Mean DPUE
Dissolved Oxygen (mg/L)
D
Winter
R² = 0.0647
Mean DPUE
Dissolved Oxygen (mg/L)

Figure 24

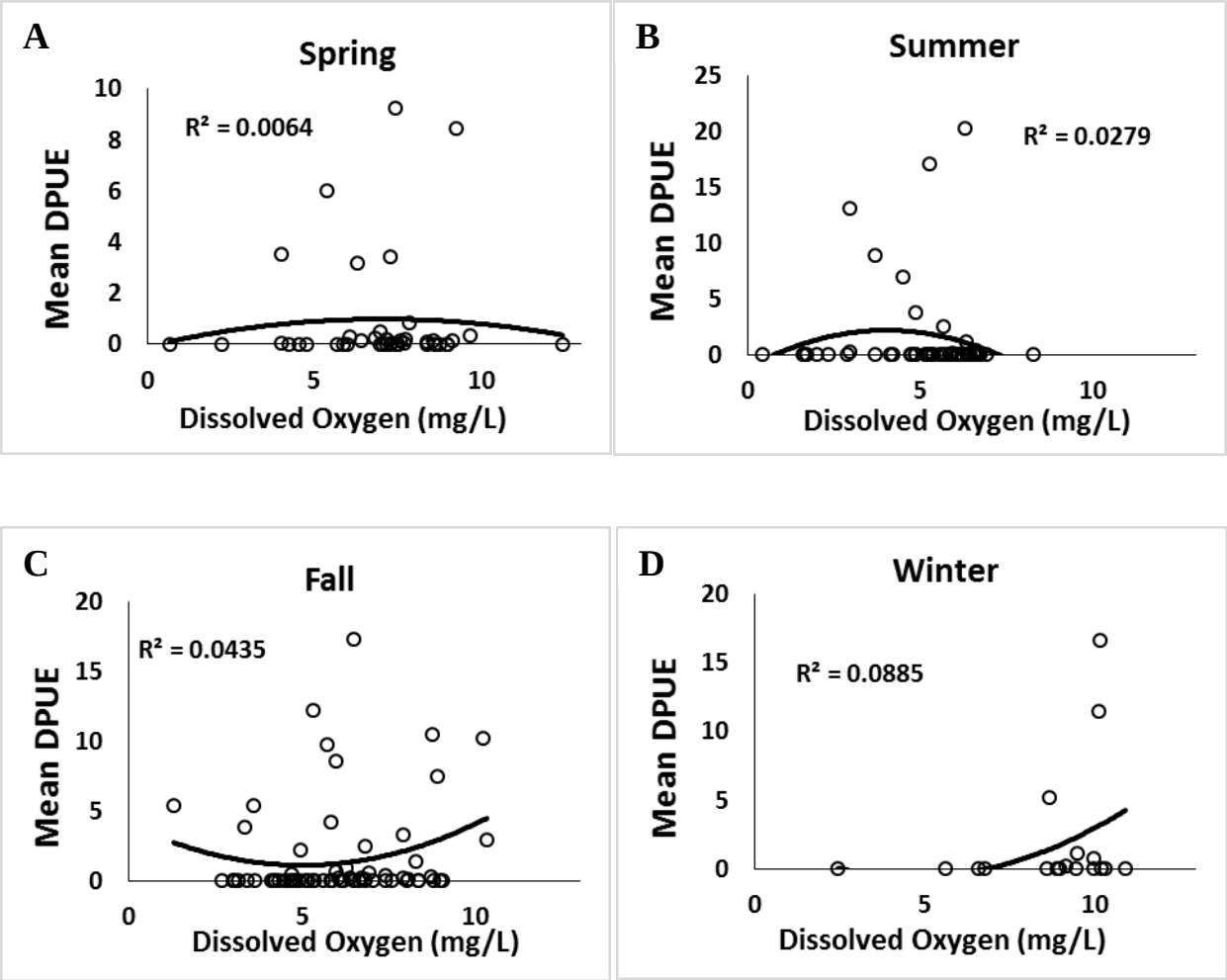

A
Spring
R² = 0.0064
Mean DPUE
Dissolved Oxygen (mg/L)
B
Summer
R² = 0.0279
Mean DPUE
Dissolved Oxygen (mg/L)
C
Fall
R² = 0.0435
Mean DPUE
Dissolved Oxygen (mg/L)
D
Winter
R² = 0.0885
Mean DPUE
Dissolved Oxygen (mg/L)

Figure 25

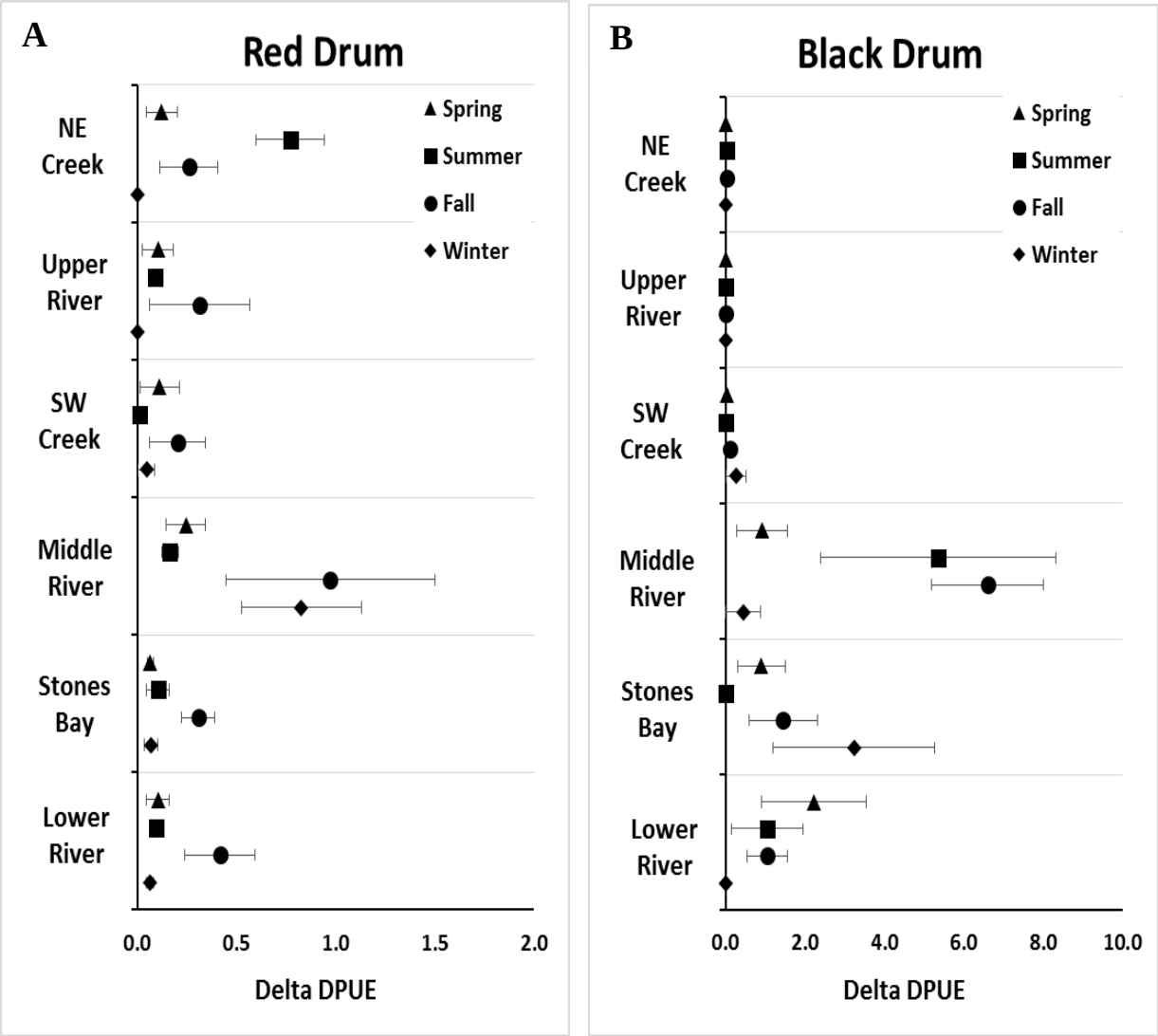

A
Red Drum
NE Creek
Upper River
SW Creek
Middle River
Stones Bay
Lower River
Spring
Summer
Fall
Winter
0.0
0.5
1.0
1.5
2.0
Delta DPUE
B
Black Drum
NE Creek
Upper River
SW Creek
Middle River
Stones Bay
Lower River
Spring
Summer
Fall
Winter
0.0
2.0
4.0
6.0
8.0
10.0
Delta DPUE

Figure 26

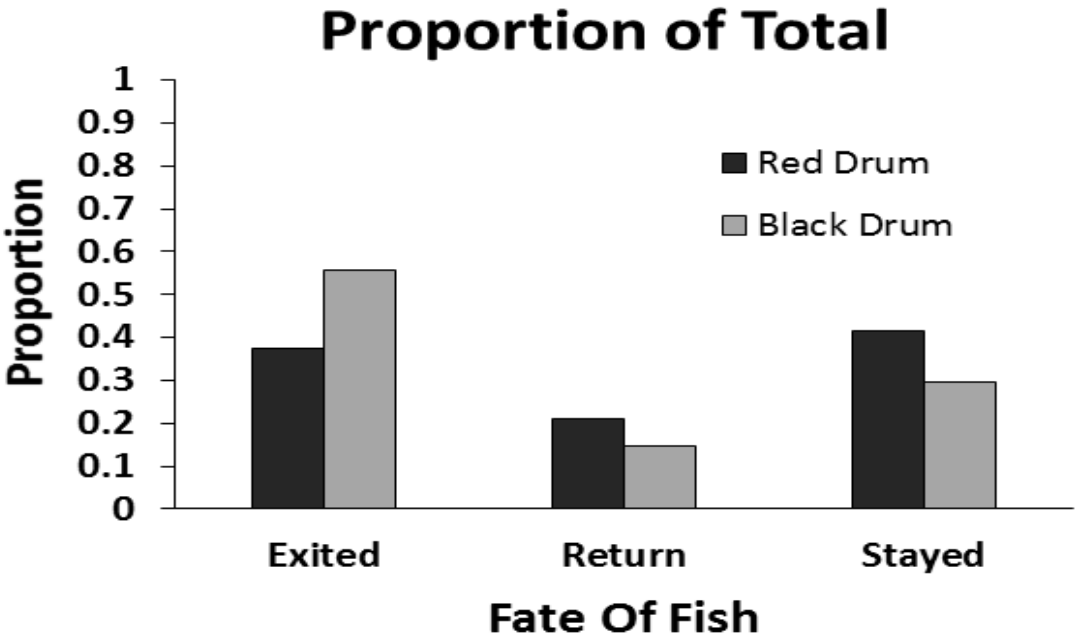
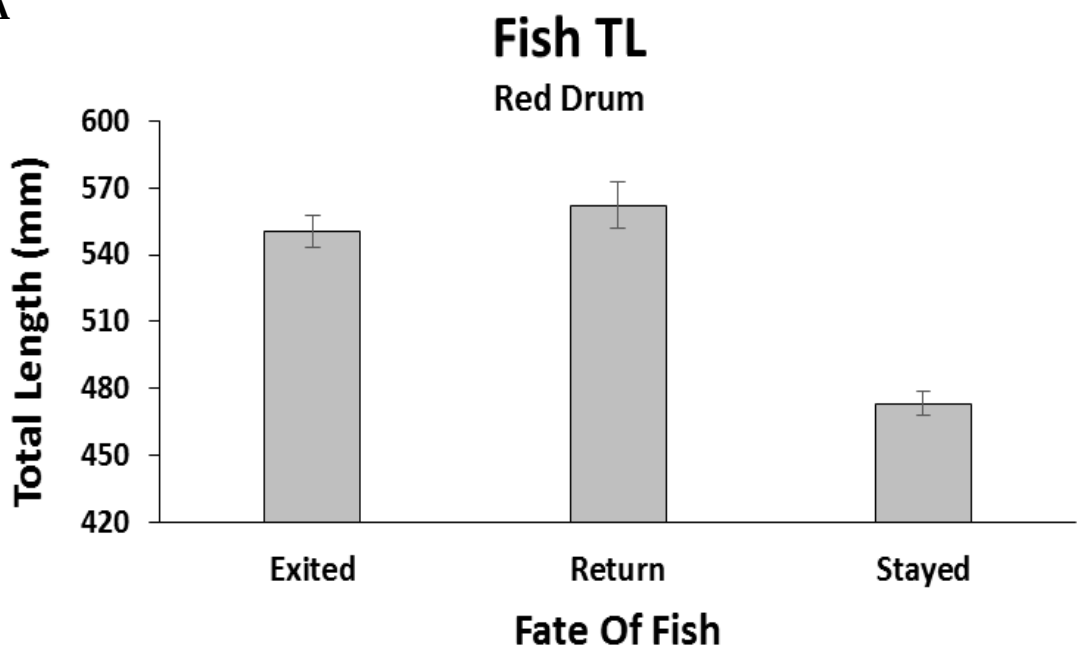

Proportion of Total
Proportion
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Red Drum
Black Drum
Exited
Return
Stayed
Fate Of Fish

Figure 27

A


Fish TL
Red Drum
Total Length (mm)
600
570
540
510
480
450
420
Exited
Return
Stayed
Fate Of Fish

B

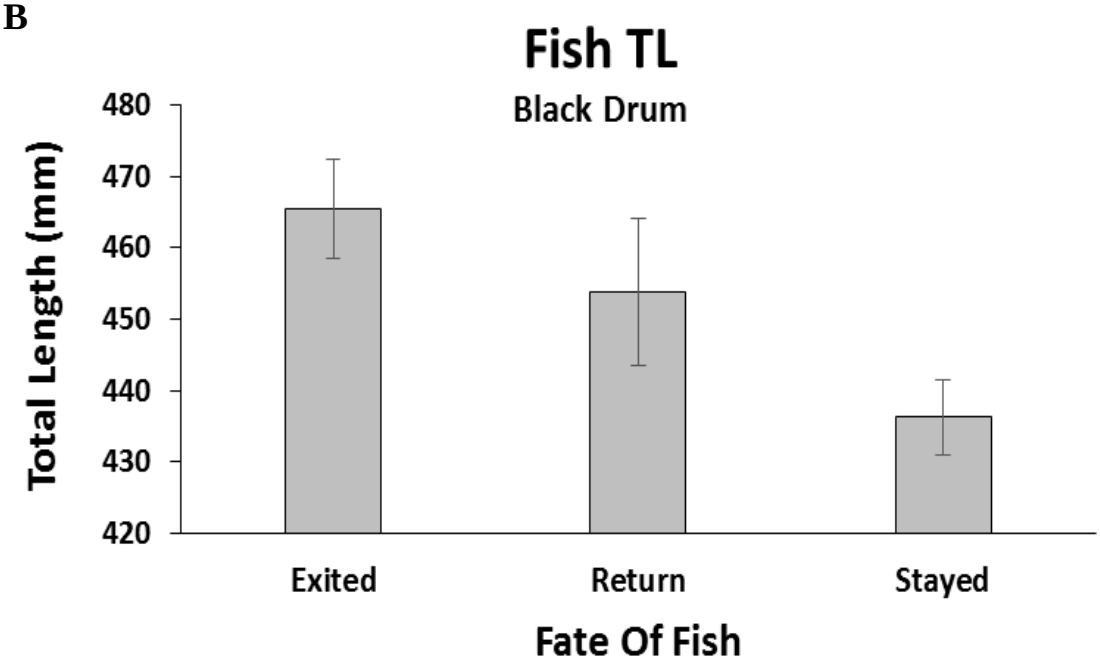

Fish TL
Black Drum
Total Length (mm)
480
470
460
450
440
430
420
Exited
Return
Stayed
Fate Of Fish

Figure 28

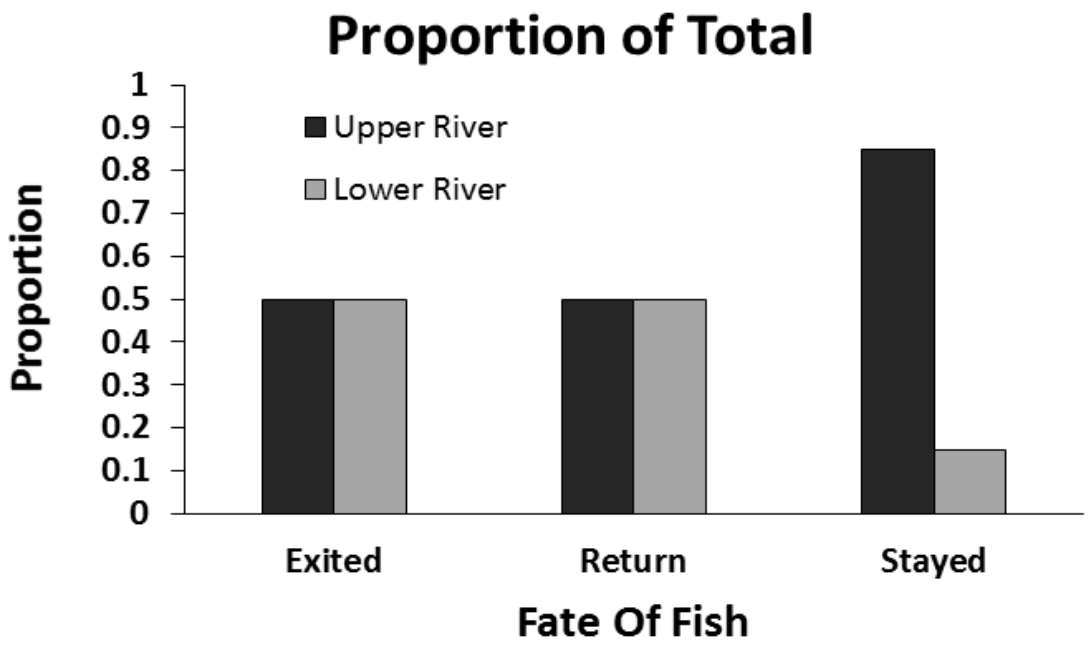


Figure 29

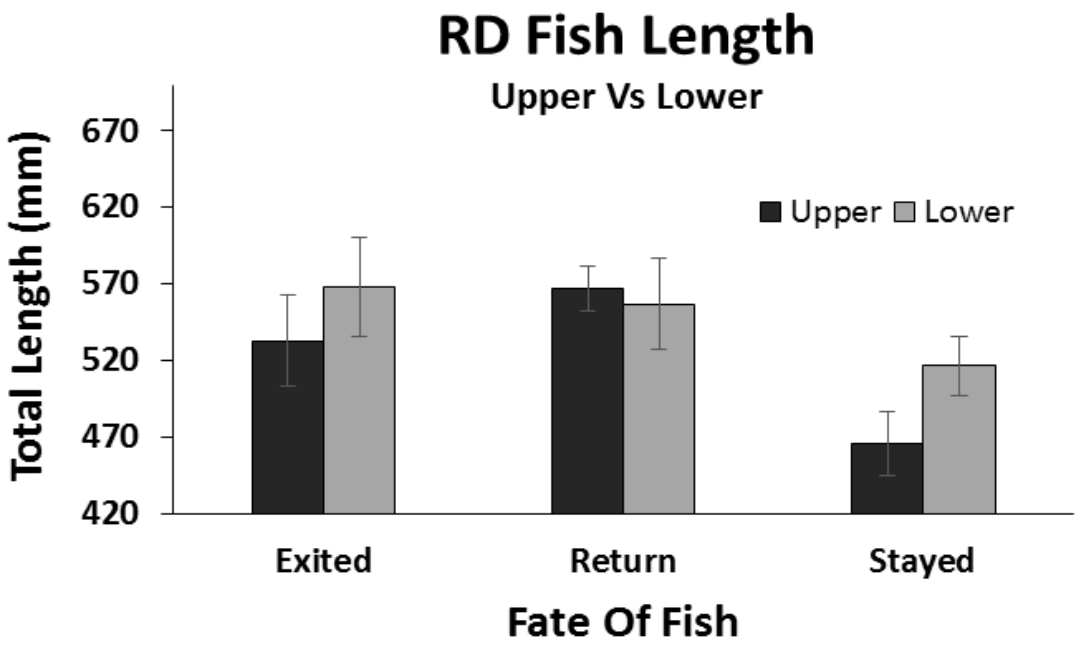


Table 1

Station	Cultch Sites	Latitude	Longitude	Description	Total Amount of shell within detection range	Material	Year Constructed
19	03-022	34.61114	-77.41568	North Stones Bay	5520	Oyster	2003
	05-028				23575	Oyster	2005
20	03-023, 03-026	34.59908	-77.43503	Stones Bay Middle	8050	Oyster	2003
24	04-042	34.58883	-77.36793	Courthouse Bay	950	Oyster	2004
	05-030				4690	Oyster	2005
	07-022				1700	Oyster	2007
	08-021				1000	Oyster	2008
28	10-018, 10-019, 10-020	34.55588	-77.36723	Hatch Point	14817	Oyster	2010
29	03-028	34.55996	-77.34738	Traps Bay	4176	Oyster	2003
	04-045				3325	Oyster	2004
	07-026				550	Oyster	2007
	09-018				5142	Oyster	2009
	10-016				2770	Oyster	2010
	10-017				3187	Oyster	2010
30	05-031	34.53024	-77.37393	Chadwick Bay	1955	Oyster	2005
	06-034				1300	Oyster	2006
	10-022				5170	Oyster	2010
	10-023				3961	Oyster	2010
	12-018				5670	Oyster	2012

Table 2

Fish ID	Date Released	Total Length (mm)	Release Location	Days at Liberty	# Detections	# Stations Visited	Recapture Location	Other Locations Detected
NR01	**8/21/2012**	**585**	**Upper**	**48.99**	**205**	**11**		
NR02*	**8/21/2012**	**570**	**Upper**	**62.49**	**533**	**14**	**LNRE**	
NR03	9/6/2012	620	Upper	233.74	132	3		
NR04	9/13/2012	540	Upper	368.61	4379	24		
NR05	9/13/2012		Upper	35.31	1581	21	WB	
NR06	**9/13/2012**	**685**	**Upper**	**25.21**	**4**	**2**		
NR09	9/13/2012	617	Upper	0.00				
NR11	9/24/2012	580	Lower	0.00				
NR12	9/27/2012	555	Lower	281.15	2381	4		
NR13	9/27/2012	401	Lower	30.24	674	12		
NR19*	10/15/2012	376	Upper	296.12	2873	6	LNRE	
NR20	10/24/2012	402	Upper	363.63	5857	14		
NR21	10/24/2012	443	Upper	159.90	863	7	LNRE	
NR22	10/24/2012	430	Upper	4.41	918	6		
NR23	10/24/2012	410	Upper	198.74	13486	3		
NR24	10/24/2012	54	Upper	327.24	1196	8		
NR26	11/9/2012	472	Upper	3.30	1021	4	UNRE	
NR27	11/9/2012	445	Upper	341.02	4821	13		
NR28	11/9/2012	440	Upper	156.66	8028	10		
NR29	11/16/2012	470	Upper	354.31	229	14		
NR30	11/16/2012	440	Upper	81.97	1797	2		
NR33	6/11/2013	440	Upper	144.59	3461	14		
NR34	6/11/2013	560	Upper	23.75	261	4	UNRE	
NR35	**7/13/2013**	**703**	**Lower**	**87.04**	**55**	**3**		
NR36	**7/13/2013**	**498**	**Lower**	**87.60**	**88**	**4**		
NR37	**7/13/2013**	**555**	**Lower**	**85.31**	**2182**	**10**	**SW**	
NR50	8/23/2013	565	Upper	67.30	738	13		
NR51	**8/23/2013**	**585**	**Upper**	**369.16**	**977**	**18**		
NR52	**8/24/2013**	**550**	**Upper**	**42.94**	**353**	**14**	**SW**	
NR53	**8/24/2013**	**555**	**Upper**	**501.01**	**12670**	**5**		
NR54	**8/24/2013**	**539**	**Upper**	**424.76**	**471**	**12**		
NR55	**8/24/2013**	**470**	**Upper**	**814.49**	**4758**	**22**		
NR56	**8/24/2013**	**560**	**Upper**	**45.69**	**1111**	**10**	**SB**	**MI**
NR57	**8/24/2013**	**570**	**Upper**	**231.24**	**535**	**14**	**LNRE**	
NR58	**8/24/2013**	**567**	**Upper**	**355.99**	**9296**	**22**		
NR59	8/28/2013	526	Lower	395.84	6219	6		
NR60	8/28/2013	673	Lower	0.00				
NR61	8/28/2013	532	Lower	245.84	9	2	LNRE	
NR62	**10/14/2013**	**595**	**Lower**	**11.13**	**501**	**5**	**SC**	
NR63	**10/17/2013**	**516**	**Lower**	**0.00**				
NR64	5/21/2014	476	Lower	503.59	3674	10		
NR68	7/11/2014	500	Lower	345.66	1031	6		
NR69	7/11/2014	620	Lower	0.00			LNRE	
NR70	**7/26/2014**	**534**	**Upper**	**23.14**	**810**	**8**	**UNRE**	
NR71	**7/26/2014**	**537**	**Upper**	**310.03**	**1461**	**13**		
NR72	**8/11/2014**	**510**	**Lower**	**7.92**	**36**	**2**		
NR73	**8/11/2014**	**668**	**Lower**	**81.86**	**3889**	**19**		
NR74	**8/11/2014**	**665**	**Lower**	**58.19**	**586**	**11**		
NR75*	**8/11/2014**	**517**	**Lower**	**9.95**	**336**	**11**	**LNRE**	
NR76	**8/11/2014**	**615**	**Lower**	**333.49**	**3689**	**8**		
NR77	**8/11/2014**	**635**	**Lower**	**384.55**	**336**	**9**		
NR78	**8/11/2014**	**495**	**Lower**	**419.04**	**3149**	**29**		
NR80*	**10/9/2014**	**363**	**Upper**	**383.76**	**294**	**6**	**UNRE**	
NR81*	10/9/2014	400	Upper	376.67	33565	28	UNRE	MC
NR82	10/9/2014	415	Upper	301.23	19540	31		

Table 3

Fish ID	Date Released	Total Length (mm)	Release Location	Days at Liberty	# Detections	# Stations Visited	Recapture Location	Other Locations Detected
NR07	9/13/2012	410	Upper	0.00			UNRE	
NR08	9/13/2012	425	Upper	3.09	181	7		
NR10	9/13/2012	445	Upper	239.56	33008	20		
NR14	10/8/2012	420	Upper	211.52	24097	11		
NR15	10/8/2012	445	Upper	240.24	10368	6		
NR16	10/15/2012	447	Upper	204.59	9315	12		
NR17	10/15/2012	447	Upper	189.06	200	3		
NR18	10/15/2012	462	Upper	208.74	5589	8		
NR25	10/26/2012	425	Upper	2.20	160	4	SW	
NR31	5/29/2013	460	Upper	16.97	44	7		
NR32	6/5/2013	447	Upper	21.28	314	11	UNRE	
NR38	8/6/2013	480	Upper	66.50	4057	6		
NR39	8/6/2013	495	Upper	88.98	46412	13		CB
NR40	8/6/2013	510	Upper	66.65	2255	11		
NR41	8/6/2013	476	Upper	64.59	2532	12		
NR42	8/6/2013	505	Upper	65.60	6789	3		
NR43	8/6/2013	483	Upper	334.58	4185	20	LNRE	
NR44	8/6/2013	460	Upper	67.73	11833	11		
NR45	8/6/2013	495	Upper	65.47	3965	3		
NR46	8/6/2013	486	Upper	129.29	74749	21		CH, GA, DB
NR47	8/6/2013	470	Upper	377.43	33181	10		
NR48	8/6/2013	480	Upper	69.55	7968	21	AB	
NR49	8/6/2013	480	Upper	94.95	29660	22	DB	
NR65	7/10/2014	465	Upper	112.73	11459	18		CH, CB
NR66	7/10/2014	482	Upper	114.70	13194	9		
NR67	7/10/2014	450	Upper	59.43	822	8	LNRE	
NR79	9/22/2014	418	Upper	40.84	3454	5		CH
NR83	10/9/2014	450	Upper	369.73	17076	19		AB, CB
NR84	10/13/2014	442	Upper	221.44	29789	14		
NR85	10/13/2014	425	Upper	123.75	21317	23		
NR86	10/13/2014	455	Upper	19.84	2760	12		
NR87*	10/13/2014	420	Upper	369.71	27862	24	UNRE	MC
NR88	10/13/2014	410	Upper	45.81	7062	23		
NR89	10/13/2014	440	Upper	364.28	20575	19		
NR90	10/13/2014	435	Upper	19.79	4805	10		
NR91	10/13/2014	426	Upper	355.15	10801	19		