REVISED FINAL DATA REPORT FOR THE FISH MOVEMENT STUDY

PALOS VERDES SHELF (OU 5 OF THE MONTROSE CHEMICAL CORPORATION SUPERFUND SITE)
LOS ANGELES COUNTY, CALIFORNIA

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Footnote: This final report was revised in December 2013 to update the list of acronyms and abbreviations and the references. Please delete previous final version dated November 2013.

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ACRONYMS AND ABBREVIATIONS

avg	average
BSB	*Paralabrax nebuilfer*, or barred sand bass
^{o}C	degrees Celsius
cm	centimeters
CSF	*Scorpaena guttata*, or California scorpionfish
CSULB	California State University, Long Beach
CPUE	catch per unit effort
CPFV	Commercial Passenger Fishing Vessels
d	days
dB	decibels
EM	sediment-bound DDT exposure metric
CDFW	California Department of Fish and Wildlife
EPA	United States Environmental Protection Agency
g	gram(s)
g/cm^3	grams per cubic centimeter
GIS	geographic information system
GPS	global positioning system
hrs	hours
ITSI Gilbane	ITSI Gilbane Company
IACUC	International Animal Care and Use Committee
kg	kilograms
kHz	kilohertz
km	kilometers
km^2	square kilometers
KUD	kernel utilization distribution
m	meter(s)
m^2	square meters
m^3	cubic meters
mg	milligrams
min	minutes
mm	millimeters
Montrose	Montrose Chemical Corporation
MSRP	Montrose Settlement Restoration Program
NOAA	National Oceanic and Atmospheric Administration
OU	Operable Unit
PCBs	polychlorinated biphenyls
POLA	Port of Los Angeles
POLB	Port of Long Beach
PGA	polyglycolic acid
PV Shelf	Palos Verdes Shelf
RAC	EPA Remedial Action Contract II
RD	remedial design
ROV	remotely operated vehicle
RPM	Regional Project Manager

s	seconds
Sanitation Districts	Sanitation Districts of Los Angeles County
SL	standard length
TL	total length
TO	Task Order
WC	*Genyonemus lineatus*, or white croaker
VPS	Vemco VR2W Positioning System

1.0 INTRODUCTION

Dr. Chris Lowe of California State University Long Beach (CSULB) received a contract through ITSI Gilbane Company (ITSI Gilbane), Walnut Creek, California, on behalf of the United States Environmental Protection Agency (EPA) Region IX, to conduct a study of fish movement patterns on Palos Verdes Shelf (PV Shelf), Los Angeles County, California (Figure 1). The work is part of the pre-design investigation being conducted to support the remedy for PV Shelf, Operable Unit (OU) 5, of the Montrose Chemical Company Superfund Site, Los Angeles, California.

1.1 PROJECT RATIONALE

From 1947 to 1982, hundreds of tons of organochlorine contaminants (DDT and PCBs) were discharged on the PV Shelf through the White Point outfalls operated by the Sanitation Districts of Los Angeles County (Sanitation Districts). Despite prohibition of discharge of these compounds through wastewater treatment systems in 1972, these contaminant deposits continue to persist and are detectable throughout the entire Southern California Bight (Young and Heeson, 1980, Chartrand et al., 1985). While a majority of these contaminants are bound in sediments, DDTs and PCBs can be found throughout the ecosystem and are trophically transferred through the food web. Therefore, organisms closely associated with contaminated sediments (e.g., polychaete worms, burrowing mollusks and crustaceans, benthic and epibenthic fishes) and those feeding high in trophic food webs (e.g., marine mammals) tend to accumulate high body concentrations of these contaminants (National Oceanic and Atmospheric Administration [NOAA], 2007). The highest concentrations of DDT and its metabolites in sediments of the Southern California Bight are found around the White Point outfalls (NOAA, 2007).

In a recent EPA and Montrose Settlement Restoration Program (MSRP) fish survey study (NOAA, 2007), fishes from around the Palos Verdes Peninsula, Santa Monica Bay, and San Pedro Bay were found to have highly variable levels of DDTs and PCBs in their tissues. Extremely high levels of these contaminants have been found in white croaker (WC; *Genyonemus lineatus*), kelp bass (*Paralabrax clathratus*), California scorpionfish (CSF; *Scorpaena guttata*), and barred sand bass (BSB; *Paralabrax nebulifer*) collected in proximity to

the White Point outfall pipes and vicinity. DDT and PCB levels recorded for fish collected in the area were used by EPA to set safe consumption limits. As a result, EPA set "no consumption" limits for WC and BSB from Santa Monica Bay to Seal Beach. Other attempts to mitigate or reduce bio-availability of these contaminants include plans to "cap" contaminated sediments along PV Shelf with clean sediments. However, in order to evaluate the efficacy of this method in reducing bio-availability of these contaminants, particularly in food fishes, it is essential to understand the movement patterns and habitat use of species already demonstrated to have high contaminant loads.

A more spatially focused analysis of contaminants in WC revealed extremely high levels in some individuals collected on the northwest side of the White Point outfall pipe, while those collected from the southeast side had lower levels. This has led to a hypothesis that the outfall pipe may provide some barrier to the movements of WC on PV Shelf (NOAA, 2007; J. Gully Pers. Comm.). Unfortunately, very little is known about the movement patterns, habitat utilization and site fidelity of many California fishes, particularly WC. In addition, heavily contaminated WC have been found in the San Pedro Bay and it is unclear whether these fish move between the bay and PV Shelf or whether they are acquiring these contaminants from the Consolidated Slip portion of the Port of Los Angeles (POLA).

Although there have been no specific studies of WC movements, purse seine catch data indicate that they are found inshore (shallower) at night during summer months, but move offshore (deeper water) during winter months (Allen and DeMartini, 1983). Although several tag and recapture studies have been done in attempts to quantify movement patterns of some species known for having high contaminant levels around the Palos Verdes Peninsula (kelp bass, BSB, CSF), most of the data have only revealed patterns of dispersal (Love et al., 1987; Lowe and Bray, 2006).

Standard tag and recapture methods are typically inadequate for quantifying fine-scale movements and degree of site fidelity. For instance, previous tag and recapture studies of kelp bass at Santa Catalina Island showed that kelp bass were recaptured at distances up to 125 km away from where they were tagged; however, a majority of individuals were recaptured less than 1 km from their original capture location (Young, 1963). Similar observations have been made

for BSB and CSF (Mason, 2009; Love et al., 1987). While these data suggest that these fish show high site fidelity to small areas, the nature of sampling for this technique can grossly underestimate movements and overestimate site fidelity (Lowe and Bray 2006).

Innovations in acoustic telemetry technology provide methods for assessing fine-scale movement, site fidelity, and habitat use over greater spatial areas and longer time periods, for increased numbers of tagged individuals (Lowe et al., 2003; Lowe and Bray, 2006; Topping et al., 2006; Bellquist et al., 2008). Recent studies examining home range size, site fidelity, and habitat use of kelp bass and BSB using acoustic telemetry techniques have indicated that both of these species have fairly small home ranges (~ 10,000 m^2) and show high site fidelity to their home ranges (Lowe et al., 2003, Mason, 2008) despite using different habitats. BSB and CSF, however, are known to exhibit seasonal spawning migrations and it is estimated that fish may move as far as 100 km from their home ranges to join seasonal spawning aggregations. Approximately 100,000 BSB are caught annually on Huntington Flats (> 30 km from Palos Verdes) during their summer spawning aggregations and it is unknown how far individuals travel to form these spawning aggregations. It is very likely that BSB with home ranges at PV Shelf travel to Huntington Flats to join these large summer spawning aggregations.

Lowe and Bray (2006) proposed a model to predict fish home range size relative to habitat complexity. They predicted that fish that show high affinity for complex substrata should have small home ranges, since they are reliant on this complex and more productive habitat (i.e., rock reef) for shelter and food. Conversely, fish associated with less complex substrata such as sand habitats should have larger home ranges due to reduced prey abundances and lack of refuging habitat. In addition, differences in foraging behavior between soft substratum-oriented species such as WC and BSB may also influence home range sizes and site fidelity. For instance, sub-adult and adult WC are schooling benthic foragers, feeding on benthic fauna, whereas BSB are ambush predators and use lie-and-wait strategies to capture prey. Therefore, WC may be expected to range over greater areas to meet their foraging needs, whereas BSB may be expected to range a lot less and show much higher site fidelity to areas where prey may aggregate.

1.2 PROJECT GOALS AND OVERALL APPROACH

The overall focus of the fish movement study was to quantify movement patterns, degree of site fidelity, habitat use, and migration patterns of WC and BSB caught around the White Point outfalls so that these data could be used to inform bioaccumulation models, with the ultimate goal of evaluating the potential success of the mitigation cap.

The specific goals of the project were to:

- Characterize fine-scale movement patterns of WC and BSB around the White Point outfall pipes over 8-24 month time periods.
- Characterize degree of site fidelity of WC and BSB around the White Point outfall pipes.
- Determine whether fish tagged at the outfall area transit into the Los Angeles and Long Beach Harbor and to what extent they move back and forth.

To accomplish these goals, we used a combination of passive acoustic telemetry techniques to monitor and quantify movement patterns of these two species over different spatial scales over a 2-year period. Fine-scale movements of fish were quantified using a Vemco VR2W Positioning System (VPS) allowing for high resolution positioning (± 5 m) of tagged individuals across an 8.5-km^2 area surrounding the outfall area of highest sediment contamination. During the time of field collection this was one of the largest VPS telemetry arrays in the United States. Additional receivers were added around the tighter VPS receiver array to provide a total of ~15 km^2 area of coverage along PV Shelf (Fig. 1). Several acoustic receivers were placed inside and outside the Los Angeles and Long Beach Harbor entrances to monitor potential movements of fish tagged along PV Shelf into the harbors and to quantify how often these migrations might occur.

The original plan was to catch and tag 100 fish (75 WC and 25 BSB) on each side of the outfall pipe with coded acoustic transmitters in order to determine whether the outfall pipes functioned as barriers to movement. Movements were analyzed in a GIS to quantify 1) the amount of time fish spend along the core outfall site; 2) how often fish cross over the outfall pipe; 3) the degree of site fidelity fish show to PV Shelf; and 4) how often fish from PV Shelf enter the Los Angeles and Long Beach Harbors.

1.3 PROJECT TEAM

Judy Huang, P.E., served as the EPA Remedial Project Manager (RPM) for PV Shelf and allocates resources and provides technical direction. ITSI Gilbane Program Manager, Robert Lindfors was the primary contract coordinator for his project.

Joe Gully and Bill Powers at the Sanitation Districts provided field assistance and coordination of receiver placement. The Sanitation Districts provided both their Ocean Sentinel research vessel and remotely-operated vehicle (ROV) to assist with recovering acoustic receiver and acoustic releases that did not release on command. Dr. Dave Witting of NOAA provided advice and guidance on receiver placement and data interpretation. The NOAA Montrose Settlement Restoration Program (MSRP) provided additional funds for a mobile receiver array.

Dr. Chris Lowe of the CSULB Shark Lab was the principle investigator and coordinator for the project. Dr. Lowe along with CSULB graduate students, Barrett Wolfe, Garry Teesdale, and Tom TinHan, and undergraduate marine biology students, Lindsay Brown and Jeremy Browning, were responsible for deployment and maintenance of the acoustic receiver array, fish capture and tagging, data maintenance and analysis.

2.0 METHODS

This section provides a detailed description of the technology, array design, tagging procedures and analytical methods used for movement analyses.

2.1 TRACKING TECHNOLOGY

The technology used to quantify movement patterns of WC and BSB was Vemco acoustic telemetry transmitters and receivers. The basis of this system is the automated VR2W omni-directional underwater acoustic receiver, which is designed to listen and record acoustic pulses emitted by transmitters operating at 69 kHz. Receivers have an acoustic detection range proportional to the power output of the transmitters used and have a narrow bandwidth. Because all transmitters operate at the same frequency, transmitter serial number is encoded in a unique pulse train; however, only one transmitter can be identifiable at a time. To allow for adequate detection frequencies with multiple tagged individuals in the same location, pulse train emissions of transmitters are randomized within a predetermined minimum and maximum interval (e.g., 50-130 s and 110-250 s). Transmitters with longer pulse emission intervals therefore have longer battery lives.

Although coded acoustic transmitters are detectable within a 360° radius of a single receiver, the exact position of the tagged fish within that detection radius cannot be determined. Using receivers in a widely spaced array can provide simple presence/absence data for the areas within the detection radius, but is lacking in spatial resolution. However, using the Vemco VPS enables us to determine an actual position using the same receivers by placing them in a more closely spaced configuration. Vemco VPS works using the same VR2W acoustic receivers, but allows for a rendered position of the tagged fish if it is detected simultaneously by at least three neighboring receivers. To correct for clock drift in each VR2W, a synchronizing transmitter is associated with each receiver and provides the ability to accurately calibrate receiver clocks so that the detection times can be used to multilaterate a position of the transmitter (Espinoza et al., 2010).

2.1.1 Acoustic Receiver Arrays and Gates

To quantify fine-scale movements of tagged fish, we deployed 24 VR2W acoustic receivers in a staggered grid, each 600 m apart from each other. This comprised the VPS array, with the shallowest end of the array in 20-m depth and the deepest row of receivers in 65-m depth. Based on acoustic detection range tests, this spacing provided sufficient overlap of detection ranges between neighboring receivers, so that VPS could be used to calculate transmitter positions within the array. This VPS array provided 8.5 km^2 of detection coverage surrounding the outfalls. Six additional receivers were placed on each side of the VPS array ("bracket arrays"), also in a staggered grid, to provide additional detection coverage, but without positioning capability. The bracket arrays provided 7.5 km^2 of additional detection coverage area. Together, the VPS array and the bracket arrays are referred to herein as the PV Shelf array.

One-to-two acoustic receivers were positioned inside and outside the mouths of Los Angeles (Angel's Gate) and Long Beach (Queen's Gate) Harbors. By positioning receivers just inside and outside the harbor entrances, we used these receivers as detection "gates", enabling us to determine when tagged fish enter and exit the harbors (Figure 1). The gate receivers provided an additional 2 km^2 of detection coverage area. The total receiver detection coverage for all arrays and gates was ~18 km^2.

Concurrent with the EPA study, Dr. Lowe and his students, with funding from POLA and the Port of Long Beach (POLB), were quantifying movement patterns of WC in the Los Angeles and Long Beach Harbors using the same technology. A number of acoustic receivers were deployed throughout the Ports in order to quantify inter-Port movements. As part of this study's experimental design, WC were tagged in four different regions of the harbors. These receiver placements were designed to operate like gates to detect directional movement through the harbors (Figure 2). Fish tagged in both studies were detectable on both sets of acoustic receivers, thereby increasing the total areas monitored by an additional 1.78 km^2; however, only data collected from fish tagged in the PV Shelf project are presented here.

Receivers were placed on the seafloor using two methods. In shallower depths (<30 m), receivers were attached to sand screws drilled into the sand substratum and were held in an upright position using two 8-lb flotation subsurface trawl floats. These receivers were deployed

and retrieved by divers. Divers used a taut mooring line and float to determine accurate positions of each receiver via GPS at the surface. Deeper receivers were secured to the seafloor using biodegradable sand bags (2 bags each, weight ~20 kg) that were dropped from the surface vessel. Sea Sub Sonic burn-wire acoustic releases were attached to the receiver line, which was suspended off the sea floor using two 8-lb flotation subsurface trawl floats (Anthony et al., 2012; Figure 3). These receivers were retrieved using the acoustic releases and redeployed by attaching the receiver/acoustic release line to new set of sand bags. In most locations acoustic receivers were positioned 2-3 m above the sea floor; however, because of the height and obstructive nature of the Sanitation Districts' outfall pipes, receivers immediately adjacent to pipes were positioned 5-7 m above the seafloor. This helped reduce acoustic shadows cast by the pipes and increased probability of detecting fish associated with the pipes.

Dive and ROV survey data indicated that even in deeper depths we were able to accurately reposition receivers to within a 10-m radius after each deployment. Accurate geopositions of these acoustic release "dropped" receivers were determined using a light break line attached to a fishing rod that could be used as an indicator to determine then the boat (GPS) was directly above the deployed receiver at depth.

Since the speed of sound is affected by water temperature, temperature dataloggers (Onset TidBits) were attached to 14 receivers spread throughout the array and were programmed to record water temperature every 30 min. Water temperature data were supplied to Vemco for rendering of VPS positions.

Extensive range tests and array calibrations were conducted in May and June 2010. Acoustic transmitters were suspended at locations throughout the VPS array and transmitters were slowly dragged throughout the array in order to calibrate detection ranges and efficiencies. Based on results of the first calibration, the receiver array was reconfigured, placing the receivers within the VPS array closer together (~500 m apart) to ensure greater detection and position rendering rates.

All receivers were recovered and downloaded every 3-4 months and rebatteried once a year. Not including lab-based preparation and equipment maintenance, average in-field gear deployment,

downloads, and maintenance required an average of 1,116 man hrs of sea time effort and 189 man hrs of diving effort. Placement, recovery and maintenance of the acoustic receiver array was complicated by trawling and fishing activity on PV Shelf as well as occasional gear losses attributed to anchor entanglements and the 2010 tsunami.

2.1.2 Mobile Acoustic Receivers

Maintaining such a large fixed position array is challenging and expensive. In addition, quite often fish exceed the area covered by the fixed acoustic array. Providing adequate coverage to encapsulate all fish movements is cost prohibitive. We employed a new method of increasing acoustic tag detection area coverage, by deploying VR2W acoustic receivers off fishing vessels operating in the Santa Monica, Long Beach and Huntington Beach areas. With funding from the MSRP, we purchased ten additional acoustic receivers that were deployed by participating recreational fishers and Commercial Passenger Fishing Vessels (CPFV) that were fishing in areas where WC and BSB have been previously captured. Fishers were instructed to record the date, time, and geographical location when at anchor and to deploy the acoustic receiver off the side of the vessel during fish activity.]

Three receivers were deployed on vessels operating out of Santa Monica Bay, five receivers were deployed off vessels operating out of San Pedro and Long Beach, and one receiver was deployed from vessels operating out of Dana Point. In addition to the vessel deployments, one receiver was deployed with a sand bag mooring and acoustic release in the area of Horseshoe Kelp, a popular sport fishing location approximately 10 km from White Point. Researchers often went out on vessels to manage deployments and record data. Receivers were retrieved and downloaded every month. Most of the mobile receiver effort occurred during summer months.

Receiver deployment coverage was estimated for all locations per year using a 1-km^2 grid system. The number of fish detections per unit listening-hour was determined for all locations by grid system. The periodicity and distance of detections throughout the recreational fishing areas relative to the tagging locations on the PV Shelf was used to estimate the timing and distances of migration.

2.1.3 Acoustic Transmitters

Due to the small average size of WC, only small acoustic transmitters could be used for this project, which limited the power output and battery life of the transmitters that could be used. To standardize the detection ranges of the receivers within the array, even larger BSB were surgically fitted with the same small size transmitters as those used for WC. WC at least 170 mm in standard length (SL) were surgically implanted with Vemco V9-1L coded acoustic transmitters (9 mm diameter X 24 mm long, 2.2 g in water, 146 dB power output). Since it was expected that WC would be more actively moving throughout the array, faster pulsing transmitters were selected (pulse interval 50-130 s, 222 d battery life) to increase detection rates during transiting movements. BSB at least 240 mm TL were surgically implanted with Vemco V9-2L coded acoustic transmitters (9 mm diameter X 29 mm long, 2.9 g in water, 146 dB power output). Since it was expected that BSB would be more sedentary within the array, slower pulsing transmitters were selected for this species (pulse interval 110-250 s, 738 d battery life).

2.2 FISH COLLECTION AND TAGGING

After calibration of the acoustic receiver array, fishing and tagging commenced in July 2010. Fish were caught on hook and line using a variety of hook sizes and baits in order to optimize capture of target species (WC and BSB) and minimize bycatch. Different fishing gear and methods were required for each species. BSB were also targeted using baited fish traps. All fishing activities took place within detection range of the VPS array. The capture and release locations of each target fish caught were recorded.

2.2.1 Transmitter Implantation

Caught target species were transferred to a cooler of chilled seawater dosed with 75 mg per ml of MS-222 (a fish anesthetic). Fish were kept in the anesthetic bath until they lost coordination and were in a level-4 sedation state. The fish were then transferred to a cooler of fresh seawater and 1.5 cm long incision was made through the abdominal wall and peritoneum. An acoustic transmitter was inserted into the abdominal cavity and the wound was sutured closed with 2-3 interrupted stitches of Chromic gut or PGA) size 2-0 or 3-0 suture. The fish was then measured, weighed, sexed based on internal morphology if possible, and transferred to another cooler to recover from the anesthetic and surgery. Surgeries were conducted while the vessel was drifting away from the capture location and all fish were released after implantation within detection

range of the PV array. Upon release, fish were monitored for indicators of post-release condition. All surgical tools were sterilized between surgeries and transmitters were sterilized prior to insertion into fish. All fish handling, surgical and post-operative care procedures were approved by the CSULB IACUC committee (Protocol #283).

2.2.2 Tagging Effects and Post-Release Survival

Although previous telemetry tracking studies on BSB had been conducted, confirming high post-release survivorship and minimal tagging effects, nothing was known about post-release effects of catch, tagging and release of WC. In fact, previous attempts at standard tag and recapture of trawl caught fish had indicated potential high mortality. Prior to the deployment of any coded transmitters in WC, a pilot study was done where two WC were caught and tagged using methods described above, but then actively tracked for 20 hrs after release to confirm post-release survivorship. Both individuals showed initial periods of reduced movement over the first 3-6 hrs following release, after which they resumed what was assumed to be normal behavior.

2.2.3 Fishing Effort and Transmitter Deployment

The original experimental design entailed catching, tagging and releasing 75 WC and 25 BSB on each side of the Sanitation Districts' outfall pipes in order to determine if the pipes function as barriers to movement and assess overall site fidelity and habitat use. However, contrary to previous indications of abundance, WC were extremely difficult to capture within the VPS array area at PV Shelf. As a result, changes were made to the transmitter deployment design. A variety of techniques were employed, including night and pre-dawn fishing, fish trapping, and use of live bait. Over 2,000 fisher (man) hours were spent in the summers of 2010 and 2011 attempting to catch and tag WC and BSB. The average CPUE for WC within the VPS array study area was 21 man hours per fish as opposed to 3.1 man hours per fish for WC within the harbors (Lowe et al., unpubl. data). In addition, the average CPUE for BSB within the VPS array area was 8.1 man hours per fish.

Due to the difficulties catching WC of sufficient size to tag, fish were tagged where ever they were caught within the array and due to the high costs of effort and low catch rates only 97 WC and 55 BSB were tagged. WC were targeted throughout the bounds of the array, from 20- to

60-m depth. During the first summer of the project (2010) the highest CPUE was found to be between 25- and 35-m depth, between the outer-most outfall pipes. Based on this finding, WC capture efforts were focused in the high CPUE area, although areas throughout the entire PV array were still targeted on occasion. Sixteen of the remaining transmitters were opportunistically placed in CSF that also were caught within the VPS array during normal fishing activities.

The CPUE for WC was relatively low throughout three seasons of capture efforts (2010-2012) for this project, as well as capture effort in a POLA funded project in 2013. Trawls conducted by the Sanitation Districts have also showed reduced catch of WC on PV Shelf in recent years (Joe Gully, pers. comm.) and fisheries independent data suggest WC abundance has declined in the years preceding the present study (Herbison et al., 2001). This suggests that the low CPUE of WC in the present study may not be atypical.

2.3 DATA ANALYSES

2.3.1 VPS Data Rendering

VPS array receiver data, tag information, and water temperature data were sent to Vemco Ltd. for position rendering after each download. Dr. Lowe has worked with Vemco in developing and calibrating this new VPS technology and position rendering software, and much of his field data have been used for adjusting and improving the position rendering process (Espinoza et al., 2010). Because this was the largest application of this new technology in the United States, Vemco agreed to provide additional complimentary data renderings and calibration analyses (approximately $10,000 worth of complimentary data renderings were provided by Vemco). Rendered fish positions were layered over available habitat maps (i.e., bathymetry, anthropogenic structures, DDT, PCB) in a GIS for movement and habitat analyses.

2.3.2 Site Fidelity

Degree of site fidelity was determined for WC and BSB over nominal battery life of the transmitters by quantifying the proportion of days fish were detected within the entire PV Shelf array. Daily presence is defined as at least two detections on a receiver(s) in the PV Shelf array on a given day. Degrees of site fidelity for individuals were based on the proportion of days fish were detected within the PV Shelf array relative to the number of days at liberty over the course

of the study. Detection data for all fish were pooled over successive 1-day or 1-week periods depending on species and site fidelity was compared over periods of time and across sample populations.

2.3.3 Size of Space Use

Overall relative coarse-scale area use of all tagged individuals within the acoustic receiver array was determined using bubble plots representing the number of fish detected of each species at each receiver and the avg. number of detections per individual at each receiver over the duration of the study. These provide a coarse-scale representation of how tagged fish use the entire array area.

Area use sizes for fish detected within the VPS portion of the array were determined by Kernel Utilization Distribution (KUD) analyses using the R package adehabitatHR, which employs a probabilistic method for quantifying area use size and shapes. Previous studies suggest a minimum sample size of 30 positions for accurate KUD analysis (Seaman et al., 1999). Therefore, only fish with ≥ 30 positions were included in area use estimations. Overall area use per individual within the VPS array was calculated using a 95% KUD with a bivariate normal kernel and core area use was calculated using a 50% KUD. A smoothing parameter (h) was selected ad hoc for each species. Degree of home ranging behavior was determined using a linearity index.

2.3.4 Habitat Use

Unfortunately, there are only poor spatial resolution benthic habitat maps for most of the outer shelf area, so no detailed benthic habitat use analyses could be made. By layering VPS-rendered position data over bathymetric data (USGS, 2002) in a GIS we determined the degree of depth selection by comparing the distribution of observed values (VPS-rendered positions) to that of the a null (uniform) distribution (randomized positions) with a Pearson's chi-squared test. P values were simulated with 2000 replicates. A similar approach was utilized along with Euclidean Distance-based Analysis (Conner and Plowmen, 2001; Mason, 2009) to determine selection for habitat of varying distances to the outfall pipes.

To determine whether the White Point outfall pipes function as a barrier to WC movement, the proportion of individuals that showed movement trajectories that indicate swimming across the pipe were determined from VPS-rendered data.

In order to quantify patterns in potential contaminant exposure across the sample population of WC, VPS-rendered position data was layered over sediment contaminant data interpolated (natural neighbor method) from sediment core data from the 2009 sediment sampling event (Total DDTs [ppb] of 0-8 cm core depth; EPA, 2013), and an exposure metric ($\bar{e} \cdot n_p$) was calculated for individual WC where $\bar{e}$ is the mean total DDTs sediment concentration (ppb) at the positions rendered for each WC, and n_p is the number of rendered positions. The distribution of the EM was compared to that of WC DDT tissue (skin-off filet) concentration data (NOAA, 2007).

To determine to what degree the outfall pipes and associated ballast act as a barrier to WC movement, the number of WC with positions 1) west of the westernmost outfall pipe, 2) between the two active outfall pipes, and 3) east of the easternmost outfall pipe were compared in order to quantify the proportion of the sample known to have crossed outfall pipes. To determine if individuals with few or no VPS renderings crossed outfall pipes, fish detected by both the westernmost and easternmost row of receivers (OA-1, OA-2, OA-3, OA-4; OA-21, OA-22, OA-23, OA-24, respectively; Figure 1) were quantified.

2.3.5 Shelf and Harbor Migrations

Degree of movement of tagged fish from PV Shelf into Los Angeles or Long Beach Harbors were determined by the number of times fish are detected moving in and out of the harbor entrance gates. Movements of BSB between Palos Verdes and Huntington Flats were determined from acoustic receiver detections from both the fixed and mobile arrays. The degree of movements between Palos Verdes and Huntington Flats were determined by the portion of fish detected at Huntington Flats and the time of year they are detected there.

2.4 DATA MANAGEMENT SYSTEM

All downloaded acoustic receiver data were maintained in the Vemco VUE database. These data were then exported out and entered into a customized database, along with tagging data, receiver deployment data, and water temperature data. This database was backed up to two external hard

drives and two dedicated project computers. All field datasheets were scanned and saved as pdf files and categorized by date. These were also stored on all back up sources. Additional background spatial explicit datasets (e.g. bathymetry, sediment contaminant concentrations) were stored in a project specific GIS. These data were also backed up on all external data storage sources.

3.0 RESULTS

This section presents the results of the fish movement monitoring study (July 2010 – September 2012) analyzed in a GIS to quantify the degree of site fidelity fish show to PV Shelf, the fine-scale area use of the main contamination field, large-scale movements of fish from PV Shelf to Los Angeles and Long Beach Harbors, and potential spawning migrations to Huntington Flats and Horseshoe Kelp.

3.1 WHITE CROAKER

Ninety-seven WC were caught, tagged, and released within the PV acoustic receiver array area between July 2010 and August 2011 (Figure 4A). Expected battery life for WC transmitters was 227 d for the majority of individuals (n = 72), and 436 d for a subset (n = 25). The mean (± SD) TL of tagged WC was 228 ± 13 mm (range: 199-260 mm) and the mean estimated age was 7.9 ± 1.3 years (range: 5.4 to 11 years; Figure 5). All tagged WC were above the length at 100% maturity (Love et al., 1984). WC are known to spawn from November to May (Love et al., 1984); however, the vast majority of tagging effort was conducted outside of WC spawning season. A mortality rate of 14.4% was estimated from 14 of the tagged WC due to stationary transmitter position data after release from tagging. Transmitters that demonstrated detection patterns consistent with mortality were removed from all analyses. There was no significant effect of TL on WC post-tagging survival (two sample t-test, $p = 0.14$). Sex was indeterminable with the exception of a small proportion of fish in which gonads were visible during tag implantation surgery, and therefore not included in analyses. WC transmitters yielded a total of 1,849,694 detections and 76,784 VPS rendered positions (Figure 6).

3.1.1 Characterization of Fine-Scale Movement Patterns Around PV Shelf

WC were detected on every array station receiver, indicating a widespread extent of use of the PV Shelf by the tagged portion of the population (Figure 7A). Stations in close proximity to the location of transmitter deployment, in 25- to 35-m depth, detected the greatest number of WC, accounting for detection of 77 tagged individuals (92.8% of tagged WC). Moderate numbers of tagged WC (range: 14-51) were detected on the middle and inshore bracket stations, and the stations with the least WC detected being the outer east bracket receivers (55-65 m of water; Figure 7A).

Intensity of general area use (total #detections/total # WC detected) ranged from 3 to 5,350 (Figure 7B). Stations in close proximity to the outfall pipes had the highest mean intensity of use (total detections/total WC detected), with greater than 3,400 total detections/all fish for stations OA-10 and OA-11 (located between the active outfalls in depths ranging from 30 to 50 m). Although only moderate numbers of individual WC (range: 18 to 36) were detected on stations OA-12, OA-16, OA-20, and OA-24, intensity of use was relatively high (range: 555 to 948 detections/fish) in comparison to stations in shallower water that were not immediately adjacent to the outfall pipes (3-646 detections/fish). Intensity of use was the lowest in the brackets (east - range: 68 to 331, west - range: 94 to 363 detections/fish).

The VPS algorithm was able to render geographical positions of 58 (69.9%) of the tagged WC. A smoothing parameter (h = 40) was selected for suitable convergence of KUD area use estimates. The mean number of VPS positions rendered per fish was 1,324 ± 2,497 (range: 11 to 12,211; Figure 8). Total area use estimates (from 95% KUD contour) ranged from 0.057 to 1.3 km^2 with a mean of 0.36 ± 0.28 km^2, corresponding to approximately 4.4 ± 3.4% (range: 0.7% to 15.8%) of the area within the VPS enabled PV receiver array over the duration of the study. Core area use estimates (from 50% KUD contour) ranged from 0.008 to 0.114 km^2 with a mean of 0.043 ± 0.026 km^2 (Figure 8), corresponding to approximately 0.5 ± 0.3% of the area of the VPS enabled array (Figures 8 and 9).

Estimates of WC total area use spanned nearly the entire VPS array, with a concentration of use across the entire array between the 20- and 30-m isobaths, and in close proximity to the outfall pipes (Figure 8A). There was no correlation between the number of detections and the size of core area use for WC tracked within the VPS array (Pearson's Product-Moment correlation: t = 0.97, df = 56, p = 0.337), suggesting areas may be revisited over time, as core area did not increase with the number of positions recorded. Core use areas were concentrated between the outfall pipes in depths shallower than 30 m (Figure 8B). Mean depth of VPS derived positions for individual WC was 30.6 ± 7.1 m (range: 22.5 – 56.3 m), with only a small subset of individuals with positions in depths greater than 50 m (Figure 10). Depth selection analysis indicated depth selection significantly different than expected from the null (random) distribution (Pearson's chi-squared test, χ^2 = 39922.6, p < 0.0005). Comparison of observed and expected

distributions suggests greater than random selection for depths of 25-35 m, similar-to-random use of the 20-25-m and 35-40-m ranges, and less than random selection for 45-80-m range (Figure 11).

VPS-derived position data indicated that tagged WC spent a considerable amount of time moving along habitat adjacent to outfall pipes. Analysis of fish proximity to outfall pipes indicated selection significantly different than expected from the null (uniform) distribution (Pearson's chi-squared test, $\chi^2 = 26203.6$, $p < 0.0005$). WC demonstrated a higher than expected affinity for habitats 0-100 m and 100-200 m from the nearest outfall pipe structure, and lower than expected selection for habitats of all other distances (with the exception of 700-800 m; Figure 12). In addition, VPS-derived position data indicated that 173 ± 860 positions per fish were found on the east side of the outfall pipes, while there were 1038 ± 860 positions per fish in between the outfall pipes, and only 68 ± 188 positions per fish to the west of the outfall pipes (Figure 13).

VPS-derived positions of WC were located in habitats with a range of DDT sediment concentrations, from virtually 0 ppb to within the vicinity of the DDT 'hotspots' with over 10^6 ppb DDTs (Figure 14C). The contaminant exposure analysis revealed a long-tailed frequency distribution with a wide range in exposure metric (EM) across the study WC sample; fourteen WC had an EM of 0, while five WC had an EM of over 10^8 (max = 4.4×10^8; Figure 14B). The mean EM value was $3.7\times10^7 \pm 9.8\times10^7$. The EM frequency across the current study's WC sample bears an apparent resemblance to the frequency distribution of DDT body burden in WC sampled throughout the Southern California Bight (Figure 14A; NOAA, 2007).

Of the 58 WC that had VPS-rendered positions, 46 (79.3%) of individuals demonstrated movements across at least one of the large easternmost and westernmost outfall pipes. Using a combination of VPS derived positions or single acoustic receiver detections, 26 individuals were found to cross both major outfall pipes.

3.1.2 Characterization of the Degree of Site Fidelity to the White Point Outfalls

Individual WC were detected in the study site for a range of 1 to 147 cumulative days, corresponding to 0.2-74.2% of transmitter battery lifespan of each fish. Forty-seven (56.6%) WC were present in the PV Shelf array for 7 cumulative days or less, and 27 individuals (32.5%)

were present for < 3 cumulative days. Fourteen (16.9%) were present in the PV Shelf array for > 60 cumulative days, while six (7.2%) were present for > 100 cumulative days (Figures 6 and 15).

Following transmitter deployment, the majority of WC temporarily emigrated from the PV Shelf array (Figures 15 and 16). The proportion of WC present in the PV Shelf array post-tagging declined to 0.81 after day 1, to less than 0.33 after day 5, to a low of 0.24 at day 9. The proportion then increased gradually to 0.37 present at day 27 post-tagging. From this peak at approximately 1 month post-tagging to 227 days (the battery life of most WC transmitters) ,the proportion of WC present in the PV Shelf array gradually decreased by approximately 2.2% per day (logit-link binomial regression, $p > 0.99$; Figure 16; Tables 3 and 4). Although over half of WC emigrated from PV Shelf 3 days post-tagging, 61 (73.5%) of WC were detected over total time spans of > 10 days and 36 (43.4%) were detected over total time spans > 100 days (Figure 17), indicating the majority of WC (including immediate post-tagging migrants) can be precluded from mortality or permanently emigration due to tagging related trauma.

Of 84 WC, 23 (27.4%) left the PV array in the northwest direction (in the direction of Santa Monica Bay) without having left the array to the southeast previously. Thirty WC (35.7%) migrated from the PV array towards the southeast (toward San Pedro bay). Eighteen WC (21.4%) left the PV array in both directions for periods of greater than a day, but of these individuals that made at forays in both longshore directions, 15 were last detected emigrating from the PV array in the southeast direction, while three emigrated towards the northwest. The direction in which 14 WC (16.7%) emigrated was indeterminable due to ambiguous detection data during the last detections made in the array.

3.1.3 Degree of WC Connectivity Between PV Shelf and LA Harbor

Forty individual WC (48.1%) were detected on harbor gate receivers indicating movements to the vicinity of, or entering Los Angeles and Long Beach Harbors. Thirty-nine WC (47.0%) were detected by Angel's Gate receivers and eight individuals (9.6%) were detected by Queen's Gate receivers. WC were detected for an average of 9.3 ± 16 days on harbor gate receivers. Thirty-four WC (41.0%) were detected by stations located inside of the Federal Breakwater, indicating those fish were confirmed to enter the harbor. However, analysis of detection efficiencies

around the harbor entrance gates indicates it is likely other WC such as those six individuals detected only on the outer gate receivers may have entered the harbor undetected.

Of the WC that migrated to the harbor, the majority made a single migration or subsequently returned to PV Shelf (Figures 6 and 18). Fourteen WC (16.9%) demonstrated multiple migration events between PV Shelf and Los Angeles and Long Beach Harbors, which ranged from eight individuals making two round trips between PV Shelf and the harbors to two individuals that made up to 9 round trips. These migrations between the PV Shelf array and the harbor entrances were typically quick and apparently directional, with the shortest time transit time of less than 4 hrs. No WC were detected by any of the mobile receiver deployments.

3.2 BARRED SAND BASS

Fifty-five BSB were successfully tagged in the study (one additional fish was tagged with what appears to have been a faulty transmitter; Figure 4B). Sex was indeterminable, with the exception of a small proportion of fish in which gonads were visible during tag implantation surgery, and therefore not included in analyses. The fish ranged in size from 280 mm to 480 mm (mean = 386 ± 45 mm; Figure 19A). A von Bertalanffy growth curve (Love et al., 1996) was used to calculate ages based on body lengths that ranged from 9.5 years to 18.8 years (mean = 13.7 ± 2.1 years; Figure 19B). Based on the length and age at 50% maturity for males and females (males: 219 mm, females: 239 mm; Love et al., 1996), all BSB tagged were sexually mature and all but three were longer than the minimum length of 12” (305 mm) mandated by the California Department of Fish and Wildlife (CDFW; increased to 14” [356 mm] as of 01 March 2013). A total of 844,656 detections were recorded from all receivers for the 55 BSB tagged within the PV Shelf array (Figure 20), resulting in 17,374 VPS-rendered fine-scale positions. In addition, while WC is an active forager, exhibiting frequent movements among areas, the BSB is an ambush predator that exhibits sedentary behavior and maintains close proximity to the substrate (Love et al., 1996), increasing the probability of signal interference from rocky structure for this species.

3.2.1 Area Use

A minimum of 30 positions was rendered for 41 of 55 BSB tagged (74.5%). A smoothing parameter (h = 8) was selected for suitable convergence of KUD area use estimates. Overall

area use (95% KUD) ranged from 4,976 m^2 to 174,750 m^2 (mean = 29,187 ± 35,597 m^2). Size of core areas used (50% KUD) ranged from 779 m^2 to 13,288 m^2 (mean = 2,834 ± 2,508 m^2; Figures 21 and 22; Table 5).

3.2.2 Site Fidelity

All tagged BSB were subsequently detected in the PV Shelf receiver array (Figures 7C and 7D). The number of individual BSB detected by PV Shelf array receivers between the 20-40-m isobaths (first two rows) ranged from 24 to 49 (mean = 41.3 ± 7.8). Intensity of area use of tagged BSB within the PV Shelf receiver array ranged from 9 to 4,369 detections/fish (mean = 1,693 ± 1,471 detections/fish). The highest intensity was concentrated at receivers near a natural rocky reef (OA1, OA2, OA5; mean = 3,055 ± 1,138 detections/fish) and along the rocky ballast of the outfall pipes (OA6, OA9, OA10, OA13, OA14, OA17; mean = 1,803 ± 1,270 detections/fish). The number of detections per individual decreased for receivers east of the rocky outfall ballast habitat (OA18, OA21, OA22; mean = 112 ± 90 detections/fish). Receiver stations in the row located between 45-55 m (OA3, OA7, OA11, OA15, OA19, OA23) detected a mean of 25.5 ± 8.2 individual BSB (range: 12–36 individuals). Intensity of use was also relatively less on receivers at this depth (mean = 104 ± 71 detections/fish). The deepest row of receivers at 55-65 m (OA4, OA8, OA12, OA16, OA20, OA24) detected between 0 and 10 individuals (mean = 5.7 ± 3.8) and had the lowest intensity (mean = 5.7 ± 3.8 detections/fish).

Coarse-scale data from individual receivers were also used to determine the presence of each fish throughout the study period and to calculate the overall proportion of fish detected on a daily basis (Figure 20). Over the course of the entire study period, 16 fish (29.1%) exhibited low site fidelity (detected <30% of days at liberty), 19 (34.5%) exhibited moderate site fidelity (detected between 30-60% of days at liberty), and 20 (36.4%) exhibited high site fidelity (detected >60% of days at liberty; Figure 20).

BSB were expected to migrate during the summer (June, July, and August), but during non-spawning season (September-May), eight fish (14.5%) exhibited low site fidelity, 12 fish (21.8%) exhibited moderate site fidelity, and 35 fish (63.6%) exhibited high site fidelity (Figures 20 and 23).

3.2.3 Spawning Migrations

No BSB were detected entering or exiting the LA or LB Harbors. Movements of BSB between White Point and potential spawning grounds in Huntington Flats were determined by mobile receiver detections. Mobile receiver deployments ranged from northern Santa Monica Bay to San Onofre with the majority of deployments occurring around Huntington Flats (Figure 24). A total monitoring time of 279 hours was logged from vessel deployed receivers, which resulted in 96 detections of 23 tagged BSB and a detection rate of 0.344 detection/hr (Figure 25). A receiver station temporarily moored at Horseshoe Kelp recorded 1,011 detections of five BSB over a 66-day period, which resulted in a detection rate of 0.639 detections per hour.

Over the duration of the study period, 23 of the 55 (42%) BSB tagged were detected in Huntington Flats and Horseshoe Kelp by mobile receivers deployed during summer months (Figure 26). No detections were recorded on mobile receivers deployed north of the PV Shelf array, or south of Huntington Flats. Maximum linear distance from the array for each fish detected ranged from 18.9 km to 29.9 km (mean = 26.4 km ± 0.8 km; see Table 6).

3.3 CALIFORNIA SCORPIONFISH

CSF were captured opportunistically while targeting BSB in the spring of 2012. A total of 16 CSF were tagged between 10 March 2012 and 14 May 2012 (Figure 4C), just prior to their known spawning season of May – September (Love et al., 1987). The total potential detection period for CSF was 5-7 months. TL ranged from 270 – 356 mm (mean = 314 ± 27.4) and mass ranged 410 – 1,010 g (mean = 717 ± 198). Fourteen of the 16 (87.5%) of CSF tagged were detected in the PV Shelf array post-tagging. The PV Shelf array recorded a total of 56,382 detections of tagged CSF over the remaining 7-month period of monitoring, with a mean of 8,321 ± 9,960 detections/fish recorded (Figures 7E and F). Only 619 VPS-rendered fine-scale positions were determined for the 11 individual CSF over the remaining monitoring period (mean = 56.2 ± 76.1 detections/fish).

3.3.1 Characterization of Fine-Scale Movement Patterns Around PV Shelf

The number of individual CSF detected was fairly even among receiver stations in the central array (OA 1-24), with only three receivers (OA-4, OA-20, OA-24) detecting fewer than four individuals, the rest detecting between 4-13 CSF (28.6 to 92.9%; Figure 7E). The east bracket

also had fairly even numbers of individuals detected, ranging between 6 and 12 CSF. No CSF were detected by the west bracket receiver stations.

Intensity of area use was greatest at station OA-13 with 5,349 detections per individual on the inshore most row between outfall pipes, followed by OA-5 with 3,128 detections per individual, on the inner most row in close proximity to the tagging location of several individuals (Figure 7F). Intensity of area use was moderately high on stations between outfall pipes (OA-10, OA-11, OA-13); however, the majority of receiver stations had < 100 detections per individual, including those that had detected almost all 14 individuals detected in the array (PVS E-2, 12 individuals, 56 detections per individual) indicating relatively low intensity of area.

Based on individual fish patterns of receiver detections, CSF largely appeared to be stationary, often being detected by a single receiver for long periods of time despite being within detection range of several receivers indicating movements very closely confined to high-interference substrate. Despite an average of over 8,000 detections per individual, as VPS trilateration relies on 3+ receiver detections occurring simultaneously, VPS rendering position was poor likely due to the inclination of CSF to rest in rugose habitat (Love et al., 1987). A majority of the VPS positions rendered appear to be when the individuals were moving at a high rate of speed (~0.3 m/sec) in or out of the array in events that lasted less than 1 day (Figure 28). These events were likely spawning related migration events (Section 3.3.3) and not reflective of normal home ranging behavior.

The majority of CSF did not have enough VPS positions to perform an accurate home range analysis; however, receiver detection patterns indicate that tagged CSF use areas comparable or smaller than to those used by BSB (Section 3.2.2).

3.3.2 Characterization of the Degree of Site Fidelity to the White Point Outfall

CSF demonstrated varying degrees of residence around the outfall pipe areas. CSF were detected on avg. 25.8 ± 16.7% of the days at liberty over the study period (range: 3.4% to 60.4%; Figure 29). Most of the individuals were tagged within a month of the May-September spawning season, and the end of the study coincided with the end of the spawning season. However, short-term site fidelity was very high for the 14 CSF tagged and released within the PV Shelf array before spawning season emigration. During the period between the date of tagging and an

emigration event, defined as the initial absence of >15 days from the array (mean 28.6 ± 18.5 days, range: 2 – 54 days), CSF were detected in the PV Shelf array 94 ± 15.6% of days (range: 41.6-100%), indicating a high degree of site fidelity prior to spawning season migration events.

All 14 CSF (100%) were absent from the array for a minimum period of 6 weeks. Three of the 14 CSF (21.4%) were not detected post-migration before the end of the study; however, the study ended ten days into October, at the end of the duration of the known spawning period (Love et al., 1987) and individuals may have returned after the end of the study period. Ten tagged individuals returned to the PV Shelf array after durations of absence ranging from 44 to 147 d; however, two of these individuals returned for less than 1 week before emigrating and not returning before the end of the study.

3.3.3 Spawning-Related Migrations of California Scorpionfish

A single receiver station was deployed and moved between two locations in a known CSF spawning aggregation site (Dago Bank; Love et al., 1987) on the southeastern edge of Horseshoe Kelp in approximately 92-m depth. Seven of the 14 CSF (50%) that had been previously detected on the PV Shelf array prior to the spawning season during a deployment were detected on the Horseshoe Kelp receiver over a two week period in July (Figure 30). A single individual was detected by a mobile receiver in slightly shallower water on the Horseshoe Kelp area. Four of the individuals detected in the spawning area at Horseshoe Kelp were again detected in the PV Shelf array before the end of the study, demonstrating inter-seasonal fidelity to the outfall area following spawning migration events.

4.0 DISCUSSION

This section presents discussion and interpretation of the results of collection and analysis of acoustic telemetry data. Topics include acoustic receiver range testing, VPS relocation rendering efficiency, fish tagging and data collection efforts, and addressing specific goals of the project in relation to quantified movement data for WC, BSB, and CSF.

4.1 ACOUSTIC RECEIVER ARRAY CALIBRATION AND PERFORMANCE

This is the first time that a Vemco underwater omni-directional acoustic receiver array using the Vemco Positioning System has been applied at this scale and at these depths. Working with the vendor we were able to not only validate the value and benefits of using this technology in a novel situation, but gather unprecedented movement data on a sensitive indicator fish species. This study was the largest of its kind within the United States and because of its success is now being used in comparable situations around the world.

To provide adequate spatial coverage surrounding the White Point contaminant field and confirm sufficient fine-scale position ability of tagged fish, we conducted numerous calibration tests prior to tagging any fish. Based on range and detection efficiency tests, the initially proposed spacing of acoustic receivers within the PV Shelf array was reduced. This space reduction was in part attributed to the need to use small transmitters (reduced power output = reduced range) to minimize stress to WC, and to acquire a higher probability of multilateral detections. Reduction of inter-receiver spacing did decrease the proposed area coverage within the VPS-enabled portion of the array, but the overall spatial coverage including the bracket receivers was maintained. In addition, repositioning receivers higher in the water column around large outfall pipes decreased the acoustic shadows created when fish were swimming in close proximity to pipes, thereby providing more positional estimates.

Differences in the numbers of VPS-rendered positions among species were as expected based on the behavior and pulse rates of transmitters used for each species. The numbers of VPS-rendered detections for BSB and CSF could have been increased by using larger and faster pulsing transmitters; however, this would have reduced the detection frequency for WC due to increasing

the number of code collisions. Therefore the trade-off in receiver configuration, transmitter size, and pulse rates was considered to optimize detection efficiency for all species.

Calibration tests around harbor entrances indicated that based on the estimated swimming speed of fish species, and transmitter pulse rates that we would be able to accurately determine fish passage and directionality into and out of the Los Angeles and Long Beach Harbors. Based on overall calibration and detection efficiency tests, we believe the receiver array and gate performances were sufficient to address all project goals.

4.2 FISH TAGGING SUCCESS

One major challenge of this study was whether WC could be successfully caught, tagged and would survive release. Prior to this study there was little evidence that WC could be successfully tagged and released. Due to the sensitive nature of this species, we initially assumed 30% tagging mortality. However, after several initial active tracks of WC caught and tracked within the harbor, we were able to refine our capture, handling, and surgical methods to ensure post-release survival. Data gathered after refinements indicated that short-term post-release survival (< 24 hrs) was high. Due to the highly mobile nature of this species, it is relatively easy to discern whether a fish has died within the array based on lack of movement of the transmitter position over time. Based on this and other criteria we estimate a tagging mortality for WC of only 14.4%, which is markedly lower than originally anticipated. This study clearly demonstrates that WC can be successfully caught, tagged and survive this process for periods of up to 1 year. The other species studied have already been shown to exhibit high post-release survival (Mason and Lowe, 2010; Hanan, 2012).

Despite historically being one of the most commonly captured species in Southern California's recreational fishery (Puffer and Gossett, 1983), the effort hours required for capturing WC specimens for tagging on the PV Shelf exceeded all estimates, with fisher hours required per fish tagged approximately an order of magnitude higher than in a similar project in the LA harbor (Ahr, Farris and Lowe, unpublished data). This is likely reflective of changes in overall abundance of WC, as similar declining trends in abundance of WC have been demonstrated in fisheries independent data throughout the Southern California Bight (Herbinson et al., 2001; Miller et al., 2011) and in trawl surveys at PV Shelf (J. Gully, pers. comm). Fishing efforts were

distributed from 25-60-m depth throughout the expanse of the PV Shelf array; however, the highest CPUE was encountered at the terminus of the inner 60-cm outfall pipe (Figure 4A). Despite indications of potential overall WC population decline, it is interesting to note that so few WC were caught on PV Shelf compared to the Los Angeles and Long Beach Harbors. This may indicate that overall habitat quality or food availability for WC is better in the harbors than on the shelf.

4.3 DISCUSSION OF RESULTS OF SPECIFIC GOALS

4.3.1 Goal 1: Quantify How Much Space Fish Use Along the Core Outfall Site

4.3.1.1 White Croaker

Size frequency analysis of WC tagged within the PV Shelf array indicate all fish were likely sexually mature and were from among the largest size class common on the shelf (Figure 5). Estimated ages of WC tagged were on avg. 7.9 ± 1.3 years, indicating that these individuals have had considerable time to bioaccumulate contaminants, particularly if they have spent appreciable time foraging in more contaminated areas. However, coarse- and fine-scale movements of tagged individuals show a wide variation in the degree of area use and time spent within specific areas of the PV Shelf array (Figures 6 and 7). Combined acoustic detections for all tagged WC over the entire study period (Figures 7A, 7B, and 8) indicated that the population used the entire area monitored on PV Shelf (~20 km^2); however, the majority of the individuals used areas adjacent to the outfall pipes and shallower habitats (> 40 m) within the array the most (Figures 12 and 13). The greatest intensity of area use (total # of detections/fish) was at receivers located between outfall pipes (Figure 7B). While this pattern of movement suggests there are specific locations within the PV Shelf where WC occasionally spend their time, the overall pattern indicates that WC are probably not a home ranging species and individuals routinely cover areas exceeding 20 km^2.

Similar trends were seen for individuals for whom fine-scale movement data (VPS positions) were acquired. Several patterns of space use were observed for fish tracked within the VPS portion of the array. When fish were within the VPS enable portion of the PV Shelf array, they used core areas averaging 0.043 ± 0.026 km^2 (Figure 8), corresponding to approximately 0.5 ± 0.3% of the VPS array area. Individuals with higher degrees of site fidelity to the PV Shelf array used core areas less than 0.12 km^2, indicating small areas of important habitat that are

intensely used by WC, areas generally within close proximity to outfall pipes or in water of less than 40 m deep (Figures 7B and 8). For WC exhibiting this pattern of behavior the outfall area appears to be important habitat, possibly for foraging or refuging, and an area where they are likely to be exposed to sediment bound contaminants depending on the location of core habitat utilized by particular WC. Other individuals exhibited a pattern of short periods spent within the array, during which they used relatively small total areas less than ~0.2 km^2 and core areas less than ~0.03 km^2 and shallower mean depth.

This behavior is consistent with transit through the array with minimal use of the PV Shelf habitat as a foraging or refuging area. Individuals exhibiting this behavioral pattern are less likely to be exposed to high levels of contaminants on PV Shelf. Approximately one-third of individuals exhibited this 'transient' pattern of behavior based on analysis of fine-scale movements; however, most of the 25 individuals with low site fidelity that were not present in the array enough to acquire fine-scale VPS positions rendered also show this similar pattern of behavior based on coarse-scale movement data.

4.3.1.2 Barred Sand Bass

Tagging efforts for BSB within the PV Shelf array targeted rocky habitats created by the ballast for the Whit Point outfall pipes and several small patches of natural rocky reef adjacent to the pipes. Combined coarse-scale detection data for all individuals indicate the population of BSB caught and tagged within the PV Shelf array used almost the entire monitored area (Figures 4B and 22), but exhibited a high affinity for the inshore (shallower) sections of the array between 20-40-m depth (Figure 22). This depth distribution pattern has been observed for other coastal and island populations of BSB (Mason and Lowe, 2010; McKinzie, 2012).

Fine-scale movement data acquired for individual BSB within the VPS-enabled portion of the PV Shelf array indicated that individuals clearly utilize home ranges, but that these areas may shift over time and these shifts may be attributed to the quality of the habitat. This was evident based on the larger avg. size of home ranges (95% KUD = 29,187 ± 35,597 m^2) compared with those measured for BSB at Santa Catalina Island (10,003 ± 4,773 m^2; Mason and Lowe, 2010) and at the Los Angeles Federal Breakwall (3,000 ± 1,000 m^2; McKinzie, 2012). While some of this difference in home range size is likely attributed to the duration over which these

movements were measure, it is also likely attributed to differences in habitat composition and quality between sites.

BSB tracked at Santa Catalina Island were also observed shifting their home ranges, thereby increasing their overall home range size over time. This was attributed to the patchy distribution of ecotone habitat found at Catalina Island, which is very different from the long continuous habitat ecotone found at the breakwall. Similar dispersion of ecotone habitat is seen within the PV Shelf array considering the scattered shallow, low relief reef habitat and outfall pipes. Analysis of core area use indicated that all BSB utilized core areas associated with the rocky relief of pipe ballast, or natural rocky reef adjacent to the pipes.

Differences in overall area use to core area use also demonstrates the occurrence of brief forays into the surrounding areas both along the rocky reefs and crossing open areas of soft bottom (Figure 22B). While these forays could be exploration for new habitat, individual BSB made repeated visits to the same general areas, which suggests a pattern of feeding behavior. Availability of mobile prey (e.g., spawning squid, fish recruitment) along PV Shelf may require that BSB periodically shift their home ranges to other locations, thereby moving them between locations with varying levels on sediment associated contaminants. Residency and home ranging behavior exhibited by BSB to these rocky ecotones within the main contamination field provide a potential explanation for the high variance in body burdens of DDT found for BSB in previous sampling surveys. In addition, BSB tagged in 2010 and 2011 demonstrated high site fidelity to very specific home ranges over the multi-year duration of the study (Figure 20B).

4.3.1.3 California Scorpionfish

CSF are known to occupy both rocky and soft substratum habitats and exhibit seasonal spawning migrations (Love et al., 1986). However, the only comparable information on CSF movements come from a previous tag and recapture study conducted along PV and Horseshoe Kelp. Based on fisheries and recaptured data, it was concluded that CSF were fairly mobile. Both coarse and fine-scale movement data from our study indicate that individuals typically remain in the areas where they are caught during the non-breeding season, but migrate to other locations for spawning and then return to a home range.

The limited number of VPS detections acquired for CSF suggests that they spend most of their time associated with complex substratum (e.g., rock, pipe habitat), which also contributes to a reduced likelihood of detection. Most fish showed high site fidelity to the areas where they were detected over the period of monitoring suggesting they have relatively small home ranges. Fish were more readily detectable when they made their migration to the spawning sites to the southeast, which suggests they were up in the water column when making this movement.

Most of the areas where CSF were detected were in the shallowest portions of the PV array where fish appeared to be using low relief rocky reefs and outfall pipe-associated habitat.

4.3.2 Goal 2: Determine Often Fish Cross Over the Outfall Pipes

4.3.2.1 White Croaker

Previous work on body burdens of contaminants in WC has suggested a significant difference in DDT loads in WC sampled on either side of the outfall pipes (NOAA, 2007) may indicate the outfall pipes act as a barrier to long-shore WC movements. We found that 79.3% of tagged WC had crossed the pipes at least once and for the others detection resolution may not have been sufficient to detect trans-pipe movements. Therefore we conclude that for the majority of WC, the outfall pipes are not an impermeable barrier to movements, but clearly influence the movements and space use of some individuals.

However, we also found significant selection for habitats adjacent to outfall pipes (within 200 m). We suggest three possible causative factors contributing to this phenomenon: 1) the outfall pipes and associated ballast act as a “leaky” barrier to WC movements; 2) the outfall pipes act as cues for WC to orient to suitable foraging habitat or refuge from predators; or 3) increased nutrient loads, decreased visibility and ecotone effects related to proximity to the outfall pipes create preferred habitat for WC by either enhancing patch foraging or refuging from predators.

Although it is concluded the outfalls do not act as an absolute barrier to movements, there is some evidence they may act as a ‘leaky’ barrier. Only 31.3% of individuals were detected having crossed both large outfall pipes (~3 m diameters), so the area would appear to be a boundary to WC movements whether or not directly due to the presence of outfall pipes. WC were found to select for habitats 100-200 m from outfall pipes, which does not necessarily suggest that the importance of the area is in direct vicinity to outfalls, but more likely adjacent to

these structures. There is also some evidence for increased production and benthic infauna production in proximity of where the three outfall pipes diverge (Sanitation Districts' unpublished data). Long-shore currents carrying detritus and fine sediments flowing across the pipes likely increase the rate of deposition of organics and fine sediments in between these pipes particularly where they diverge, also creating better habitat for benthic infauna. In addition, the patterns of movements observed also do not further elucidate why previous WC sampled to the west of the outfall pipes had high tissue contaminant levels than those to the east of the pipes (NOAA, 2007). The majority of individuals and the majority of VPS-rendered positions for those individuals were found at locations between the outfall pipes, and even fewer individuals and fewer detections were observe to locations west of the outfall pipes (Figure 13). WC monitored on the northwest side of the outfalls appeared to use the area less intensely than those on the southeast side (Figure 13), which is opposite of pattern expected from past WC tissue sampling (NOAA, 2007). It is possible that movement patterns of WC have changed since the periods when fish were sampled for tissue analysis (2002, 2006), or this may simply be a statistical anomaly. More work needs to be done to determine to what degree these individual factors cause the WC outfall pipe interactions exhibited, as they will influence bearing on future contaminant exposure monitoring and mitigation efforts.

4.3.2.2 Barred Sand Bass

There was no evidence that the outfall pipes posed any barrier to BSB, although there was not as much fine-scale movement data to support this. Coarse-scale data did indicate that fish swam across the pipes when transiting to other locations within array or when leaving the array. Individuals with core areas associated with the rocky reefs to the west of the pipes did not cross the pipes at all during regular non-spawning season activity but exhibited no difficulty in crossing the pipes when leaving or returning from summer spawning migrations to the southeast. Individuals with core areas associated with the pipes themselves crossed over the pipes regularly to use ecotone habitat on either side of the pipe without bias. This is consistent with the positive edge response (<15 m) to soft-sediment/rock ecotones measured in previous studies (Mason and Lowe, 2010).

Coarse and fine-scale movement data combined to reveal a distinct pattern of temporal and spatial area use for the BSB on PV Shelf. All tagged fish exhibited a prolonged seasonal

residency to very specific inshore areas of the array. BSB do not appear to have home ranges that encompass the focal points of the main contaminant field with the highest concentrations of DDT, which occur beyond the preferred depth range for the species. However, the fish do have a high affinity for the pipe ballast in areas of the main contaminant field where sediment still contains moderate levels of DDT (Figure 22).

4.3.2.3 California Scorpionfish

Although there is comparatively less data by which to determine whether the outfall pipes pose a barrier to movements for CSF, available coarse and fine-scale data suggest that the pipes often utilized by some individuals and that they do not inhibit movement. VPS position data indicates that when CSF leave their home range to begin their migration to their spawning sites or return to their home ranges after spawning season they readily cross the pipes and are likely up in the water column when they make these movements (Figure 28).

While the outfall pipes do not appear to function as barrier to movement, they do seem to provide important habitat for CSF, some of which spent extensive periods of time in close proximity or on top of pipes. However, it was apparent that CSF were also using low relief habitat much like BSB (Figure 28).

4.3.3 Goal 3: Determine the Degree of Site Fidelity Fish Show to the Palos Verdes Shelf

4.3.3.1 White Croaker

At least two discreet patterns of site fidelity were identified for WC caught and tagged within the PV Shelf array. Approximately half the WC monitored exhibiting very little affinity for the outfall area and residency within the PV Shelf array: 42 (50.6%) were present in the area for a total of 4 or less days (mean: 2.2 ± 1.0 and last detected on average 4.3 ± 6.7 days after tagging (range: 1-30 days; Figure 15). The other half of the tagged population exhibited varying degrees of site fidelity, with total days detected in the array averaging 50 ± 41.6 d (range: 5 to 147 d), and the total span detected in the array averaging 75.6 ± 63.6 d (range: 5 to 310 d; Figures 16 and 17). While it is possible that the fish that immediately leave the area after tag and release do so because of tagging related trauma, this behavioral response has not been observed for WC caught, tagged and actively tracked in Los Angeles and Long Beach Harbors using the exact same methods.

Of the 42 WC demonstrating a low site fidelity to the study site, only 12 emigrated during the first day, suggesting low site fidelity to the study site is not due to aversion immediately following tagging. Another, more likely explanation is that there are at least two distinct behavioral movement patterns characteristic of the WC population found in this area. This indicates that there is a highly transient portion of the tagged population that sporadically moves across PV Shelf while moving to other areas, and have a very low likelihood of returning to the outfall area after leaving. For this part of the population PV Shelf offers less valued habitat. The other portion of the population periodically uses PV Shelf habitat (particularly shallower regions and areas between outfall pipes) as likely foraging or refuging habitat, but then leaves these areas for other patches outside of the monitoring area with varying rates of return to the outfall area.

Caution should be exercised in extrapolating these findings from the current study sample to the entire WC population that occurs near PV Shelf, as WC with higher site fidelity to the outfall area were probably more likely to be encountered and tagged; therefore transient individuals are likely a greater proportion of the population than the approximate half found in the this study.

Individuals that do use PV Shelf for short to intermediate amounts of time, often use shallower habitats between or adjacent to outfall pipes. While areas most frequented by tagged WC have relatively low predicted levels of sediment associated contaminants, some individuals within the population may spend enough time at these locations foraging to account for the distribution patterns of fish caught on PV Shelf with high body burdens of DDTs (Figure 14A). While we observed two distinct behavior patterns of movement (“transient” and “foraging/refuging”); interestingly, there does not seem to be two modes in tissue burden data measured from WC caught throughout the SCB (Figure 14A). However, tissue burden data from WC caught on PV Shelf do appear to have a bimodal pattern that would match behavioral modes identified from fish tracked in this study. In addition, our DDT exposure metric model output is more similar to the tissue burden distribution pattern observed for WC collected from outside San Pedro Bay in 2002-2003, than for WC collected from the PV Shelf (D. Witting, unpubl. data). However, caution must be exercised in interpreting the results of our exposure metric model, as it does not include the subset of individuals that were in the outfall area too briefly to have had positions recorded (Table 4). These patterns in contaminant distributions along with the output from the

model incorporating movement into the DDT exposure metric indicate that few WC are spending appreciable time in proximity to the areas of high sediment contamination. Nevertheless, these movement data could be used to develop more sophisticated spatially-explicit bioaccumulation models to determine whether the patterns of contaminant acquisition is predictable, assuming patterns of movement do not change substantially over time.

4.3.3.2 Barred Sand Bass

Following release, fish were detected consistently within the array between September and May, but were conspicuously absent during the summer months of June-August (Figure 20B). Prior to leaving their home ranges within the PV Shelf array, two-thirds of tagged BSB were found to exhibit high site fidelity to rocky areas around the outfall pipes between 20 m and 40 m, and site fidelity is likely underestimated for BSB as individuals close to rugose habitat were often detected with poor efficiencies. In 2011, all 17 of the tagged fish were absent from the PV Shelf array for extended periods (mean = 62.2 ± 15.5 days), with a median departure date of 10 July and a median return date of 30 August. In 2012, only 35 (71%) of the tagged fish were absent for extended periods (mean = 92.5 ± 20.2 days), with a median departure date of 6 June and a median return date of 9 September (Figure 27; Table 6).

Because BSB are spending considerable amounts of time at home ranges in close proximity to the more contaminated sediments, it is expected that individuals sampled in these areas could have relatively high body burdens of sediment associated contaminants. The average estimated age for BSB tagged in this study was 13 years old (youngest was 9 years old), indicating that if these individuals have been residents to PV Shelf since recruiting that they could have acquired significant levels of contaminants over that time period based on their high residency to this area.

4.3.3.3 California Scorpionfish

Although CSF were only tagged and monitored over the final 5-7 months of the study, all tagged individuals showed high site fidelity to the PV Shelf array, and many returned to the array after spawning season. This behavior is very similar to that of BSB and similar assumptions about their bioaccumulation patterns may be expected, based on their high degree of site fidelity to this area.

4.3.4 Goal 4: Determine How Often Fish from PV Shelf Enter the Los Angeles/Long Beach Harbors

4.3.4.1 White Croaker

Nearly half (48%) of WC tagged on PV Shelf had been detected at harbor gates and 41% detected entering the harbors. Due to variations in detection efficiency occurring in the high-noise environment of the harbors, it is estimated that more WC may had entered the harbors than were detected, giving a true proportion of harbor migrators between 41-48%. Although WC were detected for an average of 9.3 ± 16 days on harbor gate receivers, individuals using harbor habitat were likely out of range of harbor entrance receivers for much of the time and these values are an underestimate of the temporal extent of use of harbor habitat. Although a large proportion of WC readily made migrations to the harbors, a minimum distance of ~7 km, only a single WC was detected further into the harbors than the mouth of the Main Channel- an additional 3-km distance (Figure 2). Therefore it would appear the harbors are important habitat for approximately half of the WC tagged on PV Shelf; however, only the outer harbor areas may be utilized. The WC that use both PV Shelf and harbor habitat might be doing so to take advantage of higher productivity of the harbors and greater access to dispersed prey patches.

WC were detected making between 1-9 migrations to the harbors, demonstrating varying degrees of connectivity between the two areas. However, there was no significant relationship between site fidelity of WC to PV Shelf and the number of harbor migrations made or number of days detected within the harbors. Individuals exhibiting transient and foraging type movement patterns used harbor habitat, which may be driven by more variable oceanographic conditions on the PV Shelf, habitat quality, prey availability or predator density.

4.3.4.2 Barred Sand Bass

BSB tagged within the PV Shelf array did not exhibit movement in and out of the harbors during the study period. Although BSB migrated southeast off PV Shelf during the summer spawning season, no tagged fish were detected entering the Los Angeles and Long Beach Harbors. One BSB was detected by a receiver outside of Angel's Gate, but was not detected inside the harbor. Subsequently, the individual returned to the array through the southeast bracket and was detected by inshore receivers at ~20-m depth. It is likely that the fish was returning from Huntington Flats along the Federal Breakwater when it was detected at Angel's Gate.

While BSB did not migrate into the harbors like WC, they did make seasonal migrations to Huntington Flats. Catch and landing data indicate that BSB have been one of the most important species in southern California recreational fisheries for several decades (Love et al., 1996, Erisman et al., 2011). They are landed year-round, but are most heavily targeted in their spawning aggregations that form at Ventura, Santa Monica, Huntington Flats, and San Diego during the summer months (Allen et al., 2001, Jarvis et al., 2010). Based on length and age frequency data, all of the BSB tagged in this study were considered sexually mature and of legal size for take. Thus, it was not surprising that a majority of the BSB caught and tagged within the PV Shelf array left the array during period each summer.

To assess where tagged fish might have gone to join spawning aggregations during the summer, we employed the use of "mobile" receivers that were deployed during sportfishing activity in summer months. Since recreational fishers actively target these large spawning aggregations that move around the flats, fishers are very adept at finding these large schools. By giving recreational fishers receivers to hang off their vessels while they fished gave us an opportunity to listen for our tagged BSB, covering a larger area than could be maintained within a fixed array (Figure 24).

In summer 2011, all 17 BSB that were tagged with the PV Shelf array migrated past the southeast end of the array and five were detected using these mobile receivers in Huntington Flats and Horseshoe Kelp (Figures 26 and 27). At the beginning of the spawning season in 2012, 49 tagged BSB were detected within the array, 35 fish left the array during the early weeks of summer (34 to the southeast and one to the northwest), and 21 of those migrating fish (60%) were detected by mobile receivers in Huntington Flats or Horseshoe Kelp between July and September (Figures 26 and 27; Table 6). Most of the BSB detected at Huntington Flats and Horseshoe Kelp during summer months were found to return to their non-breeding season home ranges on PV Shelf.

Despite reasonable degrees of "listening" effort and area coverage, no BSB tagged within the PV Shelf array were detected in Santa Monica Bay or the western end of the Palos Verdes Peninsula. This relocation efficiency far surpasses the long-term recapture rates achieved by traditional dart

tag and recapture studies and further validates the use of acoustic technology for studying migratory fish movements (Jarvis et al., 2010).

Since BSB caught on PV Shelf show affinity for outfall pipe associated habitat, high site fidelity, and can live to be over 10 years old, they have the capability to acquire considerable contaminant loads from PV Shelf. The high seasonal migration rates of these fish to areas outside the No Consumption Warning area (red zone) poses potential concerns for human health. While BSB from PV Shelf are likely to represent only a small fraction of the spawning aggregation targeted by the CPFV on Huntington Flats, the fact that individual BSB with potentially high body loads of DDT and other PCBs are travelling this far from the main contamination field must be considered in future risk assessments.

4.3.4.3 California Scorpionfish

No CSF caught and tagged within the PV Shelf array were found to move into the Los Angeles/Long Beach Harbors. However, half of the individuals monitored (7 of 14) on the PV Shelf array were found to migrate to Horseshoe Kelp during summer spawning season and half of these individuals were observed to return to the array following spawning season. Since this species behaves very similarly to that of BSB, they too have the ability to acquire considerable contaminant loads based on their fidelity to the LASCD outfall site. They also exhibit season migrations that extend beyond the No Consumption Warning area (red zone), thereby presenting a potential concern for human health.

Unfortunately, the sample size was too small and these individuals were not tagged until the end of the study, so it is difficult to determine how routinely these fish exhibit these spawning migrations and whether they regularly return to their home ranges. This represents the first study of this type for CSF.

5.0 CONCLUSIONS

This project represents one of the largest and most comprehensive coastal marine fish movement studies conducted within the United States. Fine-scale movement data for three key indicator species were gathered over one of the largest spatial scales (8 km^2) attempted to date, spanning a greater than 2-year period. No information on the movement patterns of WC had been available prior to this study.

The key findings of this study indicate that WC are likely not a home-ranging species, and that the population using PV Shelf around White Point exhibit two general patterns of movement encountered in equal abundance in the present study:

1. Transient individuals that spend on average 1% of their time in the vicinity of the outfall area, and are therefore not likely to forage or refuge in the area, are not likely to return, and are probably not exposed to high levels of sediment bound contaminants in the vicinity of the LASCD outfalls.
2. Foraging/refuging individuals do not demonstrate regular home ranging behavior to the area, although they do spend on average 10% of their time in the vicinity of the outfall area, and are more likely to forage or refuge in the area and utilize small patches of habitat usually less than 40 m deep or within 100-200 m of outfall pipes. WC exhibiting this foraging or refuging behavior are likely exposed to a range of sediment bound contaminant concentrations depending on exactly where and how long they are foraging in the area.

Preliminary contaminant exposure modeling suggests variation in WC tissue concentrations throughout the Southern California Bight can be explained, to some extent, by these patterns of movement in spatial and temporal relation to sediment contaminant concentrations in the White Point area. The high number of tagged individuals that routinely moved beyond the acoustic array area would suggest lower levels of exposure and might explain why so many WC sampled from the PV Shelf had low tissue burdens. However, the few individuals that spent any appreciable time on the PV Shelf, albeit over less contaminated sediments, could explain how a few individuals could acquire higher loads over time. Another possibility is that some transient individuals that only occasionally use the PV Shelf habitat may be spending more time around more highly contaminated sediments in the harbors. No seasonal changes in movement patterns were observed for WC in this study; however, some individuals seemed to use deeper habitat on the PV Shelf during winter months, and typically over areas with higher sediment contamination

levels. Unfortunately, there was not enough data from enough individuals to quantify this pattern. It is possible that this pattern is related to reproduction, although if this were the case we would have expected more individuals to exhibit this pattern.

The results of this study indicate future contaminant exposure and risk assessment modeling should take into account the disparity between the core use areas used by WC and the much greater ranges they migrate across as well as the variety of behaviors exhibited across the WC population. The outfall pipes do not act as an impermeable barrier to WC movement, but they do act to structure WC movement patterns possibly by creating preferred foraging or refuging habitat.

Approximately half (48%) of WC made migrations to Los Angeles/Long Beach Harbors and both transient and foraging WC were about equally likely to enter the harbors, but not likely to migrate beyond the outer harbor. The movement patterns and behaviors characterized in this study can be used to explain potential results of remedial actions at the population level as well as inform the planning and interpretation of future fish contaminant monitoring efforts in the region.

We found that both BSB and CSF show high site fidelity to locations where they were captured near the outfall area outside of spawning season, and many individuals return to the same area after spawning migrations, contributing to long periods of exposure to PV Shelf. BSB were found to make longer forays from their home ranges than previously known to occur, into habitats with higher contaminant sediment loads. The majority of individuals of both species migrated to known spawning grounds that are heavily targeted by the recreational fishery and CPFVs, areas where highly contaminated fish were previously not known to occur, and for BSB spawning migrations were to areas outside of the No Consumption Advisory (red zone).

These fine-scale, long-term fish movement data have greatly improved our knowledge of movement behavior for these three species and provide a basis for a sound understanding of the processes underlying the relationship between sediment bound contaminants at PV Shelf and fish tissue contaminant concentrations in the affected region.

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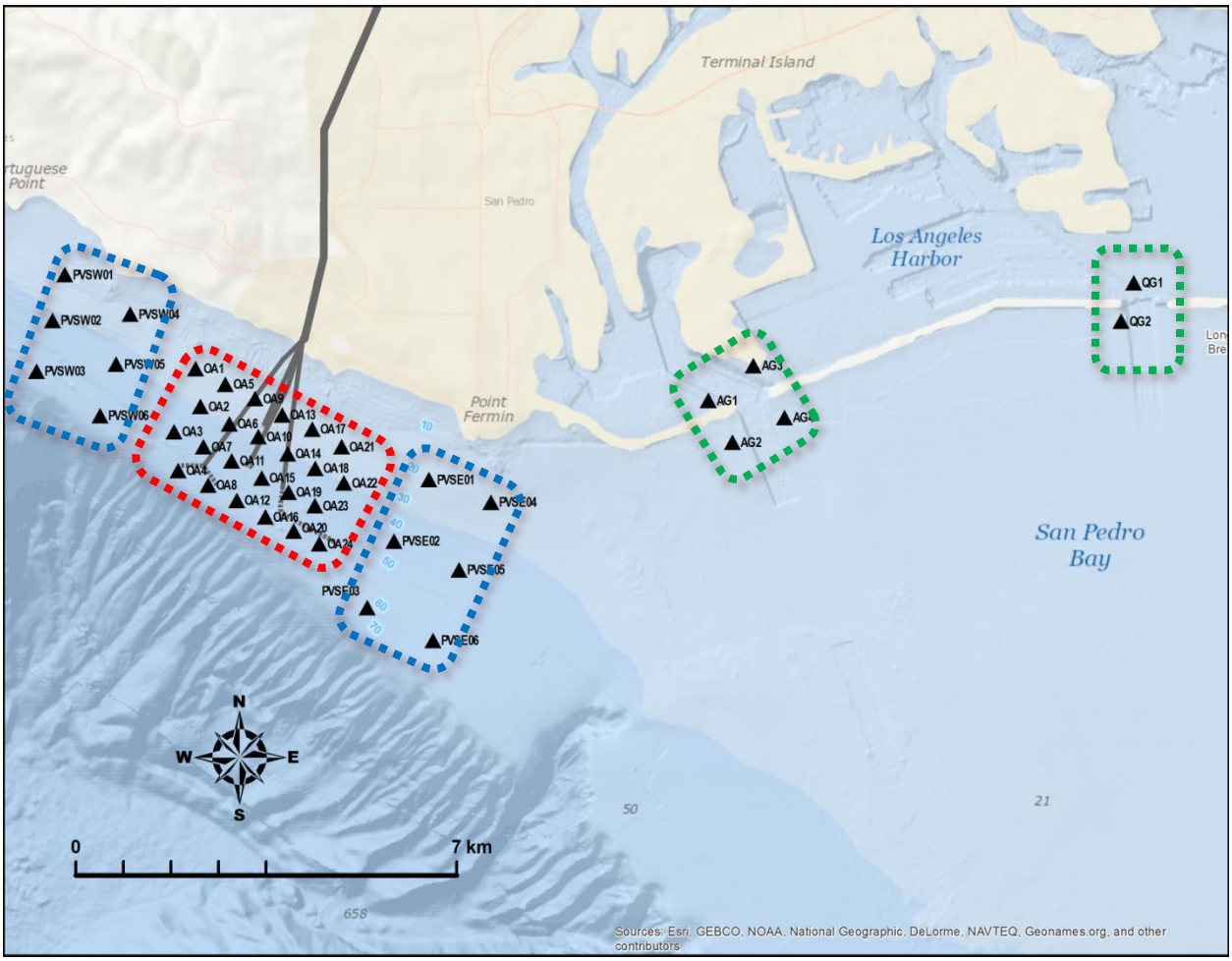


Figure 1 – PV Shelf Acoustic Receiver Array. Locations of Vemco VR2W acoustic receivers (black triangles) deployed at PV Shelf and entrances to Los Angeles and Long Beach Harbors. Each triangle represents a receiver location with an estimated acoustic detection range of 600-m radius. Red dashed box represents the VPS array, blue dashed boxes represent the east and west bracket arrays, and the green dashed circles represent the receiver gates.

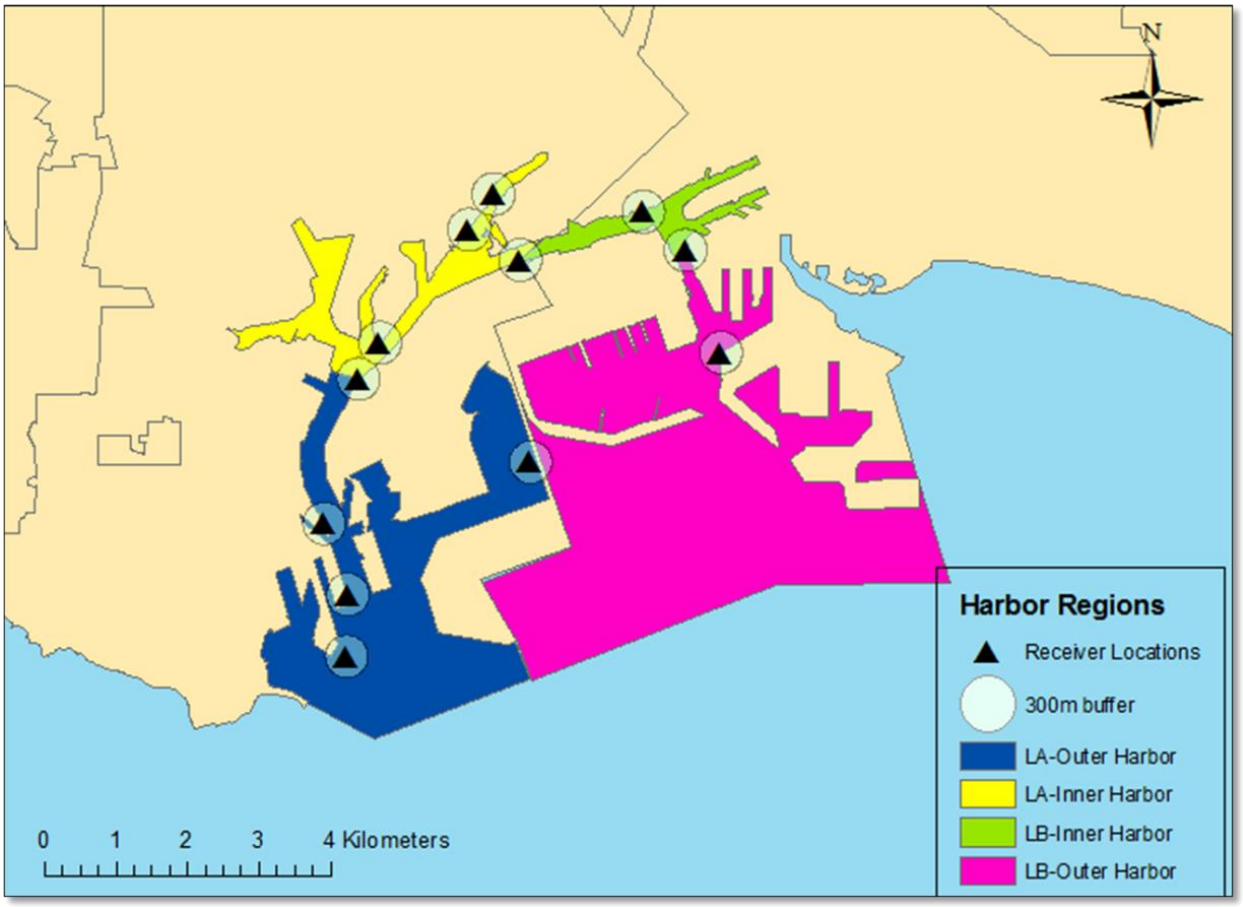


Figure 2 - LA/LB Harbor Acoustic Receiver Array. Acoustic receiver array as part of the Ports of Los Angeles and Long Beach Harbors fish movement study is shown. Vemco VR2W acoustic receiver locations are indicated by black triangles and surround circles present a conservative 300-m detection radius.

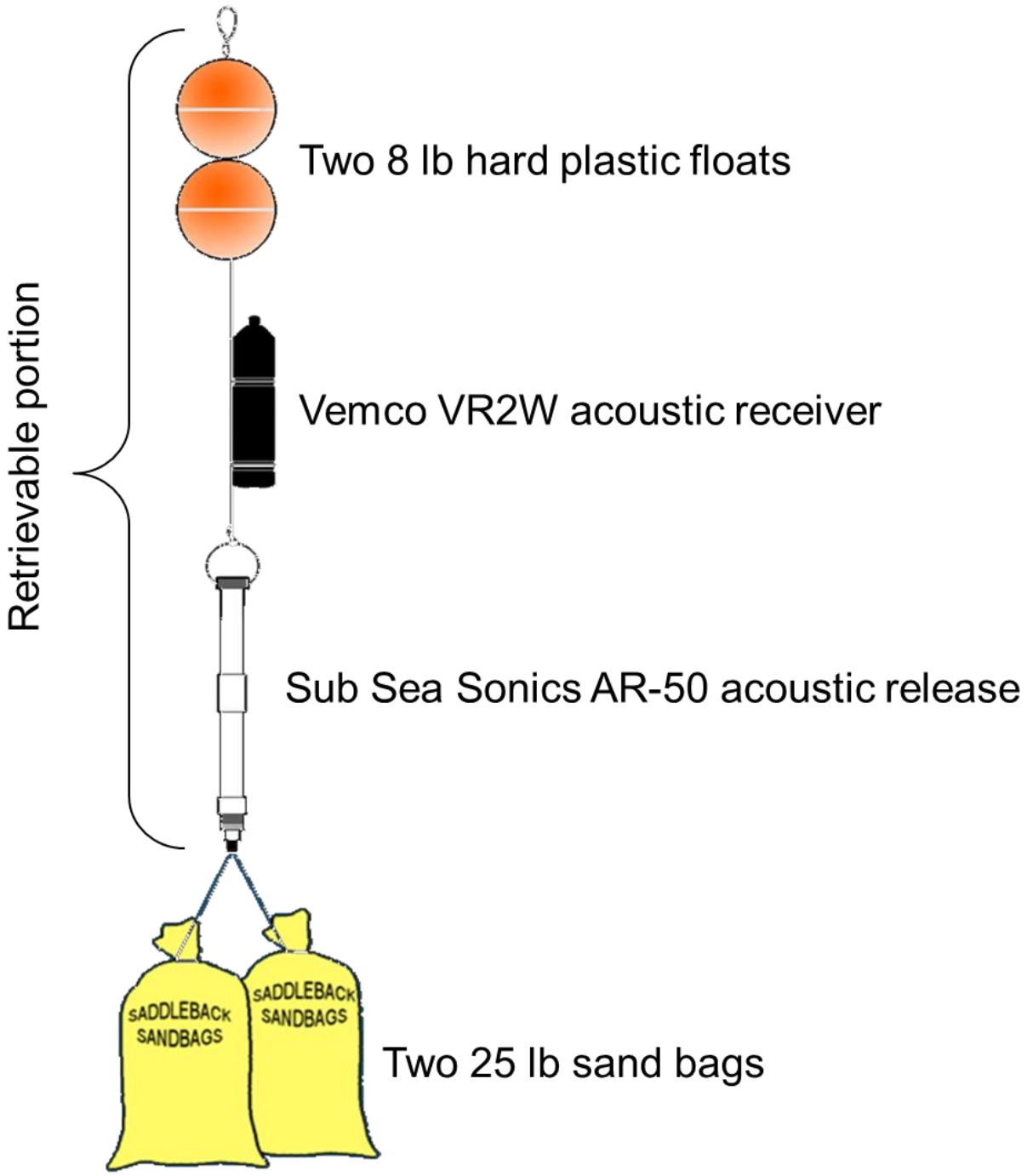


Figure 3 - Acoustic Receiver and Release Configuration.

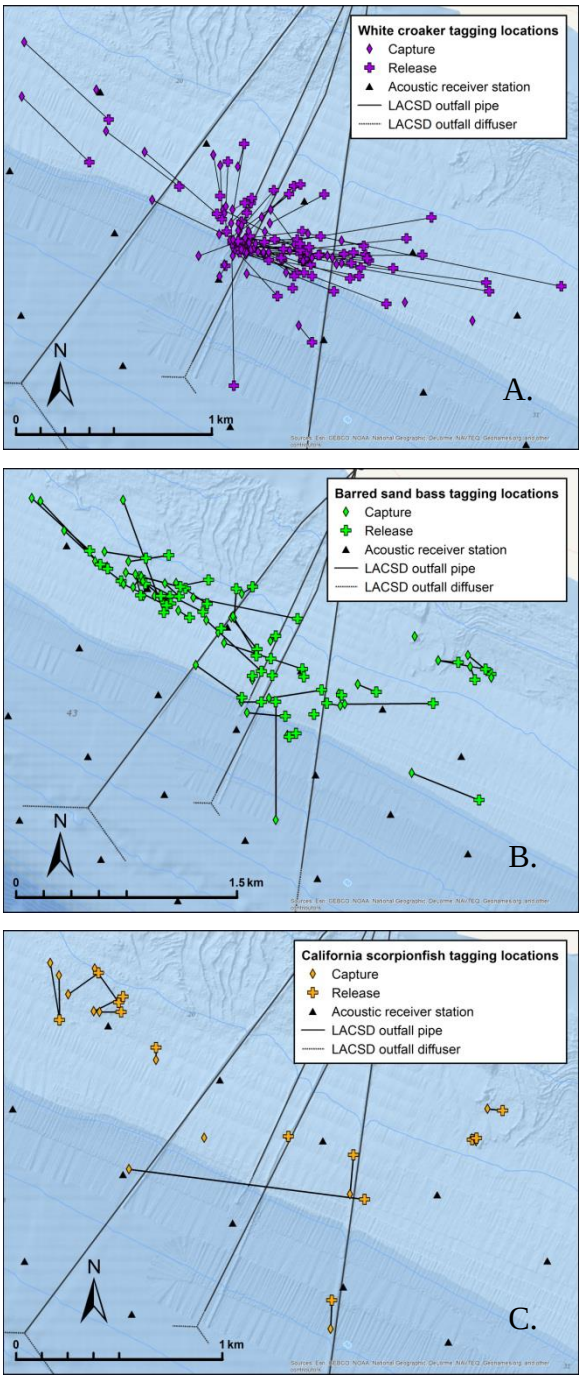


Figure 4 - Fish Capture and Release Locations. (A) Capture and post-implantation release locations of tagged WC; (B) BSB; and (C) CSF. Capture and release locations for individual fish are linked by solid black lines. All tagged fish were released within detection range of the VPS array on PV Shelf.

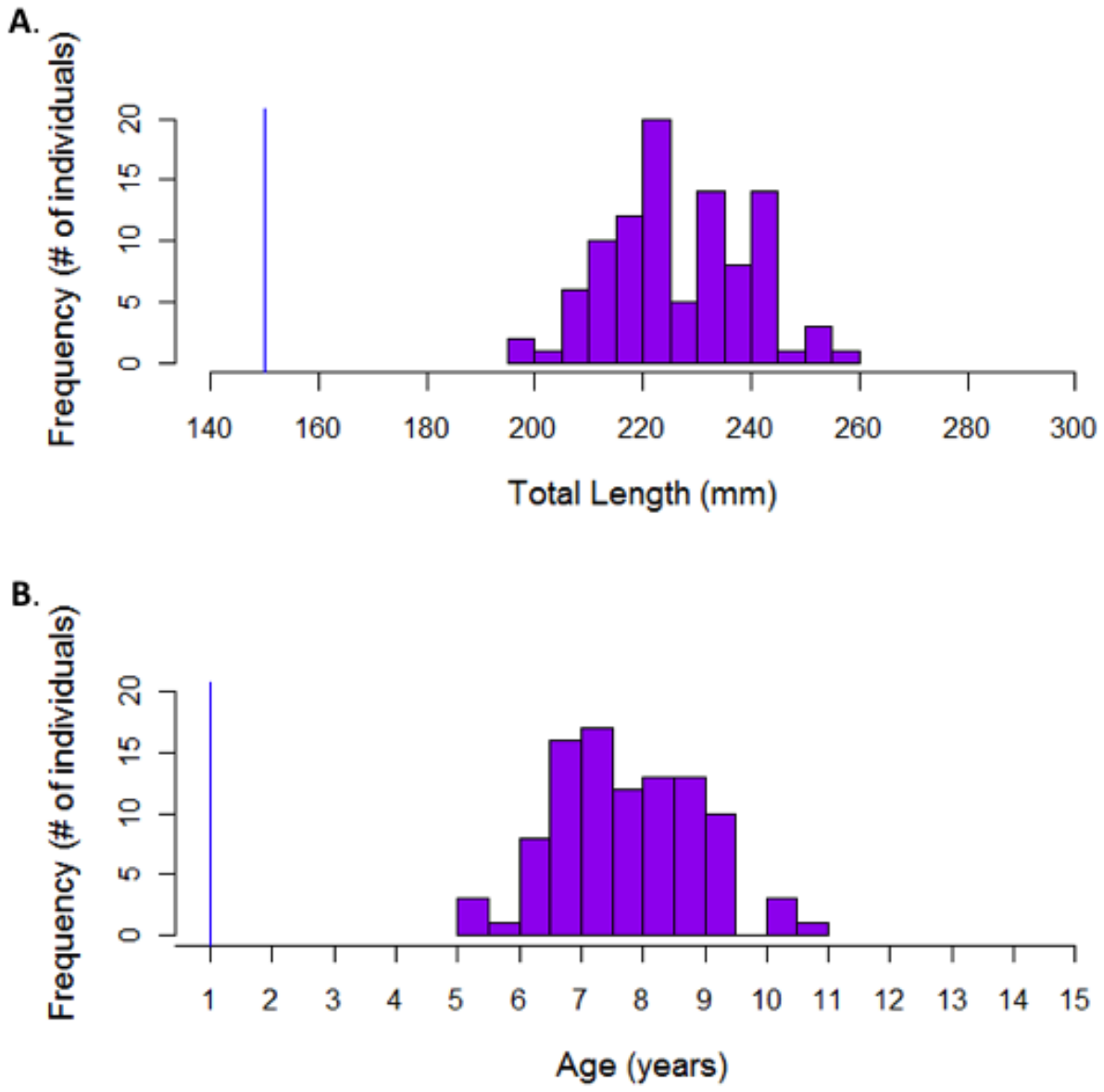


Figure 5 - WC Length and Estimated Age Frequency. Shown are histograms of total length (A) and estimate age at length (B) of tagged WC. Blue vertical line represents the value at which 50% of the population is mature (Love et al., 1984).

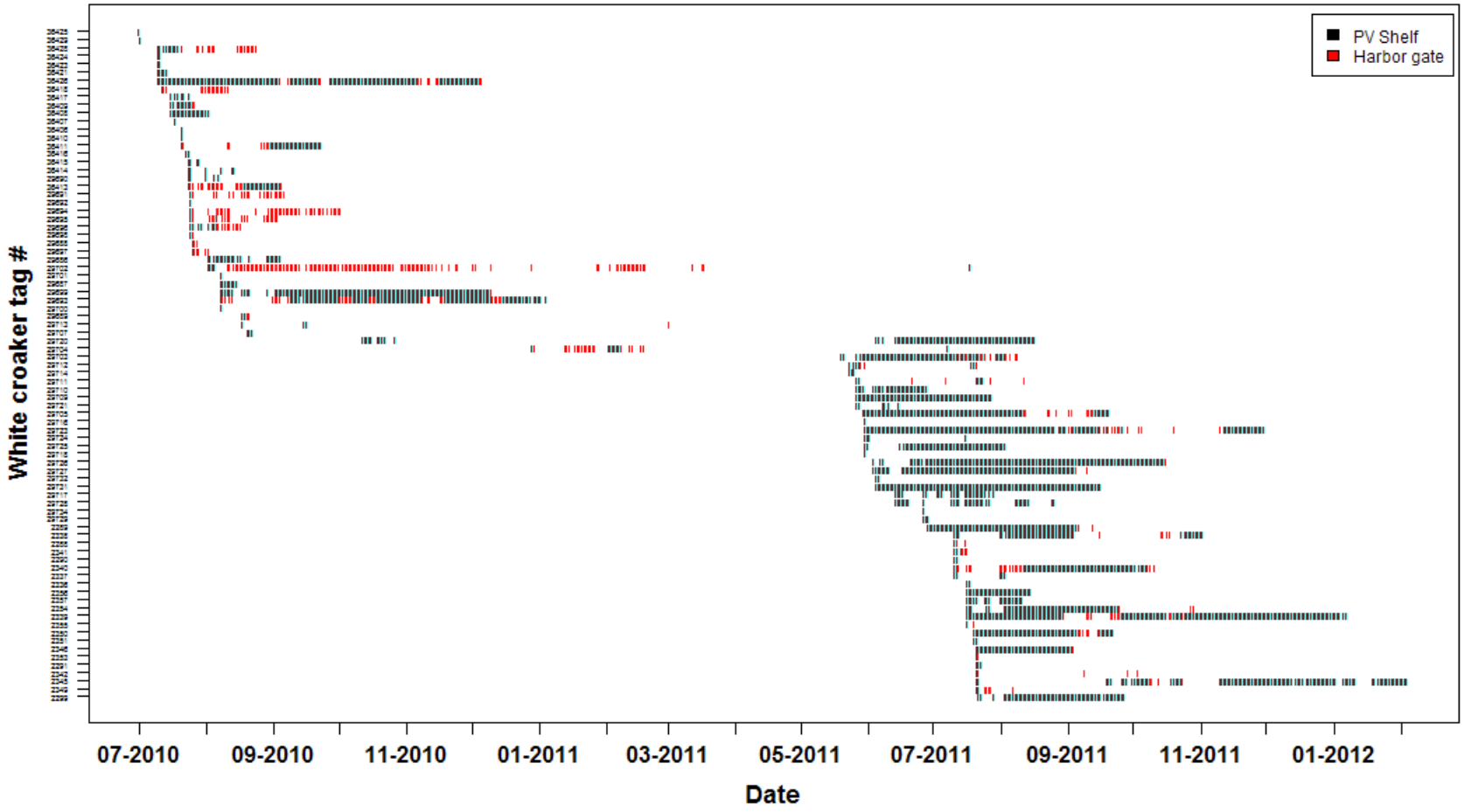


Figure 6 - Daily Acoustic Receiver Detections of Tagged WC. PV Shelf receivers are shown in black; harbor gate receivers in red.

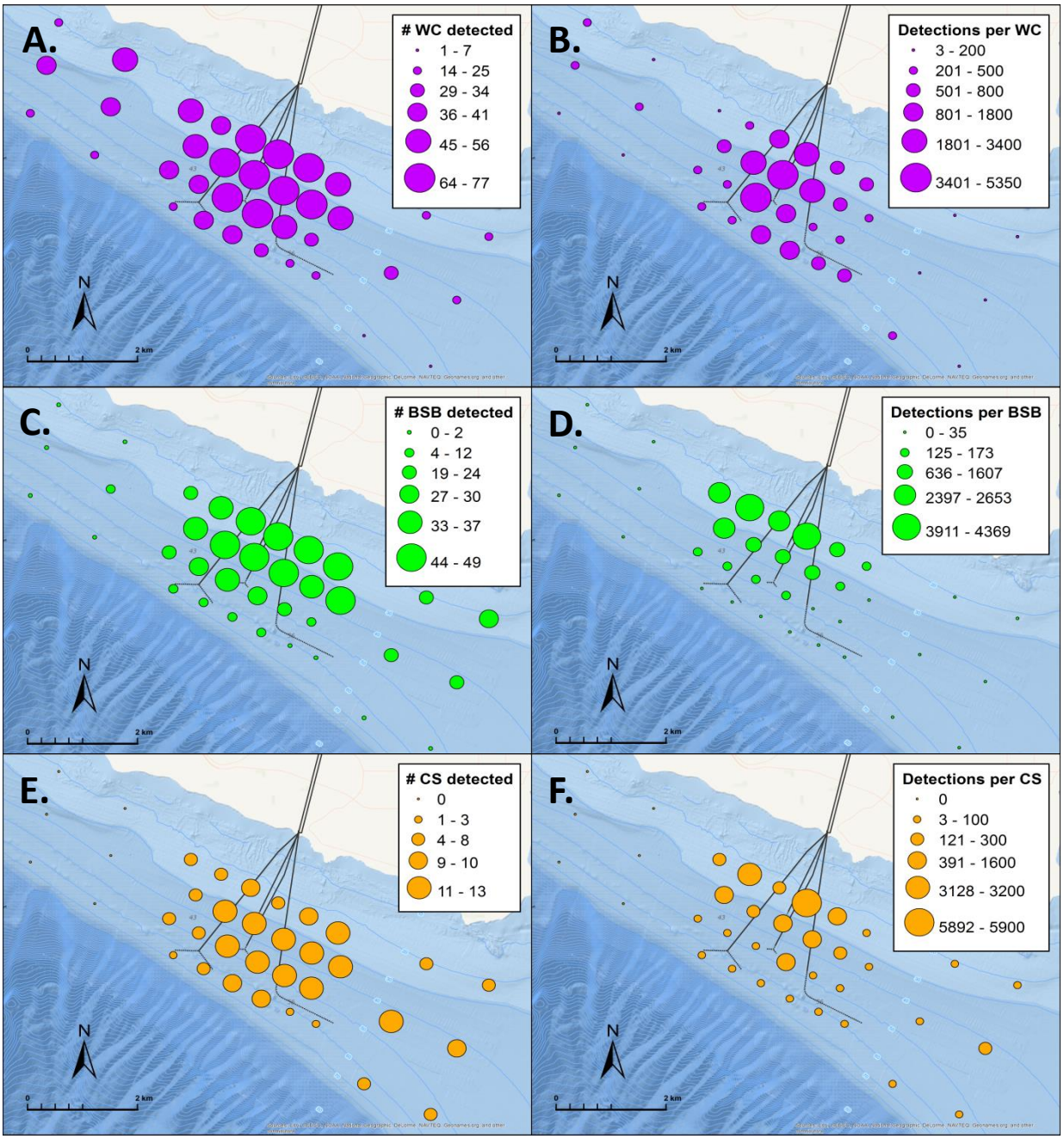


Figure 7 – Detection Overview Bubble Plots for All Species. Shown are bubble plots of number of individual fish detected by receiver station and mean intensity of use (number of detections per individual detected) by receiver station of WC (A, B), BSB (C, D), and CS (E, F). Receivers are indicated by colored circles corresponding to values in the legends.

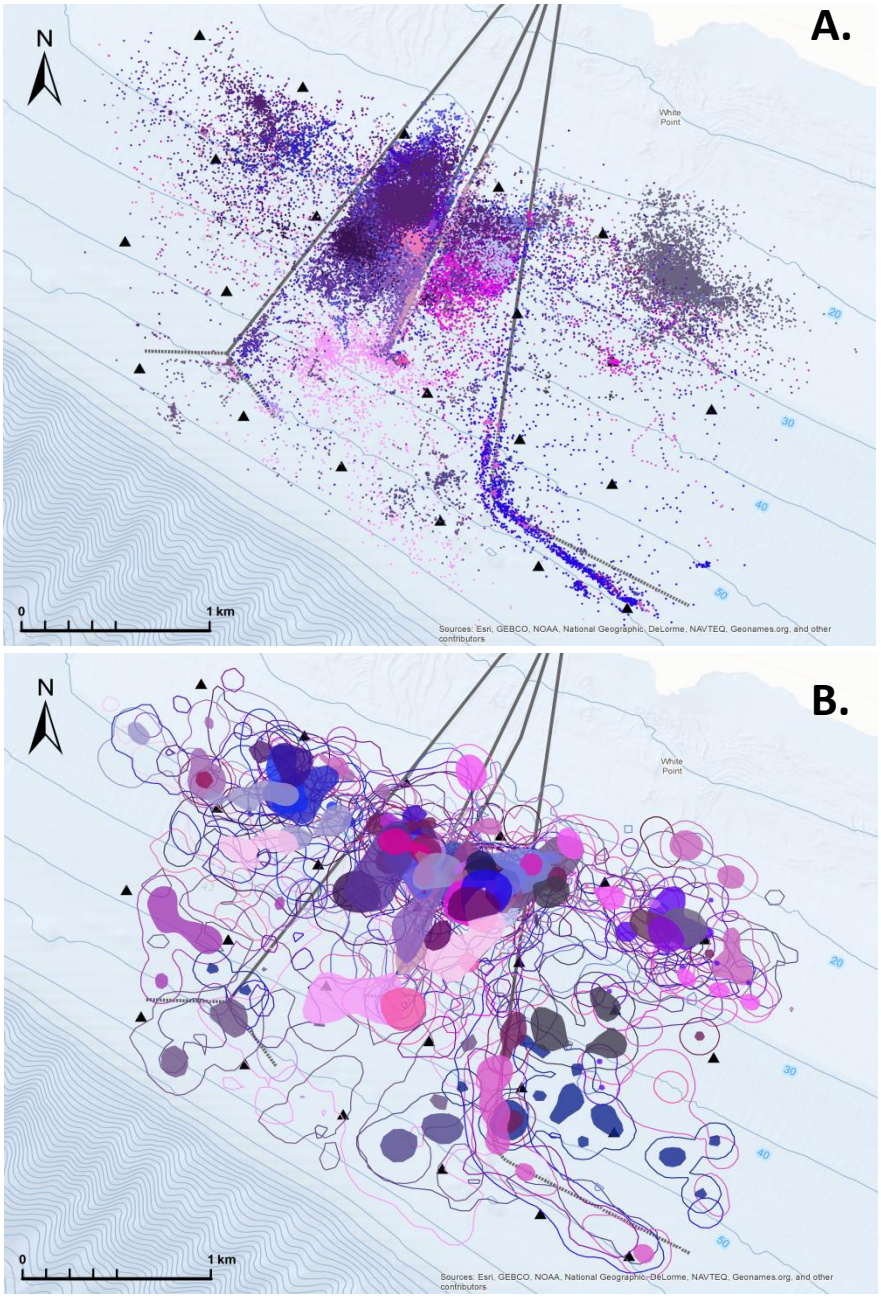


Figure 8 – WC VPS Locations and KUD Areas. WC (n=58) VPS positions (A) and area use estimates (B). Individual WC estimates are color coded, with outlines indicating boundaries of total area use estimate (from 95% KUD contour) and solid polygons indicating core area use estimates (from 50% KUD contour). Acoustic receiver stations are indicated by black triangles.

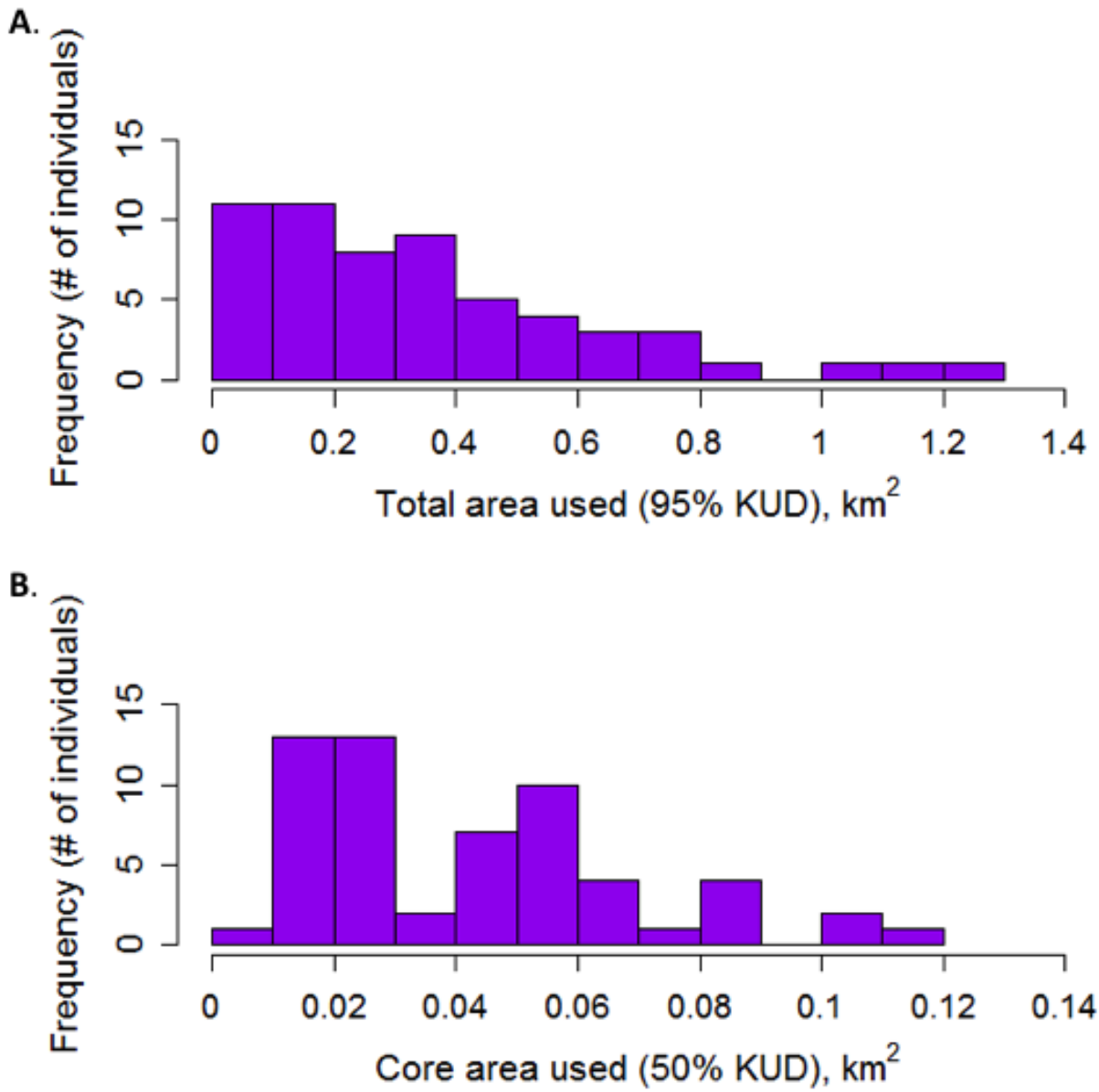


Figure 9 - WC KUD Total and Core Area Frequency. Shown are frequency distributions of total (A) and core (B) area use (km^2) of WC within the VPS array for the study duration. Total and core area was defined as the 95th and 50th percent contour of the KUD estimated from spatial analysis of VPS relocations.

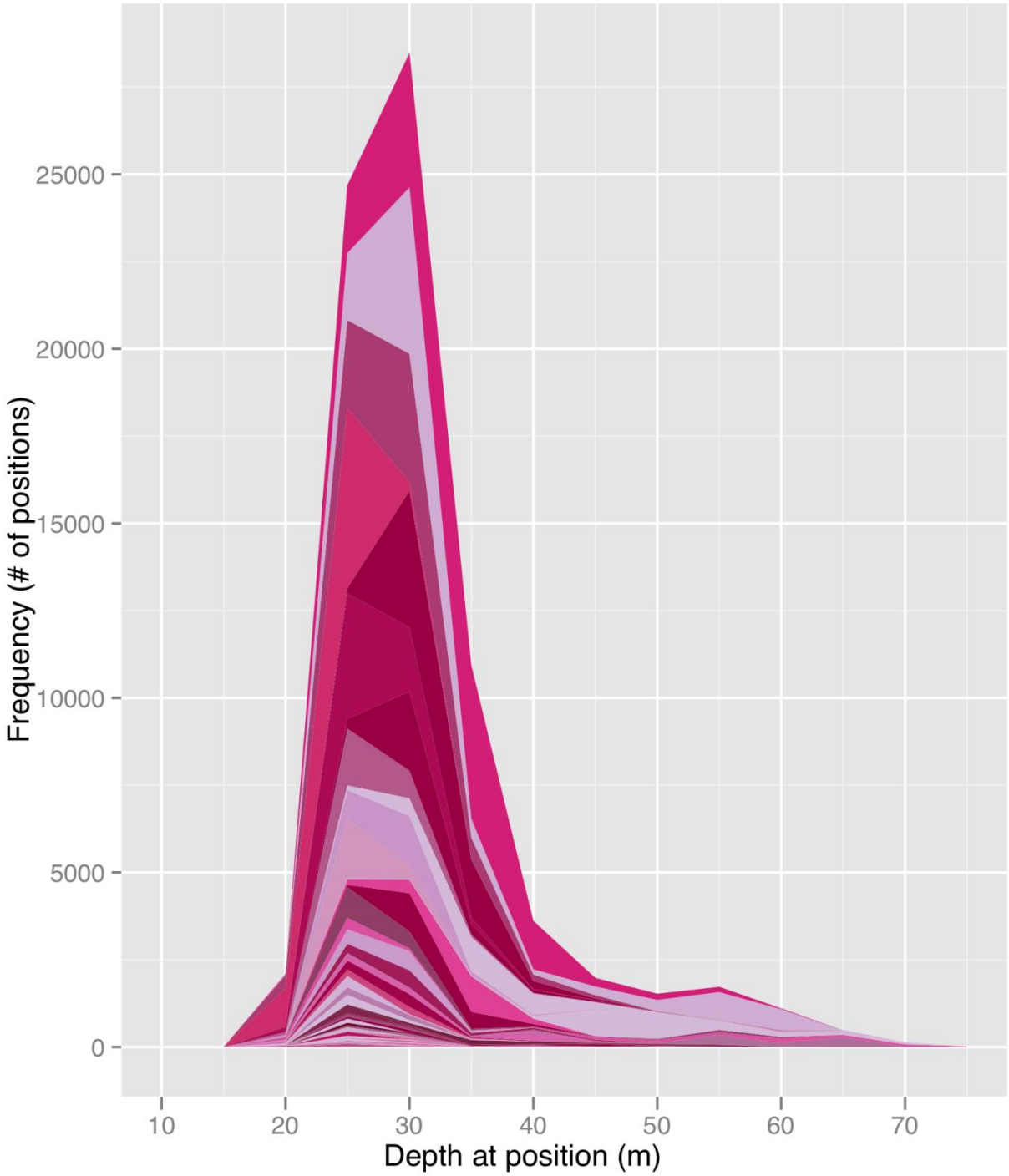


Figure 10 – WC Individual Depth Frequency. This figure shows the stacked frequency distribution of depth (m) of water at VPS-rendered position for individual WC. Depth frequencies for individual fish are color coded.

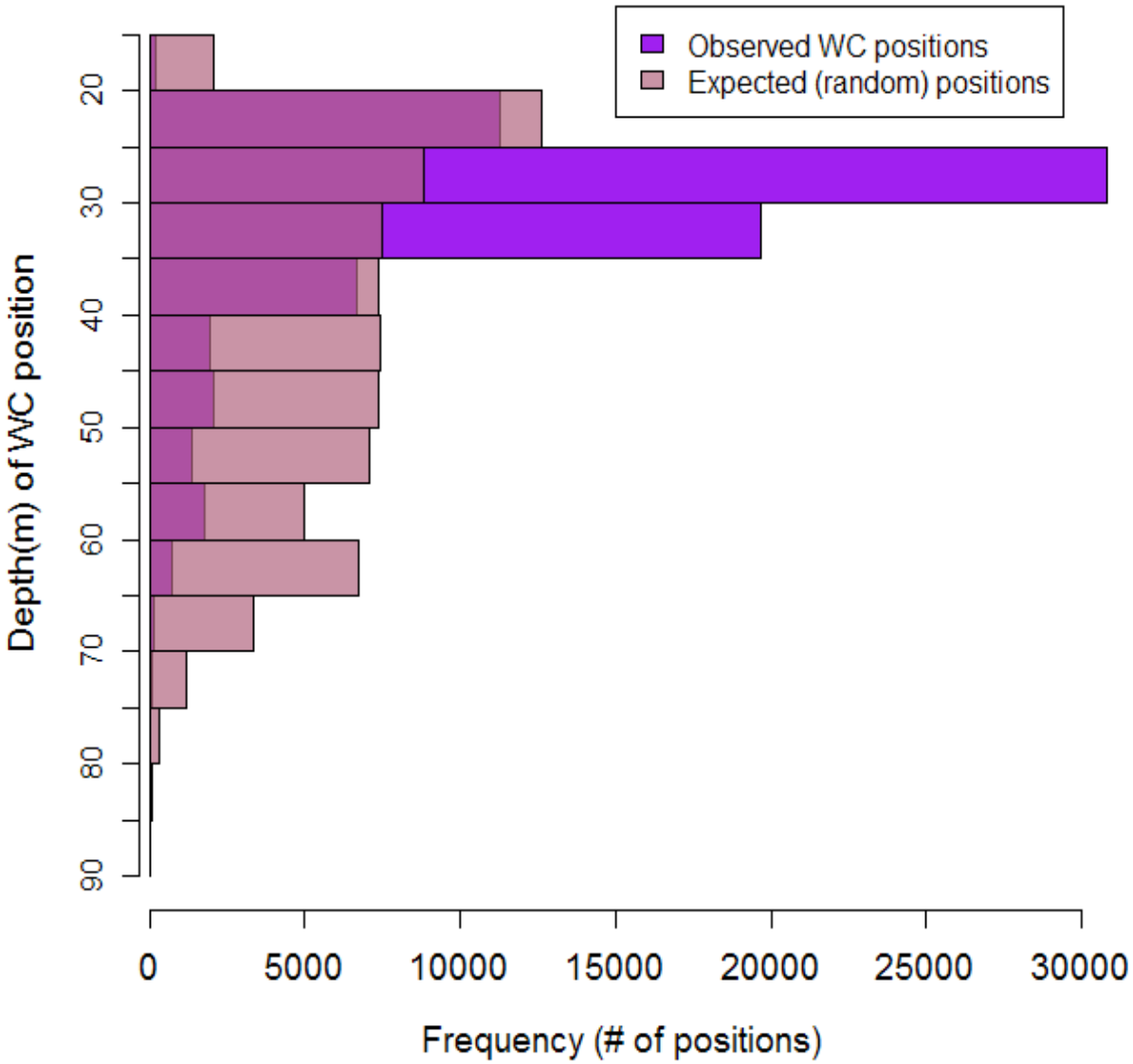


Figure 11 – WC VPS Observed vs. Expected Depth Distribution. This figure shows the frequency distribution of depth of water (m) in which WC positions (n=76,784) and an equal sample of randomized positions occurred. Observed and expected (randomized) distance distributions were significantly different (Pearson's chi-squared test, ^{2} = 39,922.6, simulated p < 0.0005).

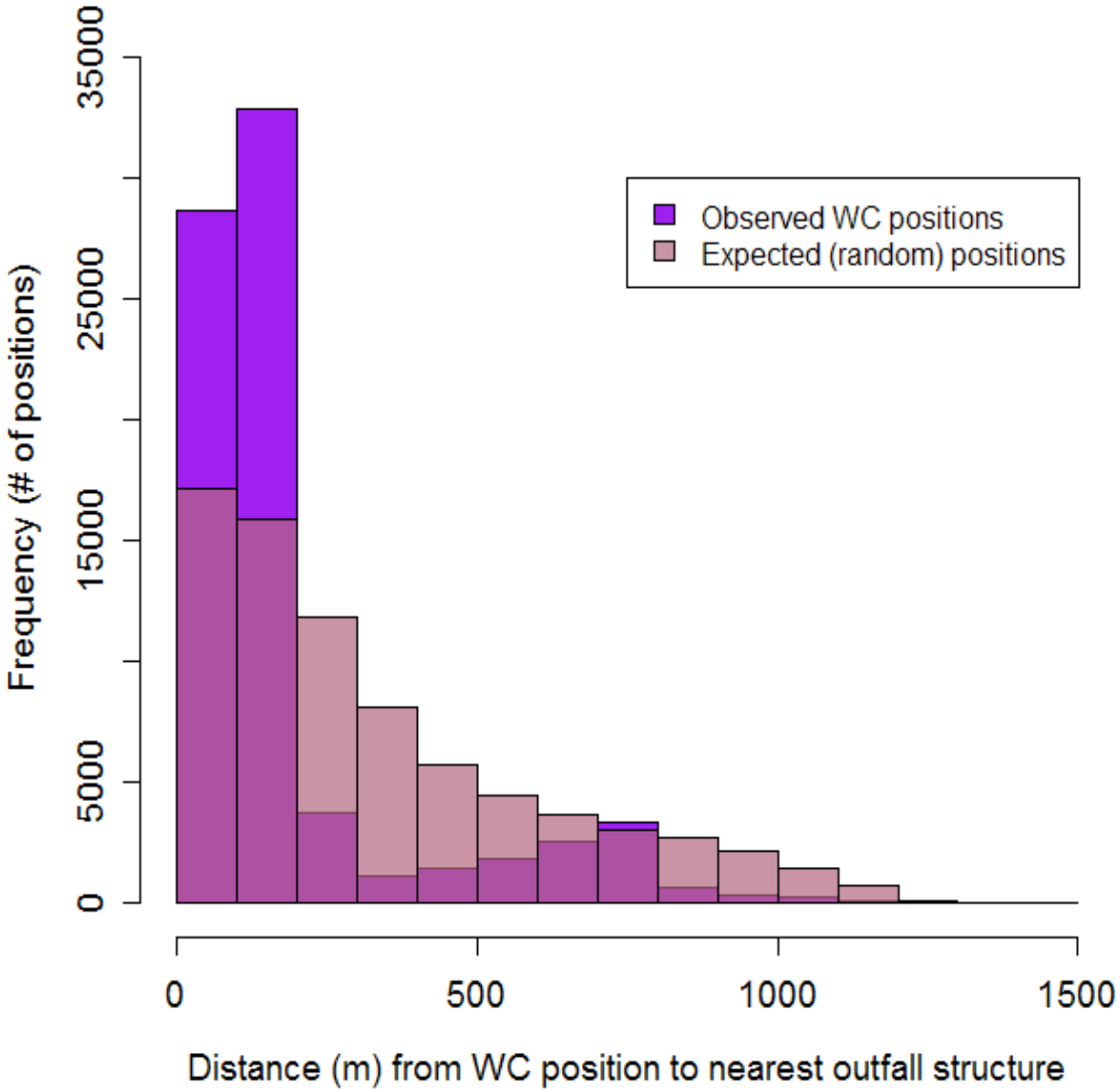


Figure 12 – WC VPS Observed vs. Expected Distance from Outfalls. This figure compares of frequency distribution of least distance (m) from the White Point outfalls to WC positions (n=76,784) and an equal sample of randomized positions. Observed and expected (randomized) distance distributions were significantly different (Pearson's chi-squared test, ^{2} = 26203.6, simulated $p < 0.0005$).

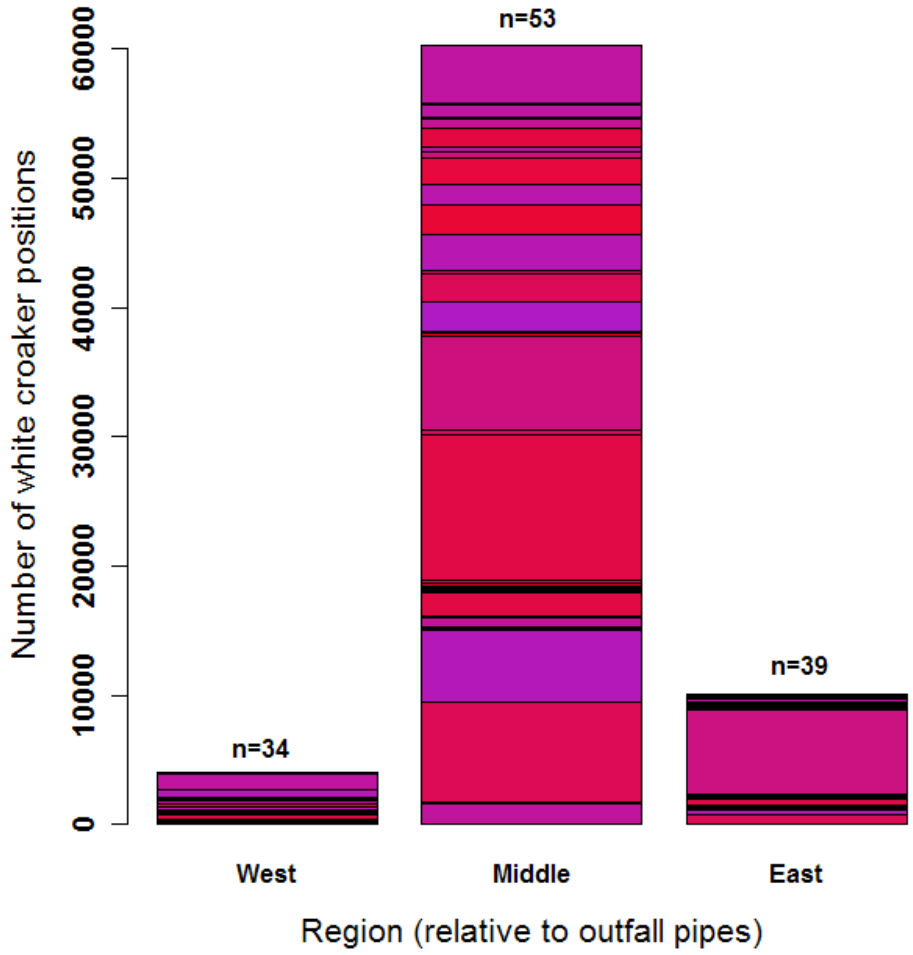


Figure 13 - Number of WC VPS Positions Relative to Outfalls. Indicated are the numbers of VPS-rendered detections of individual WC located west of the outfalls, between the outfall pipes, and the east of the outfalls. Colors represent the relative number of detections per individual per locations. Sample sizes (n =) above each bar indicates the total number of individuals with VPS-rendered positions at each general location.

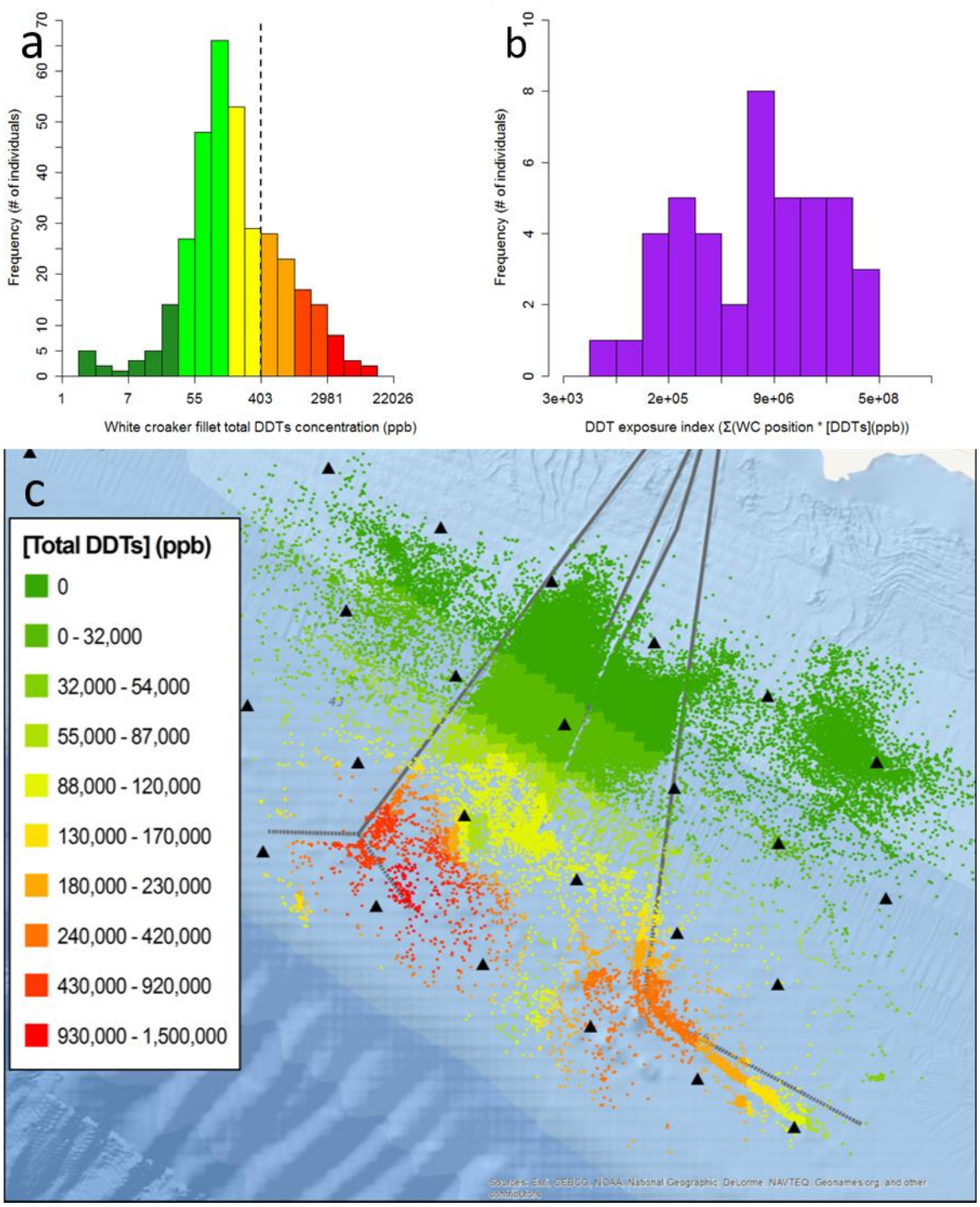


Figure 14 – WC DDT Exposure Model. Shown are the frequency distributions of (a) log-scale WC fillet DDT concentrations (n = 349), (NOAA, 2007); (b) log-scale DDT exposure metric (mean sediment [DDTs] (ppb) number of positions) for WC in the 2009 study. Figure (C) shows DDT exposure for individual WC, estimated as the sum of sediment Total DDTs (ppb) at each VPS position. Legend indicates concentrations of sediment Total DDTs, normalized for organic carbon and averaged for the 0-8-cm sediment bed interval (USEPA, 2013).

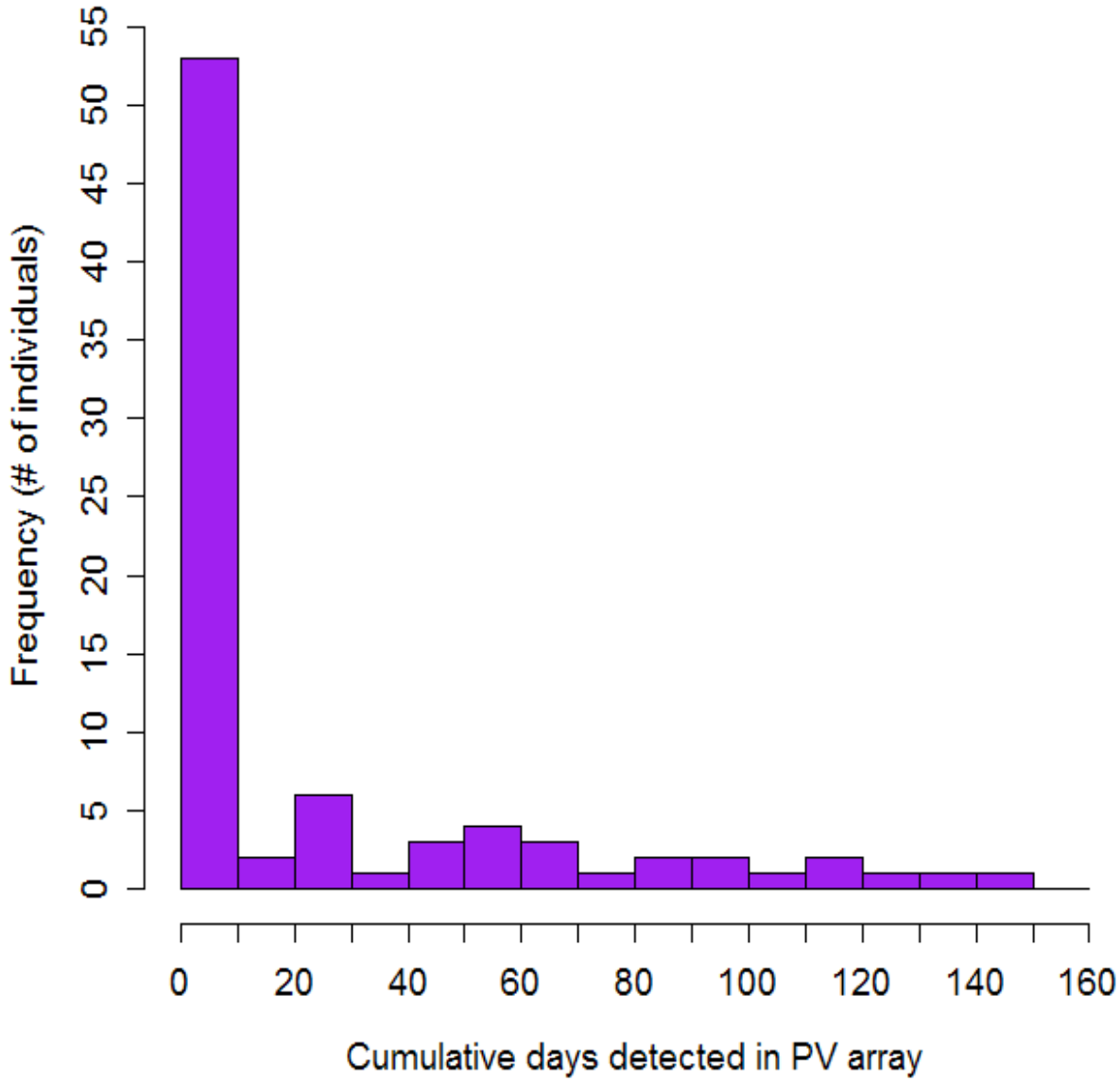


Figure 15 – WC Cumulative Presence Frequency. Shown is the frequency distribution of cumulative days (total number of days during study) that individual WC were detected by PV Shelf array receiver stations.

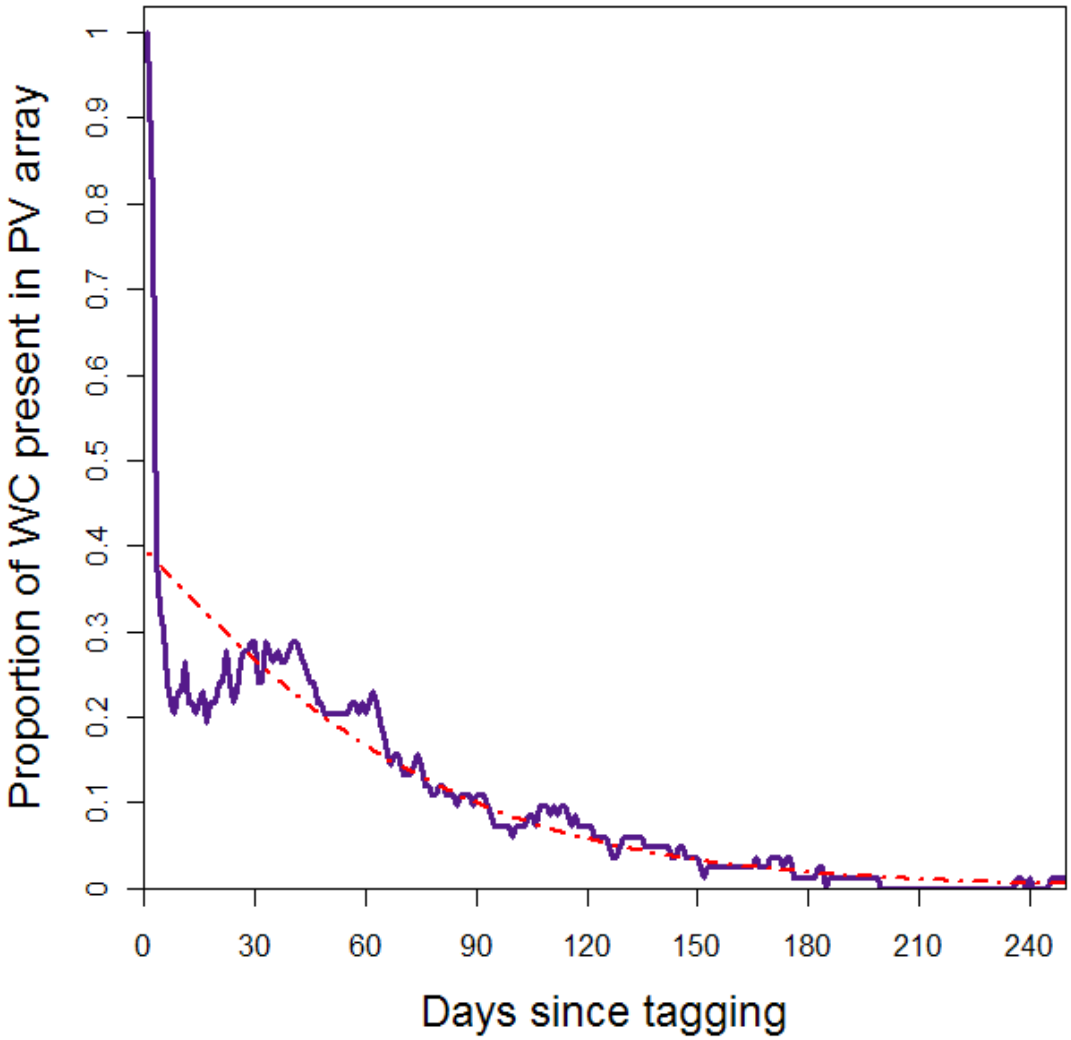


Figure 16 – WC Presence/Absence Over Study Duration. This figure shows the proportion of individual WC present in the PV Shelf array (detected by one or more receiver stations) over subsequent lengths of days post-transmitter implantation.

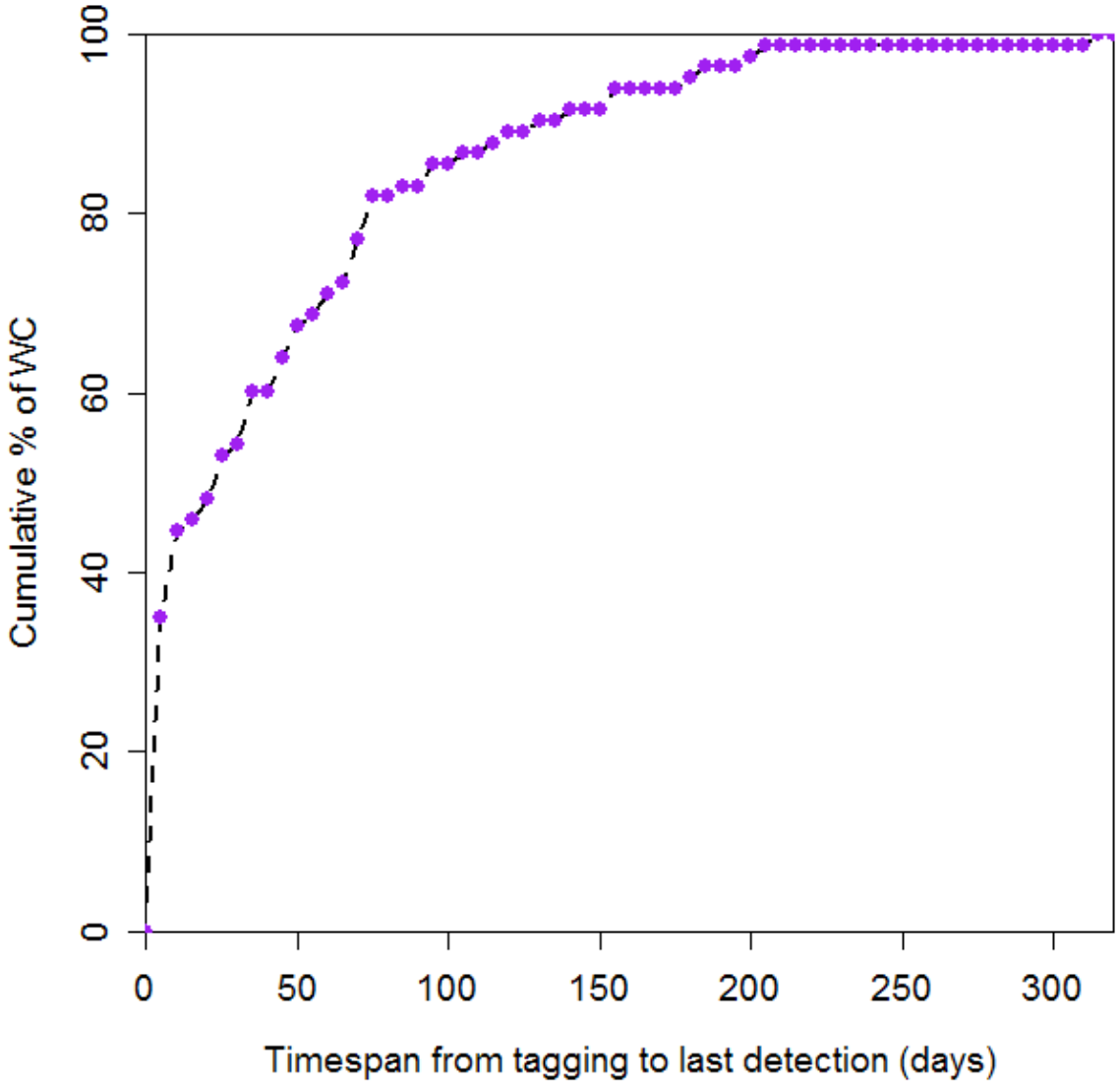


Figure 17 – WC Cumulative Probability of Detection Over Study Duration. Shown is the cumulative probability of detection of WC spanning from the date of tagging to date of last detection (in days).

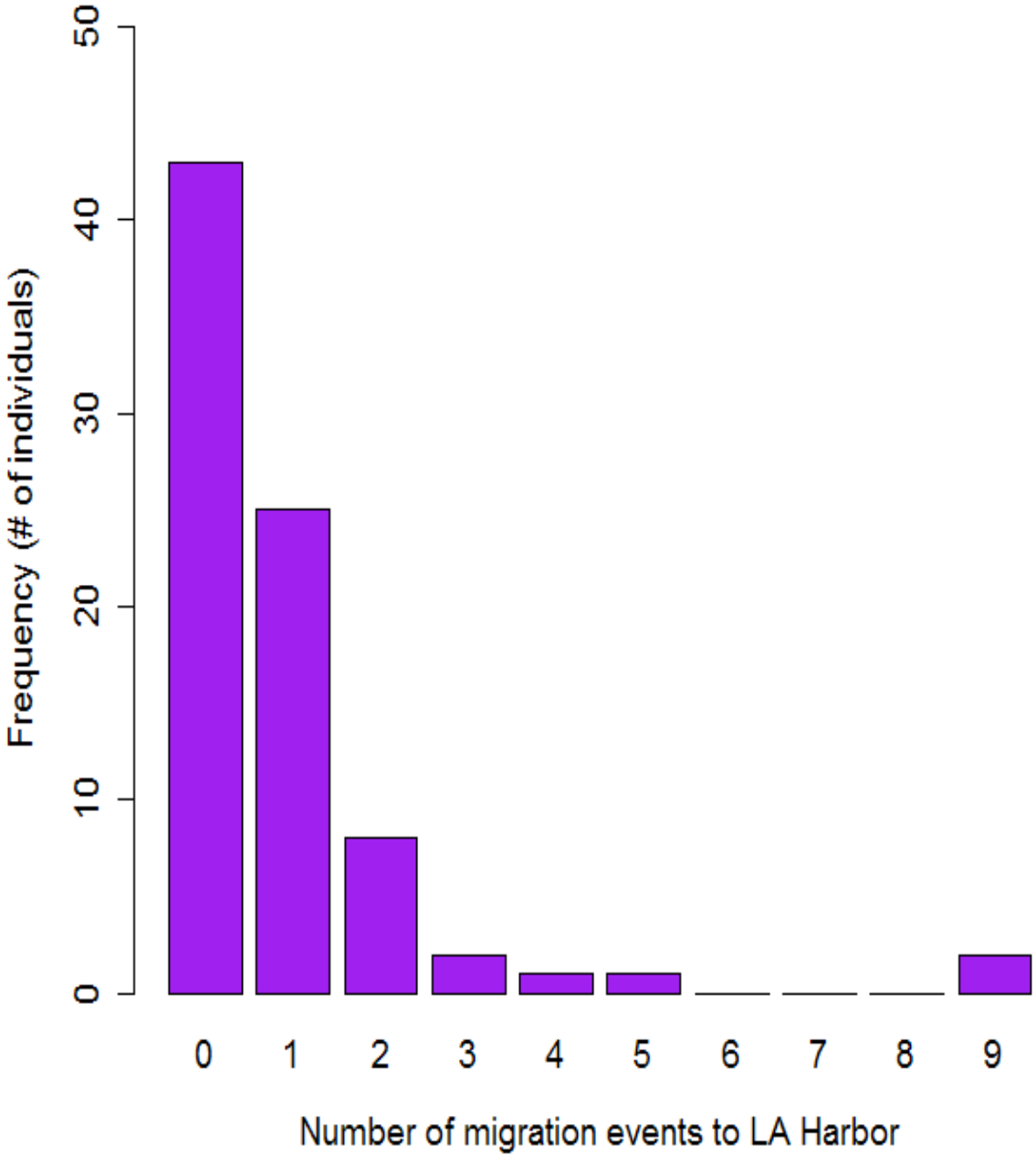


Figure 18 – WC Migration Events. This histogram illustrates the total number of migration events made from PV Shelf to LA Harbor, as indicated by harbor gate receivers. Multiple migration events were observed when a WC that had migrated to LA Harbor subsequently returned to PV Shelf before migrating again to the harbor.

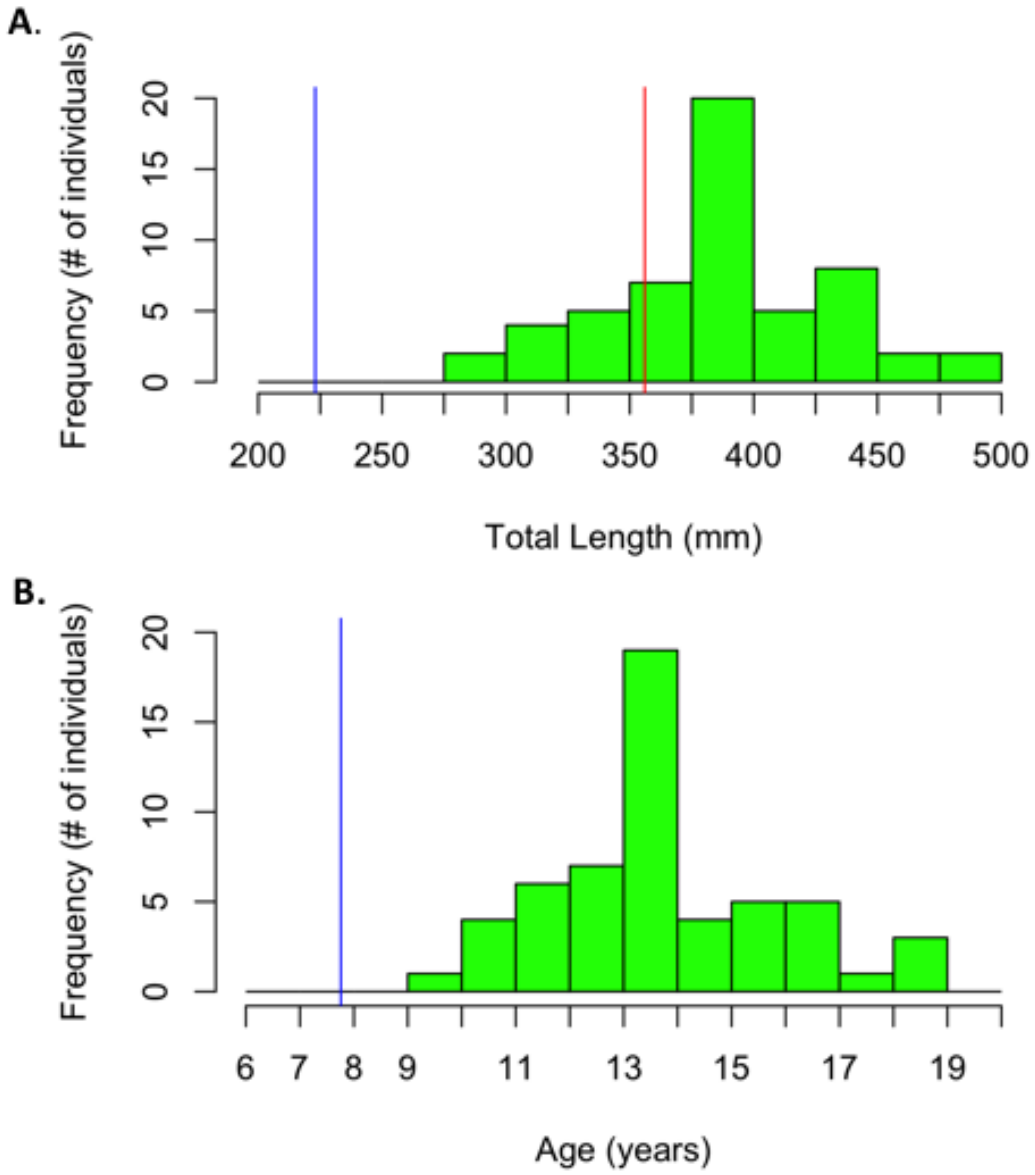
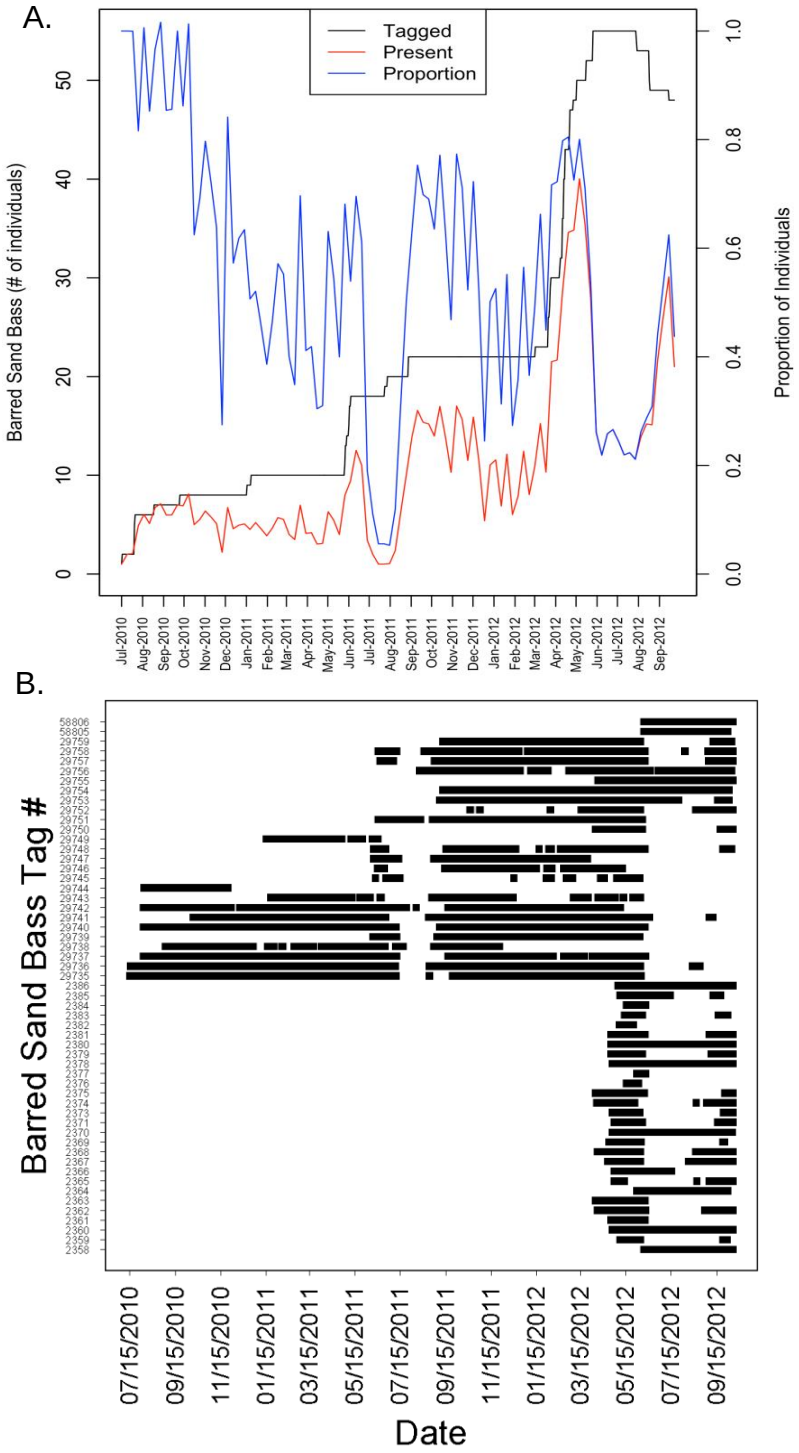


Figure 19 – BSB Length and Estimated Age Frequency. This figure presents histograms of total length (A) and estimated age at length (B) of tagged BSB. Red vertical line represents the total length at the newly mandated 14" (35.6 cm) minimum size limit. Blue vertical lines represent the value at which 50% of the population is mature (Love et al., 1996).



Red line = number of active BSB transmitters.
Blue line = number of BSB transmitters detected by at least one receiver in the PV Shelf array.

Figure 20 – BSB Presence/Absence and Daily Detections. (A) shows proportion of individual BSB present in the PV Shelf array (black line). (B) shows daily detections of all BSB (black hash marks) within the PV Shelf array.

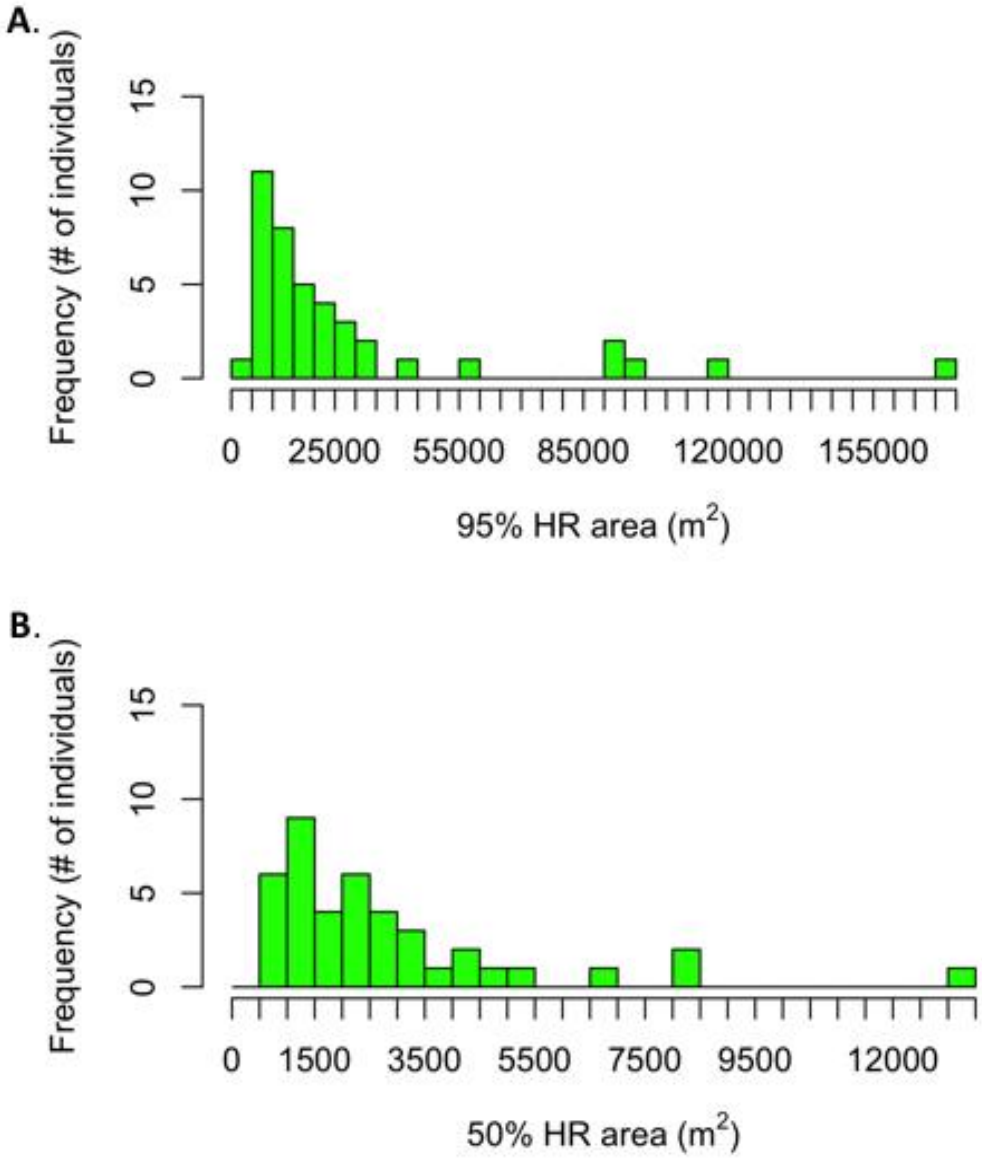


Figure 21 – BSB KUD Total and Core Area Frequency. Shown are frequency distributions of total (A) and core (B) area use (m^2) of BSB within the VPS array during the study duration. Total and core area was defined as the 95% and 50% contour of the KUD estimated from spatial analysis of VPS relocations.

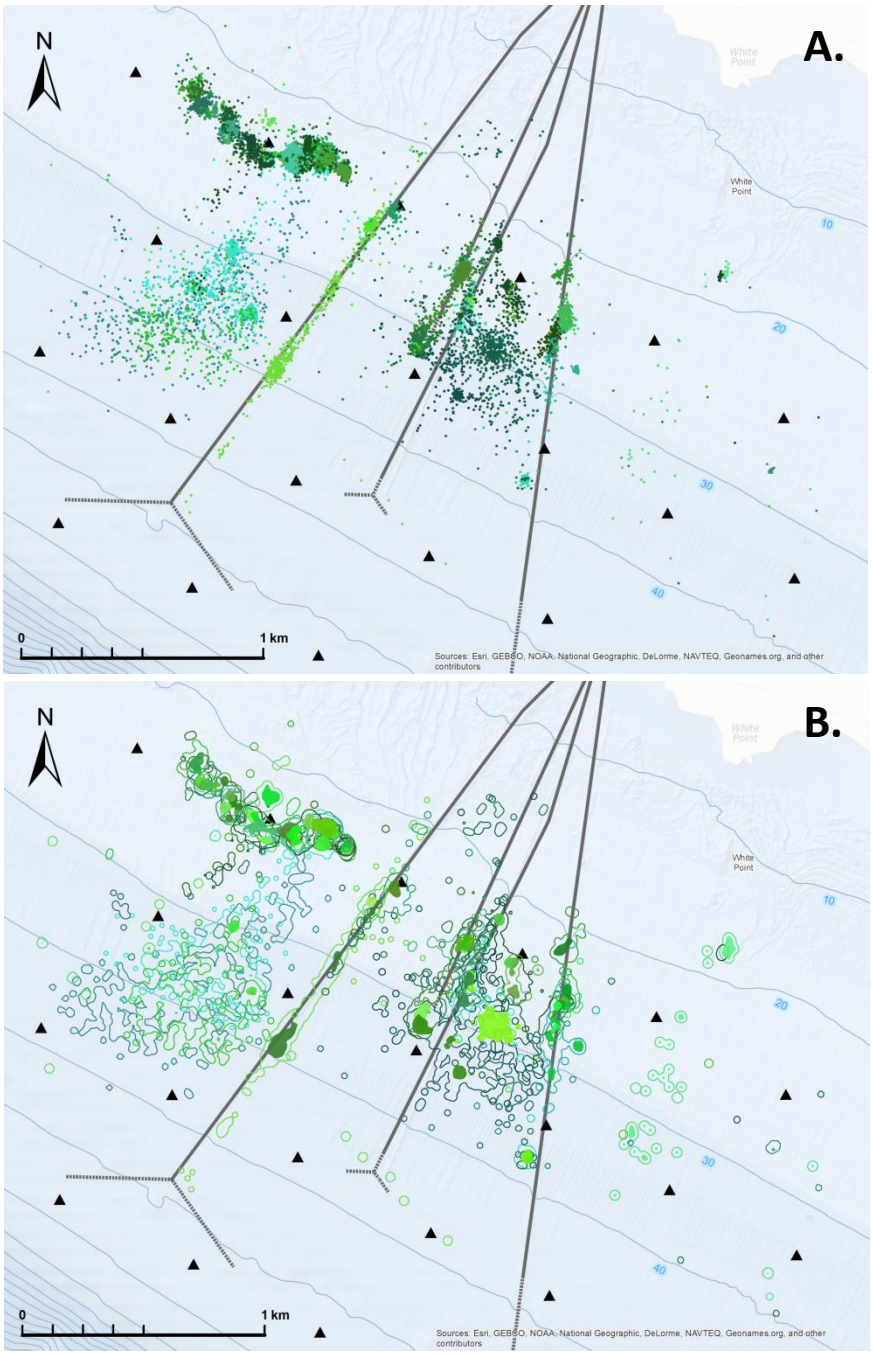


Figure 22 – BSB VPS Locations and KUD Areas. Shown are (A) VPS BSB positions (n=50); and (B) area use estimates (n=41). Individual BSB positions are color coded, with outlines indicating boundaries of total area use estimate (from 95% KUD contour) and solid polygons indicating core area use estimates (from 50% KUD contour). Acoustic receiver stations are indicated by black triangles.

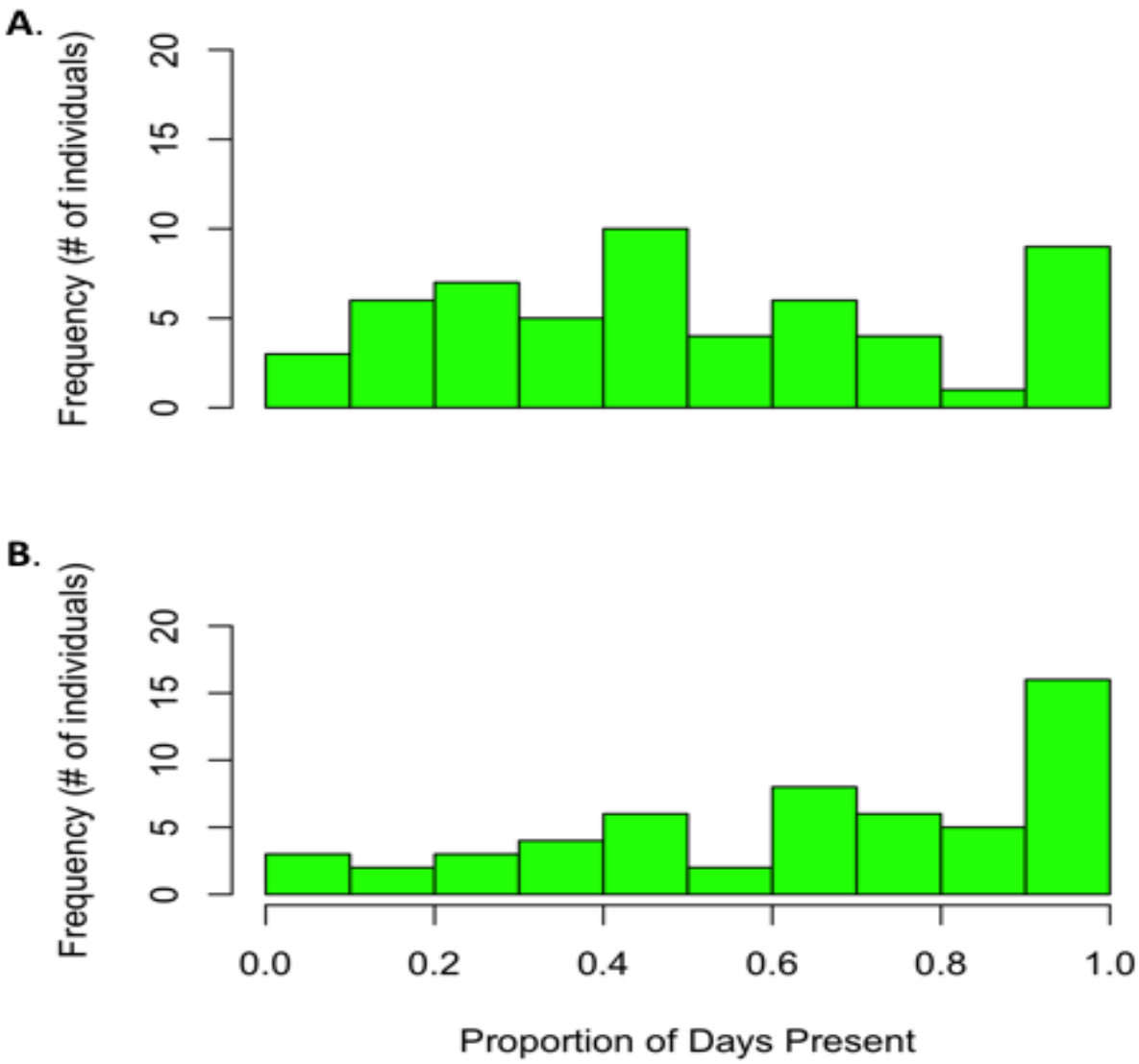


Figure 23 – Frequency Distribution of BSB Days Detected. This figure includes: (A) Frequency distribution of the proportion of total days at liberty for BSB detected within the PV Shelf array; and (B) Frequency distribution of the proportion of non-spawning days (September-May) at liberty of BSB detected within the PV Shelf array. Daily presence is defined as at least two detections on receivers in the PV Shelf array on a given day.

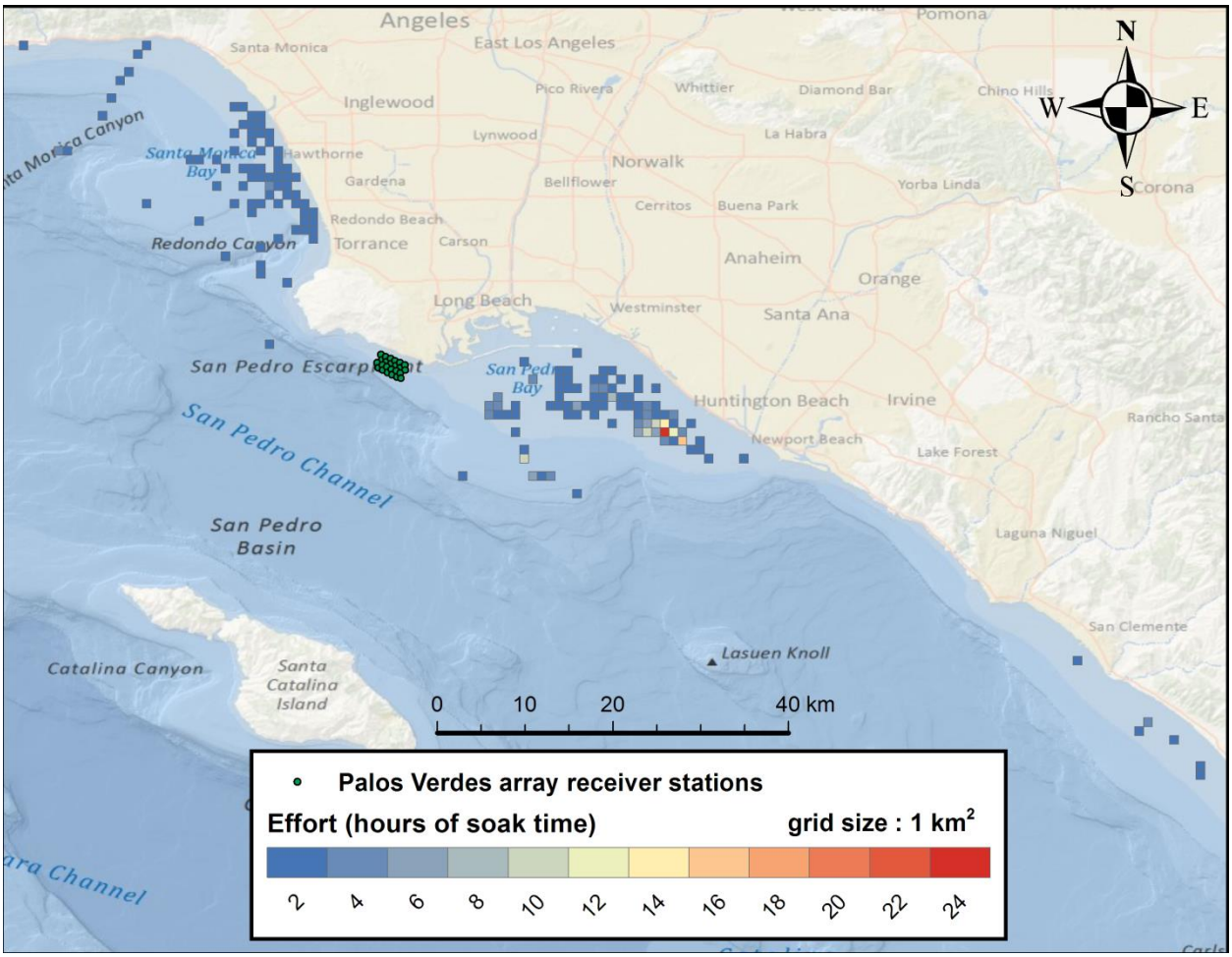


Figure 24 – Mobile Receiver Deployment Effort. Shown are vessel deployment locations for mobile receivers and effort (hours soak time) per km^2. Green diamonds represent array receiver station locations.

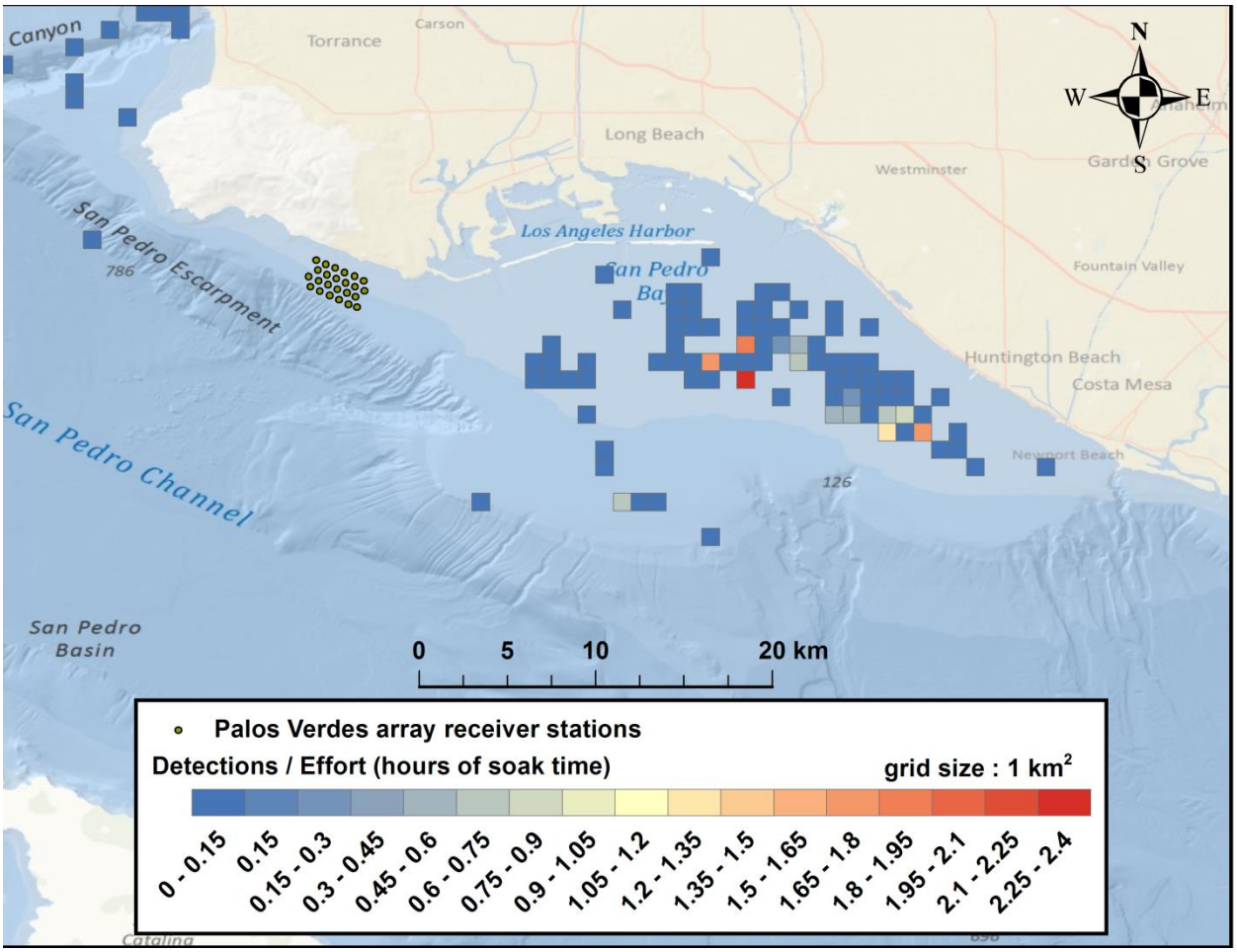


Figure 25 – BSB Mobile Receiver Detections/Unit Effort. This shows mobile receiver BSB detections per hour soak time per km^2. Green diamonds represent array receiver station locations.

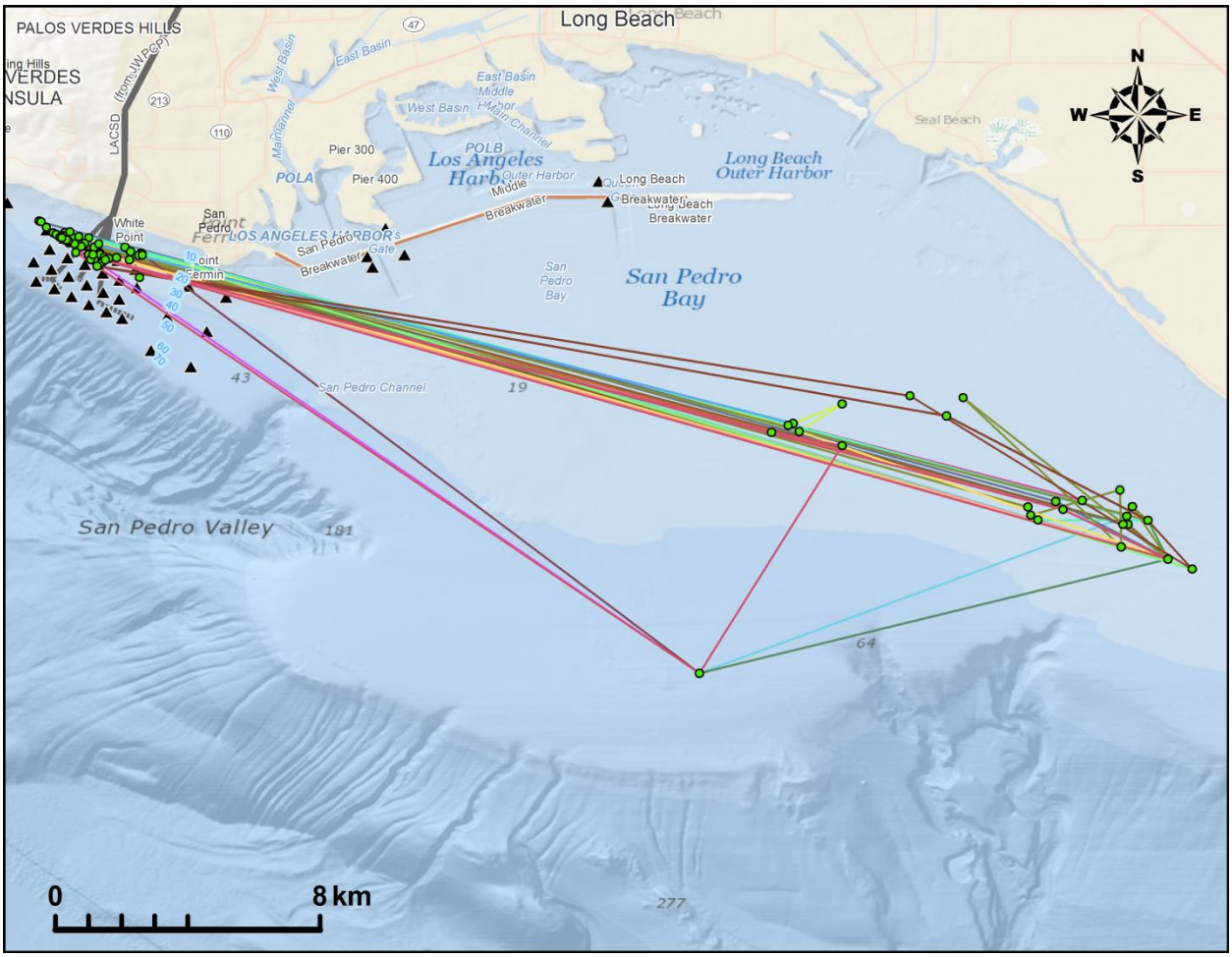


Figure 26 – BSB Mobile Receiver Detections. Colored lines connect tagging locations with chronological detections of individual BSB on Huntington Flats and Horseshoe Kelp.

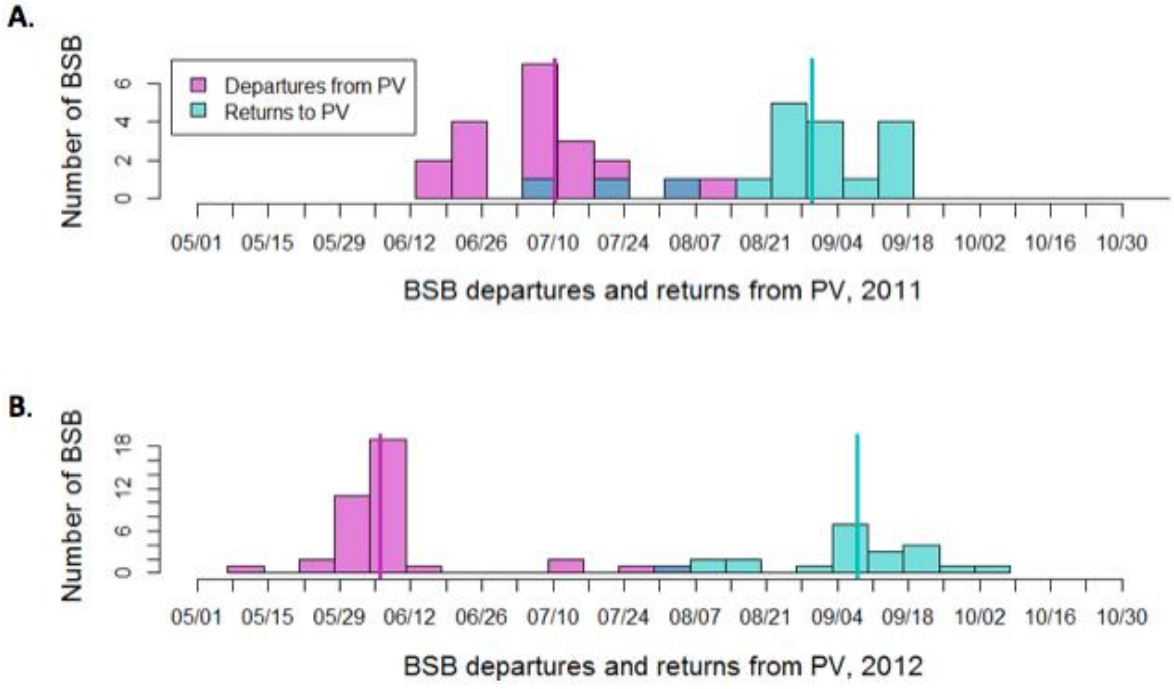


Figure 27 – BSB Migration Departures and Returns. Frequency distributions are shown for dates of BSB departures (pink) and returns (blue) from PV Shelf during the summer spawning seasons of 2011 (A) and 2012 (B). The median date for departure and return are indicated by the pink and blue vertical bars.

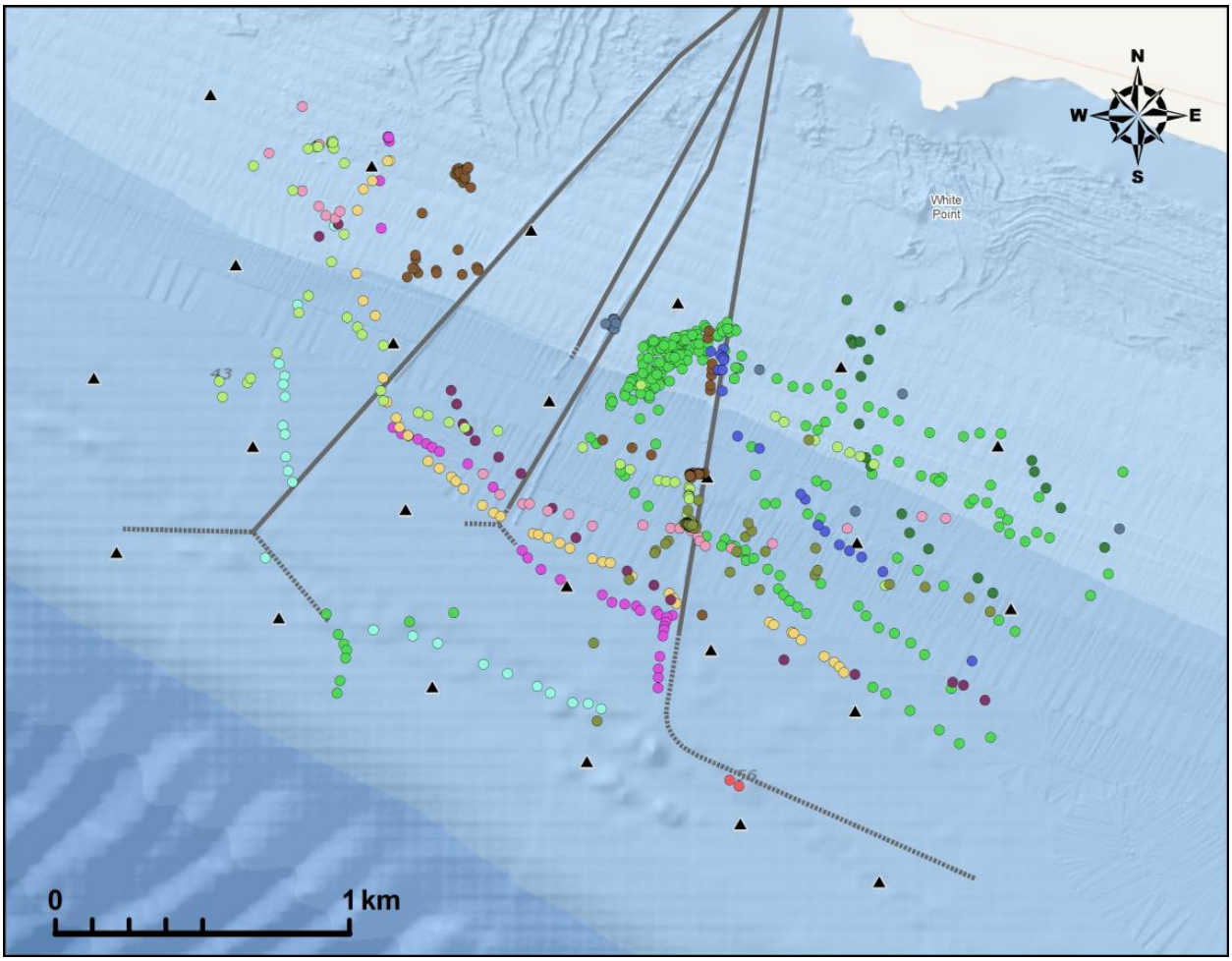


Figure 28 – CSF VPS Locations. VPS-rendered positions for CSF are shown. Individual fish positions are color-coded.

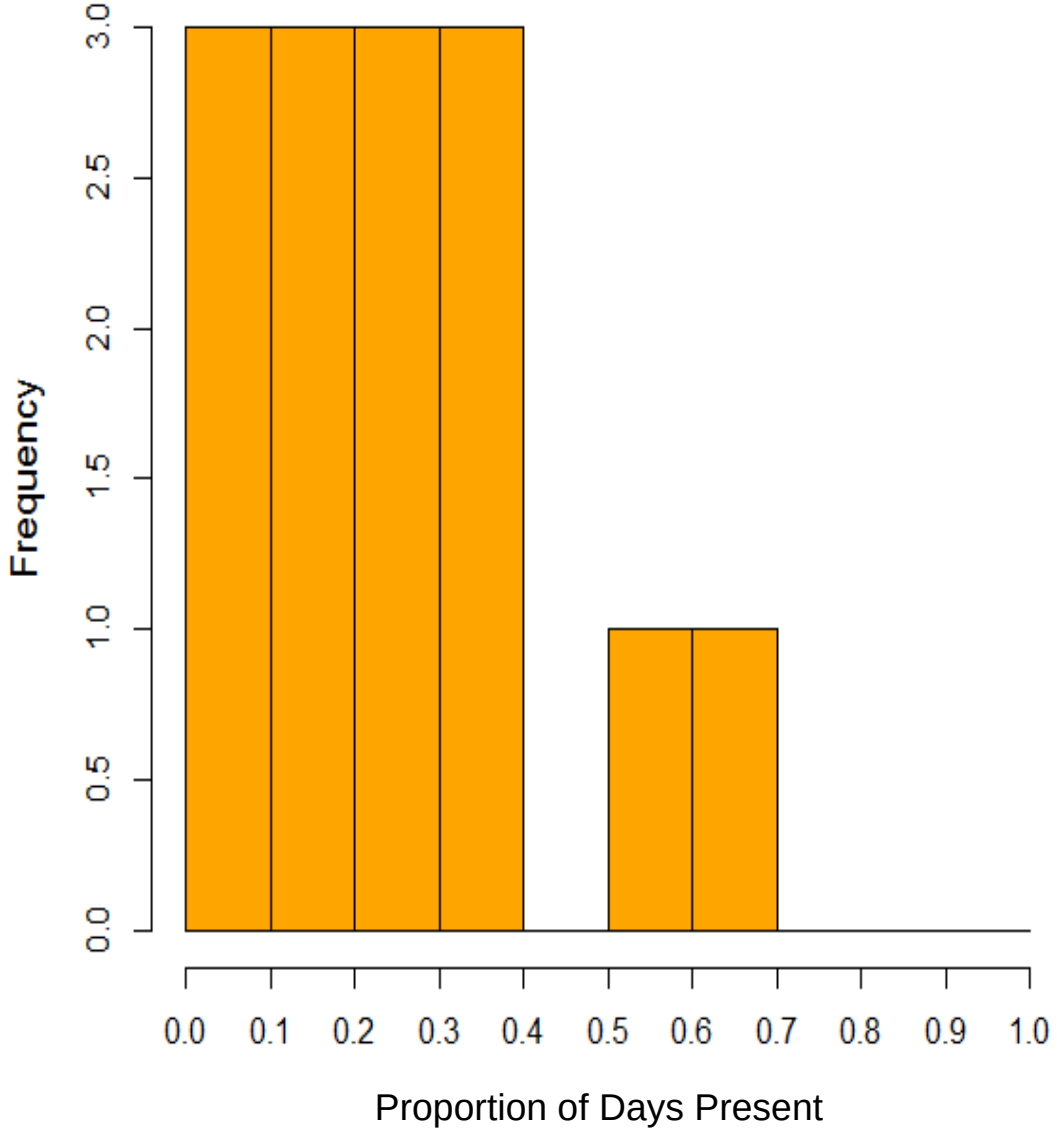


Figure 29 – CSF Daily Site Fidelity. This figure shows the frequency distribution of the proportion of total days at liberty for CSF (n=16). Daily presence is defined as at least two detections on receivers in the PV Shelf array on a given day.

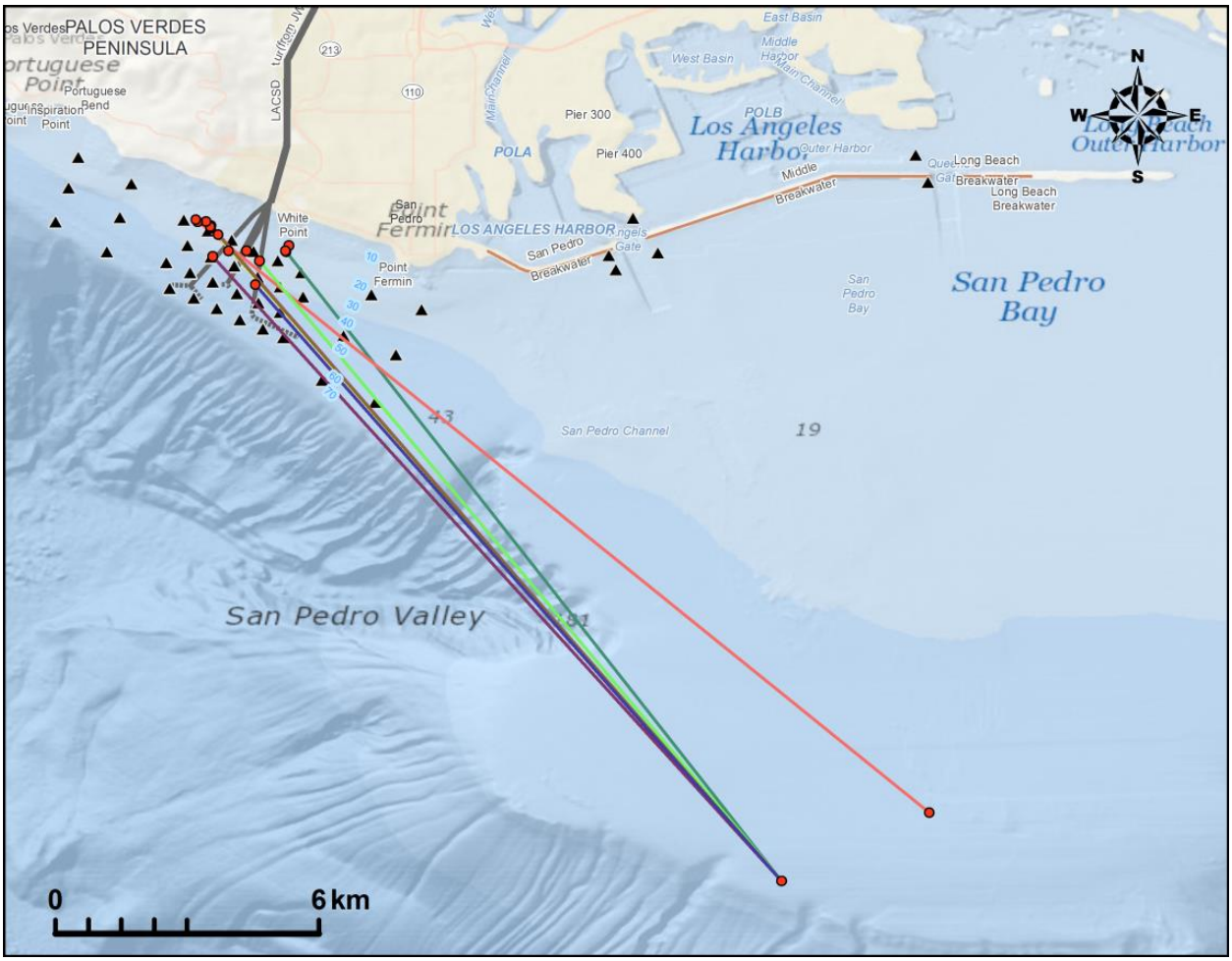


Figure 30 – CSF Migration Detections. This figure shows spawning season migration events for tagged CSF. Fish detection locations are indicated by orange circles. Individual fish movement events are color-coded.

Table 1 - Acoustic Receiver Station Locations and Depths.

Station	Latitude	Longitude	Depth (m)
OA-01	33.71419	-118.33944	22
OA-02	33.70902	-118.33840	38
OA-03	33.70552	-118.34280	48
OA-04	33.70041	-118.34220	65
OA-05	33.71202	-118.33450	26
OA-06	33.70665	-118.33380	34
OA-07	33.70337	-118.33810	49
OA-08	33.69816	-118.33740	64
OA-09	33.71006	-118.32963	23
OA-10	33.70464	-118.32910	34
OA-11	33.70151	-118.33320	48
OA-12	33.69612	-118.33250	62
OA-13	33.70779	-118.32506	23
OA-14	33.70246	-118.32430	32
OA-15	33.69906	-118.32850	50
OA-16	33.69377	-118.32770	62
OA-17	33.70593	-118.31980	25
OA-18	33.70027	-118.31960	36
OA-19	33.69712	-118.32370	49
OA-20	33.69206	-118.32300	60
OA-21	33.70346	-118.31550	24
OA-22	33.69840	-118.31440	34
OA-23	33.69495	-118.31950	47
OA-24	33.68992	-118.31690	59
PVSW-01	33.727002	-118.361032	22
PVSW-02	33.720763	-118.363023	38
PVSW-03	33.713810	-118.365680	64
PVSW-04	33.721600	-118.350192	23
PVSW-05	33.714760	-118.352540	38
PVSW-06	33.707750	-118.355170	63
PVSE-01	33.699000	-118.300950	21
PVSE-02	33.690610	-118.306690	44
PVSE-03	33.681520	-118.311120	65
PVSE-04	33.695906	-118.290711	23
PVSE-05	33.686690	-118.295950	42
PVSE-06	33.677050	-118.300240	53
AG-1	33.709000	-118.254000	
AG-2	33.704110	-118.250860	15
AG-3	33.714590	-118.247400	
AG-4	33.707500	-118.242230	
QG-1	33.726000	-118.184000	
QG-2	33.721870	-118.186940	

Table 2 - Acoustic Transmitter Deployment Log. No WC were fitted with external tags. SL = standard length; TL = total length.

Species	Date	Lat Landed	Long Landed	Lat released	Long released	Depth (m)	Trans-mitter ID	TL (mm)	SL (mm)	Age (yrs)	Weight (g)	Time released	Dart Tag ID
G. lineatus	7/21/2010	-	-	33.71210	-118.33469	24.8	36425	221	192	7.2	125	11:28	
G. lineatus	7/22/2010	33.70933	-118.33501	33.71184	-118.33811	27.0	36429	224	192	7.5	120	10:39	
G. lineatus	7/30/2010	-	-	33.70327	-118.31742	-	36419	239	207	8.9	165	13:56	
G. lineatus	7/30/2010	-	-	33.70398	-118.32052	-	36420	209	183	6.2	105	13:42	
G. lineatus	7/30/2010	-	-	-	-	-	36421	242	222	9.1	175	13:17	
G. lineatus	7/30/2010	33.70600	-118.32803	33.70722	-118.31930	30.9	36422	234	205	8.4	145	12:02	
G. lineatus	7/30/2010	33.70600	-118.32803	33.70392	-118.32137	30.9	36423	241	213	9.0	175	11:51	
G. lineatus	7/30/2010	33.70600	-118.32803	-	-	30.9	36424	215	187	6.7	100	11:38	
G. lineatus	7/30/2010	-	-	33.70588	-118.32780	-	36426	235	208	8.5	145	13:29	
G. lineatus	7/30/2010	33.70600	-118.32803	-	-	30.9	36427	236	207	8.6	135	11:25	
G. lineatus	7/30/2010	33.70607	-118.32743	33.70498	-118.32478	31.4	36428	229	196	7.9	-	10:20	
G. lineatus	8/1/2010	33.70512	-118.32598	33.70440	-118.32378	32.0	36418	210	187	6.3	115	10:07	
G. lineatus	8/5/2010	33.70620	-118.32560	33.70608	-118.32492	30.3	36408	223	192	7.4	110	11:05	
G. lineatus	8/5/2010	33.70622	-118.32793	33.70628	-118.32697	33.0	36409	246	209	9.5	190	10:50	
G. lineatus	8/5/2010	33.70568	-118.32385	33.70557	-118.32217	30.5	36417	219	192	7.0	130	10:02	
G. lineatus	8/7/2010	33.70627	-118.32823	33.70842	-118.32562	30.9	36407	229	195	7.9	150	12:59	
G. lineatus	8/11/2010	33.70672	-118.32817	33.70602	-118.32805	29.8	36406	238	210	8.8	130	9:57	
G. lineatus	8/11/2010	33.70600	-118.32832	33.70590	-118.32500	-	36410	221	190	7.2	110	12:11	
G. lineatus	8/11/2010	33.70567	-118.32478	33.70530	-188.32255	29.0	36411	224	191	7.5	110	13:10	
G. lineatus	8/12/2010	33.70668	-118.32695	33.70742		28.7	36405	209	179	6.2	110	11:08	
G. lineatus	8/12/2010	33.70507	-118.32778	33.70452	-118.32567	34.7	36416	225	196	7.6	115	14:18	
G. lineatus	8/13/2010	33.70581	-118.32783	33.70498	-118.32262	32.0	29690	199	170	5.4	90	10:07	
G. lineatus	8/13/2010	33.70609	-118.32842	33.70421	-118.32637	31.5	36412	231	209	8.1	145	8:23	
G. lineatus	8/13/2010	33.70660	-118.32497	33.70613	-118.32241	27.4	36413	225	197	7.6	115	10:42	
G. lineatus	8/13/2010	33.70581	-118.32783	33.70511	-118.32515	32.0	36414	232	204	8.2	150	9:59	
G. lineatus	8/13/2010	33.70610	-118.32792	33.70610	-118.32542	30.9	36415	222	193	7.3	125	9:11	
G. lineatus	8/14/2010	33.70643	-118.32785	33.70621	-118.32533	30.1	29691	224	196	7.5	130	7:31	
G. lineatus	8/14/2010	33.70643	-118.32785	33.70588	-118.32288	27.2	29692	224	196	7.5	125	7:43	
G. lineatus	8/14/2010	33.70622	-118.32738	33.70578	-118.32449	29.9	29694	244	209	9.3	180	8:10	
G. lineatus	8/14/2010	33.70622	-118.32738	33.70528	-118.32106	29.9	29695	225	193	7.6	140	8:25	
G. lineatus	8/14/2010	33.70616	-118.32784	33.70601	-118.32610	29.2	29696	229	195	7.9	130	9:29	
G. lineatus	8/14/2010	33.70616	-118.32784	33.70580	-118.32443	29.2	29698	225	195	7.6	125	9:38	
G. lineatus	8/15/2010	33.70636	-118.32841	33.70638	-118.32546	30.7	29688	215	185	6.7	100	8:10	
G. lineatus	8/15/2010	33.70637	-118.32841	33.70669	-118.32523	30.4	29697	245	213	9.4	170	8:49	
G. lineatus	8/21/2010	33.70612	-118.32791	33.70510	-118.32550	32.0	29686	218	185	6.9	110	9:05	
G. lineatus	8/21/2010	33.70631	-118.32819	33.70568	-118.32620	31.6	29702	241	210	9.0	160	9:15	
G. lineatus	8/28/2010	33.70588	-118.32815	33.70589	-118.32809	32.6	29687	215	187	6.7	110	8:01	
G. lineatus	8/28/2010	-	-	33.70542	-118.32881	35.0	29693	215	185	6.7	110	8:27	
G. lineatus	8/28/2010	-	-	33.70575	-118.32842	33.8	29699	245	214	9.4	190	8:13	

G. lineatus	8/28/2010	33.70623	-118.32844	33.70575	-118.32999	32.0	29700	219	189	7.0	120	9:14	
G. lineatus	8/28/2010	33.70626	-118.32810	33.70698	-118.32816	31.5	29701	216	190	6.8	130	7:40	
G. lineatus	9/1/2010	33.70642	-118.32045	33.70595	-118.32581	31.3	29685	210	176	6.3	90	8:18	
G. lineatus	9/6/2010	33.70636	-118.32854	33.70826	-118.32654	31.9	29689	243	208	9.2	140	17:55	
G. lineatus	9/6/2010	33.70585	-118.32778	33.70740	-118.32778	-	29713	216	189	6.8	115		
G. lineatus	9/8/2010	33.70620	-118.32770	33.70498	-118.32560	30.3	29707	216	186	6.8	120		
G. lineatus	1/18/2011	33.70631	-118.32817	33.70789	-118.33212	-	29704	260	231	11.0	-	10:28	
G. lineatus	6/9/2011	33.70625	-118.32768	33.70649	-118.32439	-	29703	235	204	8.5	155	10:50	
G. lineatus	6/13/2011	33.70537	-118.32876	33.70497	-118.32903	-	29708	242	219	9.1	165	10:02	
G. lineatus	6/13/2011	33.70598	-118.32512	33.70598	-118.32512	-	29712	214	191	6.6	125	10:58	
G. lineatus	6/13/2011	33.70598	-118.32512	33.70598	-118.32512	-	29714	204	185	5.8	125	10:58	
G. lineatus	6/16/2011	33.70736	-118.32915	33.70972	-118.33247	29.1	29709	220	190	7.1	140	12:25	
G. lineatus	6/16/2011	33.70840	-118.33088	33.71052	-118.33424	29.0	29710	220	188	7.1	120	11:46	
G. lineatus	6/16/2011	33.70598	-118.32793	-	-	31.0	29711	235	215	8.5	155		
G. lineatus	6/16/2011	33.71392	-118.33800	33.71096	-118.33412	-	29721	225	200	7.6	135	12:50	
G. lineatus	6/19/2011	33.70723	-118.32710	33.70848	-118.32531	26.3	29705	211	186	6.4	120	8:34	
G. lineatus	6/19/2011	33.70700	-118.32672	33.70810	-118.32422	26.5	29722	215	186	6.7	115	9:13	
G. lineatus	6/20/2011	33.70700	-118.32849	33.71003	-118.32790	-	29715	222	198	7.3	125	12:29	
G. lineatus	6/20/2011	33.70668	-118.32870	33.70738	-118.32881	-	29716	220	190	7.1	140	9:55	
G. lineatus	6/20/2011	33.70916	-118.32819	33.71003	-118.32790	-	29718	242	214	9.1	170	12:30	
G. lineatus	6/20/2011	33.70700	-118.32849	33.07790	-118.32837	-	29719	235	215	8.5	150	12:12	
G. lineatus	6/20/2011	33.70804	-118.32900	33.70961	-118.32932	-	29723	241	206	9.0	150	10:11	
G. lineatus	6/20/2011	33.70764	-118.32874	33.70935	-118.32865	-	29724	233	206	8.3	130	10:38	
G. lineatus	6/20/2011	33.70715	-118.32893	33.70921	-118.32900	-	29725	199	174	5.4	85	11:05	
G. lineatus	6/23/2011	33.70752	-118.32844	33.70778	-118.32788	-	29726	253	220	10.3	170	20:54	
G. lineatus	6/23/2011	33.70600	-118.32801	33.70650	-118.32764	31.8	29727	236	206	8.6	170	21:47	
G. lineatus	6/25/2011	33.70670	-118.32770	-	-	28.9	29706	216	190	6.8	120		
G. lineatus	6/25/2011	33.70619	-118.32823	33.70706	-118.32802	31.4	29720	240	210	9.0	140	8:50	
G. lineatus	6/26/2011	33.70691	-118.32802	33.70796	-118.32755	27.8	29732	225	197	7.6	140	9:08	
G. lineatus	6/27/2011	33.70600	-118.32758	33.70638	-118.32650	-	29731	254	220	10.4	175	9:33	
G. lineatus	7/4/2011	33.70576	-118.32408	33.70579	-118.31972	-	29717	225	196	7.6	130	10:30	
G. lineatus	7/4/2011	33.70633	-118.32343	33.70459	-118.31334	-	29728	241	207	9.0	150	11:08	
G. lineatus	7/4/2011	33.70547	-118.32343	33.70473	-118.31679	-	29733	209	181	6.2	100	10:59	
G. lineatus	7/14/2011	33.70309	-118.32539	33.70245	-118.32478	38.0	29730	211	189	6.4	115	20:28	
G. lineatus	7/17/2011	33.70658	-118.32905	33.70777	-118.32760	31.2	29734	223	199		120	9:46	
G. lineatus	7/17/2011	33.70670	-118.32811	33.70811	-118.32584	29.7	29729	218	194		110	11:58	
G. lineatus	7/19/2011	33.70543	-118.32366	33.70440	-118.31665		2289	240	207		150	11:08	
G. lineatus	7/31/2011	33.70589	-118.32701	33.70582	-118.32332	31.3	2288	210	186	6.3	105	10:51	
G. lineatus	7/31/2011	33.70589	-118.32677	33.70489	-118.32304	32.0	2290	231	202	8.1	135	11:06	
G. lineatus	7/31/2011	33.70565	-118.32481	33.70581	-118.32234	29.5	2337	235	206	8.5	150	11:57	
G. lineatus	7/31/2011	33.70559	-118.32677	33.70591	-118.32726	32.0	2338	214	186	6.6	105	10:34	
G. lineatus	7/31/2011	33.70562	-118.32615	33.70489	-118.70575	30.9	2340	234	207	8.4	120	11:55	
G. lineatus	7/31/2011	33.70589	-118.32701	33.70566	-118.32226	31.3	2341	215	191	6.7	120	10:56	
G. lineatus	8/6/2011	33.70620	-118.32813	33.70615	-118.32809	31.3	2336	220	191	7.1	130	10:45	

G. lineatus	8/6/2011	33.70597	-118.32531	33.70547	-118.32298	28.7	2339	255	223	10.5	185	12:19	
G. lineatus	8/6/2011	33.70617	-118.32819	33.70597	-118.32531	32.0	2354	232	204	8.2	130	12:06	
G. lineatus	8/6/2011	33.70583	-118.32531	33.70581	-118.32701	28.2	2355	230	206	8.0	160	12:44	
G. lineatus	8/6/2011	33.70620	-118.32813	33.70615	-118.32809	31.3	2356	224	194	7.5	120	10:45	
G. lineatus	8/6/2011	33.70594	-118.32757	33.70615	-118.32809	31.2	2357	245	214	9.4	160	10:45	
G. lineatus	8/9/2011	33.70595	-118.32524	33.70752	-118.32887	-	2350	231	207	8.1	150	11:02	
G. lineatus	8/9/2011	33.70542	-118.32484	33.70752	-118.32668	-	2351	231	209	8.1	135	12:08	
G. lineatus	8/10/2011	33.70554	-118.32520	33.70554	-118.32520	-	2291	224	198	7.5	-	10:48	
G. lineatus	8/10/2011	33.70558	-118.32518	33.70558	-118.32518	-	2342	245	221	9.4	-	11:06	
G. lineatus	8/10/2011	33.70559	-118.32517	33.70563	-118.32517	-	2345	241	213	9.0	-	11:20	
G. lineatus	8/10/2011	33.70555	-118.32519	33.42334	-118.19511	-	2346	222	197	7.3	-	10:07	
G. lineatus	8/10/2011	33.70563	-118.32516	33.70563	-118.32516	-	2349	238	212	8.8	-	11:30	
G. lineatus	8/10/2011	33.70555	-118.32519	-	-	-	2353	229	205	7.9	-	10:23	
G. lineatus	8/11/2011	33.70576	-118.32518	33.70578	-118.32518	-	2299	240	213	9.0	-	9:19	
P. nebulifer	7/15/2010	-	-	33.70958	-118.31820	17.4	29735	336	285	11.5	480	13:45	844
P. nebulifer	7/16/2010	33.70738	-118.32811	33.70757	-118.32810	26.0	29736	301	248	10.2	320	10:30	843
P. nebulifer	8/3/2010	33.70925	-118.32983	33.70845	-118.32698	-	29737	300	252	10.2	360	9:46	241
P. nebulifer	8/3/2010	33.70925	-118.32983	33.70793	-118.32505	-	29740	326	274	11.1	400	9:53	244
P. nebulifer	8/3/2010	33.70265	-118.31838	33.70127	-118.31427	-	29742	325	278	11.1	490	9:09	248
P. nebulifer	8/4/2010	33.70615	-118.32247	33.70618	-118.31707	-	29744	280	245	9.5	305	14:06	837
P. nebulifer	9/1/2010	33.70571	-118.32844	33.70553	-118.32609	-	29738	365	312	12.6	690	10:58	240
P. nebulifer	10/9/2010	33.70626	-118.32878	33.70625	-118.32755	34.9	29741	360	347	12.4	770	9:30	250
P. nebulifer	1/16/2011	33.70466	-118.32544	33.70466	-118.32544	-	29749	382	344	13.4	815	8:10	
P. nebulifer	1/22/2011	33.70562	-118.32435	33.70562	-118.32435	29.7	29743	368	314	12.8	690	10:43	249
P. nebulifer	6/9/2011	33.70026	-118.32668	33.70626	-118.32668	-	29739	409	356	14.7	930	9:59	239
P. nebulifer	6/10/2011	33.70753	-118.32496	33.70753	-118.32496	24.0	29747	310	265	10.5	375	10:13	814
P. nebulifer	6/10/2011	33.70760	-118.32689	33.70758	-118.32691	25.4	29748	445	402	16.6	>1000	9:09	813
P. nebulifer	6/12/2011	33.71200	-118.32909	33.71052	-118.32922	-	29745	390	343	13.7	895	11:03	236
P. nebulifer	6/15/2011	33.70935	-118.32700	33.70960	-118.32668	24.0	29746	379	335	13.3	695	9:59	247
P. nebulifer	6/16/2011	33.71392	-118.33803	33.71660	-118.34156	25.0	29751	380	330	13.3	690	13:06	232
P. nebulifer	6/16/2011	33.70647	-118.32874	33.70813	-118.33156	31.5	29758	385	331	13.5	770	10:24	
P. nebulifer	6/18/2011	33.70457	-118.32597	33.70448	-118.32586	33.1	29757	401	349	14.3	955	9:00	
P. nebulifer	8/7/2011	33.70607	-137.36430	33.70619	-118.32356	-	29753	358	314	12.4		11:35	
P. nebulifer	8/11/2011	33.70893	-118.32782	33.71054	-118.32938	-	29756	326	292	11.1		11:50	817
P. nebulifer	9/11/2011	33.70715	-118.32167	33.70676	-118.32054	-	29754	335	294	11.4	>500	14:41	242
P. nebulifer	9/11/2011	33.70715	-118.32167	33.70676	-118.32054	-	29759	316	275	10.7	435	14:41	245
P. nebulifer	3/16/2012	33.71161	-118.33313	33.71131	-118.33359	-	29752	400	345	14.2	740	11:05	819
P. nebulifer	4/4/2012	33.71225	-118.33463	33.71163	-118.33475	25.0	2363	351	306	12.1	610	12:24	222
P. nebulifer	4/4/2012	33.71163	-118.33368	33.71163	-118.33407	25.3	2375	415	354	15.0	1080		226
P. nebulifer	4/4/2012	33.71125	-118.33308	33.71247	-118.33495	28.2	29750	480	424	18.8	1660		217
P. nebulifer	4/6/2012	33.71260	-118.33495	33.71207	-118.33538	25.4	2374	471	415	18.2	1650		824
P. nebulifer	4/7/2012	33.71089	-118.33262	33.71053	-118.33194	27.3	2362	395	345	14.0	990		229
P. nebulifer	4/7/2012	33.71213	-118.33253	33.71244	-118.33078	24.4	2368	390	344	13.7	810	8:40	230
P. nebulifer	4/8/2012	33.71174	-118.32876	33.71210	-118.32809	22.4	29755	390	343	13.7	930	8:42	216

P. nebulifer	4/21/2012	33.70998	-118.33000	33.70977	-118.33018	25.3	2367	381	332	13.3	850		228
P. nebulifer	4/22/2012	33.71239	-118.33611	33.71339	-118.33770	26.8	2369	441	387	16.3	1310	12:31	820
P. nebulifer	4/25/2012	33.71123	-118.33086	33.71229	-118.33276	24.8	2361	421	367	15.3	1040	12:18	821
P. nebulifer	4/25/2012	33.71115	-118.33334	33.71223	-118.33596	27.0	2379	389	342	13.7	860	12:00	828
P. nebulifer	4/25/2012	33.71282	-118.33582	33.71202	-118.33218	24.5	2380	387	333	13.6	1060	9:48	823
P. nebulifer	4/25/2012	33.71166	-118.33492	33.71273	-118.33524	26.1	2381	363	316	12.6	680	9:32	822
P. nebulifer	4/27/2012	33.71388	-118.33712	33.71355	-118.33460	23.9	2360	379	333	13.3	720	13:30	825
P. nebulifer	4/27/2012	33.71313	-118.33696	33.71301	-118.33693	24.9	2370	344	295	11.8	610	12:19	841
P. nebulifer	4/27/2012	33.71338	-118.33567	33.71370	-118.33321	23.4	2373	480	421	18.8	1530	12:46	818
P. nebulifer	4/27/2012	33.71155	-118.33170	33.71048	-118.32535	25.0	2378	459	408	17.4	1540	14:49	830
P. nebulifer	4/29/2012	33.71323	-118.33738	33.71495	-118.33958	25.0	2365	439	384	16.2	1330	9:06	835
P. nebulifer	4/29/2012	33.71161	-118.33257	33.71227	-118.33344	25.2	2366	426	368	15.5	1040	12:46	829
P. nebulifer	4/29/2012	33.71323	-118.33738	33.71644	-118.34103	25.0	2371	391	338	13.8	880	9:17	836
P. nebulifer	5/5/2012	33.71650	-118.33600	33.71080	-118.33350	19.3	2386	370	321	12.9	740	13:42	840
P. nebulifer	5/6/2012	33.70826	-118.31554	33.70836	-118.31676	19.9	2359	395	337	14.0	800	10:20	158
P. nebulifer	5/6/2012	33.70863	-118.31496	33.70767	-118.31355	18.1	2382	426	371	15.5	1140	11:39	191
P. nebulifer	5/6/2012	33.70836	-118.31676	33.70792	-118.31388	19.4	2385	442	378	16.4	1150	10:56	187
P. nebulifer	5/11/2012	33.70748	-118.31353	-	-	19.0	2383	381	335	13.3	830	-	146
P. nebulifer	5/16/2012	33.70804	-118.31482	33.70738	-118.31453	19.4	2376	430	372	15.7	1140	-	159
P. nebulifer	5/16/2012	33.71262	-118.33488	33.71210	-118.33249	24.4	2384	385	335	13.5	890	12:11	148
P. nebulifer	5/30/2012	33.70668	-118.32283	33.70660	-118.32266	24.9	2364	380	327	13.3	840	13:09	139
P. nebulifer	5/30/2012	33.70645	-118.32709	33.70686	-118.32388	28.2	2377	435	381	16.0	1300	12:53	141
P. nebulifer	6/9/2012	33.70860	-118.32786	33.71061	-118.32929	25.5	2358	385	335	13.5	890	13:27	152
P. nebulifer	6/9/2012	33.70781	-118.32755	33.71040	-118.33092	26.5	58805	394	339	13.9	840	15:03	102
P. nebulifer	6/9/2012	33.71238	-118.33478	33.71082	-118.33112	25.8	58806	416	358	15.0	1040	16:19	103
S. guttata	3/10/2012	33.70798	-118.32667	33.70801	-118.32665	22.0	2327	334	285	-	740	12:03	224
S. guttata	3/24/2012	33.70682	-118.33359	33.70573	-118.32332	26.3	2330	351	298	-	1010	11:02	827
S. guttata	4/4/2012	33.71252	-118.33393	33.71252	-118.33488	25.1	2313	271	234	-	410	-	227
S. guttata	4/6/2012	33.71308	-118.33385	33.71255	-118.33513	23.3	2306	356	302	-	1010	8:58	231
S. guttata	4/6/2012	33.71287	-118.33404	33.71410	-118.33508	23.3	2308	340	295	-	950	12:40	223
S. guttata	4/6/2012	33.71308	-118.33385	33.71255	-118.33513	23.3	2315	305	266	-	610	8:58	234
S. guttata	4/6/2012	33.71394	-118.33492	33.71316	-118.33624	22.8	2322	298	256	-	650	12:47	218
S. guttata	4/21/2012	33.70796	-118.33031	-	-	25.4	2309	301	256	-	560	12:02	225
S. guttata	4/21/2012	33.71123	-118.33241	33.71078	-118.33241	24.4	2334	295	251	-	560	13:25	220
S. guttata	4/22/2012	33.70592	-118.32396	33.70734	-118.32381	27.8	2328	307	262	-	670	9:58	221
S. guttata	4/27/2012	33.70793	-118.31865	33.70789	-118.31863	20.2	2298	339	291	-	900	8:38	831
S. guttata	4/27/2012	33.70784	-118.31846	33.70795	-118.31845	20.1	2305	300	256	-	640	9:45	833
S. guttata	4/29/2012	33.71430	-118.33702	33.71223	-118.33662	22.7	2319	350	296	-	990	10:50	832
S. guttata	4/29/2012	33.71385	-118.33664	33.71223	-118.33662	23.3	2332	300	259	-	580	10:50	834
S. guttata	5/5/2012	33.70103	-118.32481	33.70207	-118.32475	38.4	2387	311	261	-	740	10:10	839
S. guttata	5/14/2012	33.70901	-118.31797	33.70895	-118.31731	18.1	2324	270	235	-	460	10:17	140

Table 3 - Results of WC Site Fidelity Tests. Columns indicate WC transmitter ID #, total number of movement bursts tested, the number of bursts that demonstrated site fidelity in the mean squared displacement test (lower MSD than 95% of randomized distribution of bursts), number of bursts that demonstrated linearity or transit behavior (greater MSD than 95% of randomized distribution of bursts), and the number of bursts demonstrating site fidelity and linearity in the linearity index test.

Tag	# of bursts	MSD (site fidelity)	MSD (directed)	LI (site fidelity)	LI (directed)
2299	19	13	0	11	1
2338	8	3	2	4	1
2339	105	64	9	51	5
2340	36	27	4	26	2
2341	2	0	2	0	0
2342	1	0	1	0	1
2345	7	3	0	3	0
2349	1	0	0	0	0
2350	14	8	0	8	0
2351	1	0	0	0	0
2353	1	1	0	1	0
2354	38	17	1	10	3
2356	22	6	1	5	1
2357	2	0	0	0	0
29686	1	0	0	0	0
29687	1	0	0	0	1
29688	2	0	0	0	0
29689	1	0	1	0	1
29691	1	0	0	0	0
29693	52	13	14	9	16
29694	1	0	0	0	0
29695	1	1	0	0	0
29696	2	1	0	0	0
29699	108	23	6	27	5
29701	1	0	0	0	0
29702	1	1	0	0	0
29703	47	15	3	9	1
29704	6	1	2	0	2
29705	75	23	4	14	1
29707	1	0	0	0	0
29709	69	23	0	20	1
29710	4	1	0	2	0
29711	1	0	0	0	0
29712	1	1	0	1	0
29713	2	1	1	0	0
29714	2	1	1	1	1
29717	17	2	0	2	1
29720	55	26	4	11	3
29723	57	10	4	12	2
29724	3	1	0	0	0
29725	63	12	4	11	2
29726	49	26	2	24	2
29727	20	4	1	3	2
29728	25	2	3	4	2
29731	48	14	1	12	2
36408	29	10	1	1	1
36409	3	0	1	0	0
36411	20	0	7	3	3
36413	10	3	0	1	0
36414	2	0	0	0	0

36415	1	0	0	0	0
36416	1	0	0	0	0
36417	1	0	1	0	0
36421	1	0	1	0	0
36423	1	0	0	0	0
36426	87	26	10	18	8
36428	2	0	1	0	1

Table 4 - WC Movement Data Summary. Columns indicate WC transmitter #, total days detected in the PV Shelf array, proportion of total transmitter battery lifespan detected in the PV Shelf array, total area utilized in VPS array (95% KUD contour), core area utilized in VPS array (50% KUD contour), total number of VPS positions rendered, and number of individual migration events to the harbor per WC.

Tag	Days on PV Shelf	Proportion days on PV Shelf	Total PV array area use	Core PV array area use	Total # positions	# Migrations to harbors
2288	2	0.009569	NA	NA	NA	1
2289	70	0.316742	NA	NA	NA	1
2290	2	0.009569	NA	NA	NA	0
2291	3	0.015075	NA	NA	NA	0
2299	58	0.292929	317860.6	40495.53	1721	0
2336	2	0.009852	NA	NA	NA	0
2337	5	0.023923	NA	NA	NA	0
2338	47	0.22488	749725.7	109160.8	311	1
2339	147	0.724138	850477.5	41896.2	9383	3
2340	59	0.282297	353296.8	30262.29	6007	2
2341	4	0.019139	522866.3	78942.37	81	1
2342	2	0.01005	92333.09	18645.03	11	1
2345	95	0.477387	591898.1	68898.73	160	2
2346	46	0.231156	98231.96	18850.85	26	1
2349	2	0.01005	94228.84	18761.09	22	1
2350	56	0.28	500994.1	54251.4	936	1
2351	2	0.01	122270.7	20185.91	19	0
2353	2	0.01005	123591.9	23605.74	12	1
2354	59	0.29064	1040524	88002.14	2247	1
2355	1	0.004926	NA	NA	NA	1
2356	30	0.147783	624417.3	40889.6	779	0
2357	18	0.08867	476726.3	102762.7	61	0
29686	21	0.09292	102067.3	18281.25	118	0
29687	7	0.030973	141037.5	28408.24	140	0
29688	2	0.00885	116356.3	28412.16	122	1
29689	3	0.013274	172863.1	20499.52	375	1
29690	4	0.017699	NA	NA	NA	0
29691	2	0.00885	80816.78	17110.28	153	1
29692	1	0.004425	NA	NA	NA	0
29693	99	0.438053	1144627	80758.79	12211	5
29694	2	0.00885	142162.9	19846.84	126	1
29695	4	0.017699	115571	24176.9	117	2
29696	8	0.035398	95737.91	16384.54	362	1
29697	3	0.013274	NA	NA	NA	2
29698	2	0.00885	NA	NA	NA	1
29699	111	0.49115	469609.2	53846.37	7452	1
29700	1	0.004425	NA	NA	NA	0
29701	1	0.004425	56947.64	13461.12	20	0
29702	4	0.017699	71342.64	16871.31	260	1
29703	66	0.292035	379608.9	29310.55	6532	9
29704	8	0.035398	431135.6	65310.19	197	2

29705	83	0.367257	350684.1	51236.32	2432	1
29707	3	0.013274	83649.95	19739.31	15	0
29709	63	0.278761	296285.8	15705.02	2271	0
29710	28	0.123894	151109	28441.23	70	0
29711	6	0.026549	279943.5	66112.01	17	2
29712	7	0.030973	270419.4	59254.43	23	2
29713	3	0.013274	279641.9	50635.79	34	1
29714	3	0.013274	57933.98	7932.139	109	0
29716	1	0.004425	NA	NA	NA	0
29717	24	0.106195	617532.7	59395.01	429	0
29718	1	0.004425	NA	NA	NA	0
29720	78	0.345133	481591	21652.37	2984	0
29721	3	0.013274	NA	NA	NA	0
29723	127	0.561947	712986.6	48321.11	2604	9
29724	3	0.013274	226738.7	45403.84	60	0
29725	49	0.216814	364638.8	44129.8	1722	0
29726	120	0.530973	509327.4	23463.36	2356	1
29727	87	0.384956	274534.3	32034.1	436	1
29728	31	0.137168	1264539	114329.8	1066	0
29729	3	0.013453	NA	NA	NA	0
29731	104	0.460177	609211.5	28579.18	1570	0
29732	2	0.00885	NA	NA	NA	0
29734	1	0.004484	NA	NA	NA	0
36406	1	0.004425	NA	NA	NA	0
36407	1	0.004425	NA	NA	NA	0
36408	18	0.079646	228908.9	43216.43	747	0
36409	9	0.039823	172945.4	13325.17	110	1
36410	1	0.004425	NA	NA	NA	0
36411	28	0.123894	499852	60389.29	667	1
36413	22	0.097345	339780.6	53112.5	1052	3
36414	5	0.022124	179863.1	27780.56	58	0
36415	3	0.006623	96042.16	26531.93	37	0
36416	2	0.004415	96273.77	16724.67	44	0
36417	6	0.013245	252260.5	54850.48	20	0
36418	4	0.00883	NA	NA	NA	2
36421	5	0.011038	399677.3	82231.38	29	0
36423	2	0.004415	398043.4	88390.36	23	0
36424	2	0.004415	NA	NA	NA	0
36425	1	0.002208	NA	NA	NA	0
36426	133	0.293598	723491.1	52830.37	5806	4
36428	9	0.019868	320505.6	52907.23	32	1
36429	1	0.002208	NA	NA	NA	0

Table 5 - BSB VPS Relocations and Area Use Estimates. Columns indicate BSB transmitter #, number of VPS-rendered positions used to estimate KUD estimates, 95% KUD area (m^2), core area 50% KUD area (m^2).

Transmitter	Relocations	95% KUD area (m^2)	50% KUD area (m^2)
29735	4	-	-
29736	174	7,034	1,015
29737	5	-	-
29738	14	-	-
29739	113	22,563	3,044
29740	94	7,459	988
29741	585	96,391	6,761
29742	41	27,083	5,003
29743	84	7,683	1,273
29744	463	31,163	2,345
29745	0	-	-
29746	1	-	-
29747	32	11,617	2,661
29748	106	20,998	2,638
29749	1	-	-
29750	1195	174,751	4,063
29751	114	14,556	1,828
29752	753	14,279	2,288
29753	432	9,911	1,428
29754	103	24,588	4,577
29755	526	55,172	8,282
29756	79	14,468	2,654
29757	580	91,648	13,288
29758	377	44,735	3,330
29759	107	14,352	2,143
2358	855	16,942	1,007
2359	0	-	-
2360	778	16,000	2,375
2361	55	5,976	807
2362	1327	115,564	8,463
2363	195	29,872	3,300
2364	249	9,067	1,563
2365	37	25,843	2,467
2366	768	9,062	1,354
2367	111	19,270	1,946
2368	1572	19,741	2,938
2369	222	8,771	1,306
2370	263	7,786	902
2371	322	20,526	897
2372	0	-	-
2373	49	11,163	1,809
2374	79	33,847	4,439
2375	669	94,081	3,519
2376	0	-	-
2377	14	-	-
2378	540	4,976	921
2379	1080	9,214	1,180
2380	1142	12,526	1,483
2381	360	17,911	2,115
2382	0	-	-
2383	1	-	-
2384	78	7,818	1,031
2385	0	-	-
2386	604	10,257	779
58805	18	-	-
58806	3	-	-

Table 6 - BSB Spawning Season Migration Data. Columns represent BSB transmitter #; tagging date; 2011 departure date from the PV Shelf array; 2011 return date to the PV Shelf array; duration absent from the area in 2011; 2012 departure date from the PV Shelf array; 2012 return date to the PV Shelf array; duration absent from the area in 2012; and maximum distance detected from the PV Shelf array.

Transmitter	Tag date	2011 departure	2011 return	2011 duration (days)	2012 departure	2012 return	2012 duration (days)	Max distance (km)
29735	7/15/10	7/10/11	8/24/11	45	6/5/12	-	-	21.7
29736	7/16/10	7/9/11	8/24/11	46	6/4/12	8/13/12	70	28.5
29737	8/3/10	7/11/11	9/18/11	69	6/11/12	-	-	-
29738	9/1/10	6/25/11	7/9/11	14	-	-	-	-
29738	9/1/10	7/19/11	8/30/11	42	-	-	-	-
29739	6/9/11	7/11/11	9/3/11	54	6/3/12	-	-	-
29740	8/3/10	7/10/11	9/7/11	59	6/10/12	-	-	28.9
29741	10/9/10	6/26/11	8/28/11	63	6/16/12	9/5/12	81	-
29742	8/3/10	7/12/11	7/19/11	7	-	-	-	-
29742	8/3/10	7/24/11	8/6/11	13	-	-	-	-
29742	8/3/10	8/8/11	9/18/11	41	-	-	-	-
29743	1/22/11	6/20/11	8/27/11	68	6/4/12	-	-	-
29745	6/12/11	7/15/11	12/16/11	154	6/3/12	-	-	-
29746	6/15/11	6/24/11	9/14/11	82	-	-	-	-
29747	6/10/11	7/13/11	8/30/11	48	-	-	-	-
29748	6/10/11	6/26/11	9/15/11	81	6/10/12	9/23/12	105	28.2
29749	1/16/11	6/15/11	-	-	-	-	-	-
29750	4/4/12	-	-	-	6/6/12	9/20/12	106	18.9
29751	6/16/11	8/12/11	8/28/11	16	6/6/12	-	-	-
29752	3/16/12	-	-	-	6/4/12	8/16/12	73	-
29753	8/7/11	-	-	-	7/25/12	9/16/12	53	-
29757	6/18/11	7/6/11	8/31/11	56	6/10/12	9/4/12	86	29.1
29758	6/16/11	7/11/11	8/17/11	37	6/10/12	8/3/12	54	28.7
29758	6/16/11	-	-	-	8/3/12	9/9/12	37	-
29759	9/11/11	-	-	-	6/4/12	9/10/12	98	-
2359	5/6/12	-	-	-	6/4/12	9/23/12	111	27.4
2361	4/25/12	-	-	-	6/10/12	-	-	27.2
2362	4/7/12	-	-	-	6/11/12	8/30/12	80	29.4
2363	4/4/12	-	-	-	6/10/12	-	-	-
2365	4/29/12	-	-	-	5/13/12	9/5/12	115	28.3
2366	4/29/12	-	-	-	7/16/12	-	-	26.3
2367	4/21/12	-	-	-	6/4/12	8/8/12	65	-
2368	4/7/12	-	-	-	6/4/12	8/17/12	74	20.1
2369	4/22/12	-	-	-	6/5/12	-	-	29.6
2371	4/29/12	-	-	-	6/6/12	9/16/12	102	29.9
2373	4/27/12	-	-	-	6/3/12	9/24/12	113	28.4
2374	4/6/12	-	-	-	5/27/12	10/2/12	128	20.7
2375	4/4/12	-	-	-	6/9/12	9/26/12	109	29.4
2376	5/16/12	-	-	-	6/1/12	-	-	27.5
2377	5/30/12	-	-	-	6/11/12	-	-	-
2379	4/25/12	-	-	-	6/6/12	9/7/12	93	29.4
2381	4/25/12	-	-	-	6/10/12	9/5/12	87	-
2382	5/6/12	-	-	-	5/25/12	-	-	-
2383	5/11/12	-	-	-	6/6/12	9/17/12	103	28.1
2384	5/16/12	-	-	-	6/11/12	-	-	-
2385	5/6/12	-	-	-	7/14/12	-	-	19.2