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The Biology of Yellowtail (Seriola lalandi) in the Southern California Bight: Spatial Insights from Recreational Catch Records, Tagging and Life-History Characteristics.

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The Biology of Yellowtail (*Seriola lalandi*) in the Southern California Bight: Spatial Insights from Recreational Catch Records, Tagging and Life-History Characteristics.

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Marine Biology

by

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Brice Semmens

2017

The Dissertation of Noah Jacob Ben-Aderet is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California, San Diego

2017

DEDICATION

To my parents and brothers and in memory of Dr. Jeff Graham.

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ABSTRACT OF THE DISSERTATION

The Biology of Yellowtail (*Seriola lalandi*) in the Southern California Bight: Spatial Insights from Recreational Catch Records, Tagging and Life-History Characteristics.

by

Noah Jacob Ben-Aderet

Doctor of Philosophy in Marine Biology

University of California, San Diego, 2017

Professor Stuart Sandin, Chair

Most organisms shift between different ecological niches or habitats throughout their lives. These shifts are prompted by growth and changing resource needs. In the marine realm, understanding why and when fish shift habitats is particularly important due to the increasing use of spatial management as a conservation strategy. Effective spatial management requires understanding how a species habitat usage changes throughout its' lifespan.

Within the Southern California Bight (SCB)Yellowtail (*Seriola lalandi*) are iconic gamefish and widely targeted throughout the region, both in U.S. and Mexican territorial waters. Their cross-border movements mean these fish encounter a diverse array of anthropogenic pressures, ranging from ocean-warming to agricultural and urban run-off to significant recreational, artisanal, and commercial fishing.

This work attempts to understand and quantify how yellowtail use the Southern California Bight and how that usage affects their biology. This was carried out in 3 separate chapters dealing with analysis of long-term recreational catch records, conventional tagging, passive acoustic telemetry as well as spatially-explicit analysis of age, growth, diet and trophic position.

The primary differences detected across all investigated parameters were size-mediated. Thus, one contiguous population with distinct ontogenetic shifts in habitat and diet is the most parsimonious explanation for the results from each chapter presented in this thesis. Recreational catch data showed inshore and offshore catch sizes were different between years and across seasons and fish size, rather than tagging season best explained detection rates of acoustically tagged fish. These findings supported claims by recreational anglers that large fish caught inshore are potentially year-round SCB residents. The conclusion of one, panmictic, SCB yellowtail population is further supported by results from life-history analysis as fish size again was the only source of significant differences in age/growth, diet, or trophic position regardless of sampling location or region.

Results from tag returns, acoustic telemetry and life-history analysis indicate that there is likely one contiguous population of yellowtail in the SCB and that due to high levels of fishing pressure, this population may be reliant on seasonal influxes of fish from the south to sustain current fishing levels.

Introduction

Humans have likely been following fish movements since discovering them as a food source (Yesner et al. 1980). Seasonal migrations of coastal pelagic fish occur throughout the world (Laurs and Lynn 1977, Felix-Uraga et al. 1994, Kimura et al. 1994). Movements can be driven by many different factors: environmental conditions, changes in food availability, spawning behavior, or a combination of elements. In addition, fish can also transition between habitats as they age (Werner 1988).

Ontogenetic niche/habitat shifts

Most organisms, especially fish, occupy different niches or habitats as juveniles than as adults. As they grow and their resource needs change, they shift from one niche to another (Werner 1988). In the marine realm, understanding why and when fish shift habitats is an interesting ecological question, particularly important in light of marine reserves rising popularity as a management tool (Gaines et al. 2010, Johannes 1998). Knowing how species-specific habitat usage changes throughout a lifespan is critical for effective conservation of the organism or management of their habitats.

Fish shift habitats or niches as they grow for multiple reasons: food availability, predation risk, growth optimization, breeding, rearing young, etc. These reasons are a series of trade-offs between maximizing potential and minimizing risk and are a function of body size (Werner and Gilliam 1984). Arguably, the three most important drivers of size-mediated ontogenetic niche shifts are growth, food availability and predation risk. While these factors are inherently related, they can be viewed separately to determine individual effects as to why organisms change habitats as they age. The interplay between growth, food availability and predation risk has been discussed at length in the literature, most notably by Werner and Gilliam (1984), Werner (1988) as well as by deRoos and Persson (2013). Essentially, the system is comprised of multiple internal feedback loops and is highly variable and intensified by a constantly changing environment (Wells et al. 2013).

Marine organisms in the Southern California Bight (SCB) face constant physical, environmental and chemical changes that affect growth, diet, and predation risk in every habitat they occupy throughout their lives (Bray et al. 1999). Storms and seasonal upwelling can cause sudden shifts in water temperature and nutrients (Dayton 1985). Large-scale perturbations such as El Niño change patterns of water movement and temperatures, causing many species to shift their ranges (Squire 1987). Anthropogenic changes due to fishing or pollution can significantly alter a systems' species composition or viability as suitable habitat (Dayton et al. 1998). All species in the Southern California Bight (SCB), including yellowtail, are impacted by these and other forces (Lluch-Belda et al. 2005).

Yellowtail in California

Yellowtail is the common name of several species (*Seriola* spp.) of large, highly mobile, predatory fishes in the family Carangidae. They are globally distributed and are found in most sub-tropical and temperate boundary current ecosystems (Miller et al. 2011), (Vergani et al. 2008). Along the West coast of North America, the yellowtail, *S. lalandi* ranges approximately from Cabo San Lucas, Baja California Sur north to Point Conception, California (Baxter 1960). This is a large, robust fish with a dedicated following of recreational anglers. Although this fish captivates the angling public in California, surprisingly little is known about its movement patterns and population structure.

Within US territorial waters, yellowtail are most abundant in the portion of the Southern California Bight (SCB) from the Channel Islands to the Mexican border. The entire bight extends from Point Conception (CA, USA) south to Cabo Colonet (Baja California Norte, Mexico). This area of coastline encompasses three of the largest cities in the United States and Mexico: Los Angeles, San Diego, and Tijuana, with a total population exceeding 20 million (U.S. census bureau). Proximity to a large human population leads to many issues, including widespread coastal development, high levels of urban runoff, and intense recreational and commercial fishing pressure (Schiff et al. 2000).

In response to anthropogenic pressures, marine resources and fisheries need to be managed effectively to preserve their future value (Johnson & Welch 2009). However, species- and ecosystem-specific data are needed to effectively manage a fishery. This is especially true in regards to species that are migratory, highly mobile or ontogenetically shift habitats (Link 2002). A combination of spatial (migratory patterns, home ranges, etc.) data and life history information (age, length, weight, growth-rate, reproductive capacity, etc.) is necessary to understand a species' habitat choice and corresponding environmental effects (Francis et al. 2007).

While yet to be explicitly quantified in California, globally yellowtail undergo similar life-history shifts as many other predatory marine fish (Sakakura & Tsukamoto 1997). The drivers of these shifts are same trade-offs of risks and potential benefits as discussed above. In Australia, adult *S. lalandi* are known to spawn offshore in their 3rd year (Gillanders et al. 1999). The same trend has been suggested for California fish (Baxter 1960) and can be inferred from offshore catches during summer months (Ben-Aderet *in prep*). The fertilized eggs and the newly-hatched larvae are planktonic in the pelagic environment (Sumida et al. 1985). Post metamorphosis, juveniles recruit to and aggregate around floating objects, usually drifting macro-algal mats (e.g. *Macrocystis spp.*, (Sakakura & Tsukamoto 1997). However, as they grow, individuals begin to range further away from floating structure. Kasai demonstrated through acoustic telemetry that distance from floating structure is correlated with body size of juvenile Japanese yellowtail (Kasai et al. 2000). In California, similar patterns are assumed to hold true as well.

To date, there exists only one published study on California yellowtail demographics, a California Department of Fish and Game (now Department of Fish and Wildlife, CA-DFW) fisheries bulletin published in 1960 (Baxter 1960). Baxter and colleagues predominantly sampled yellowtail by purse-seine offshore of Baja California Norte, Mexico, analyzed basic morphology and diet composition, as well as developed the age/growth and length/weight relationships still in use today. Additionally, Baxter described the recreational and commercial yellowtail fishery at the time and tagged over 15,000 fish to quantify basic movement patterns. While comprehensive, this study is now over 50 years old and predates realization of anthropogenic climate change as well as huge increases in California and Baja California's human population and their associated marine impacts (Schiff et al. 2000).

Analysis of catch reports and historical tagging data suggests that after several years in the offshore habitat, upon reaching sizes indicative of sexual maturity, yellowtail begin to be caught inshore. (Baxter 1960), (Kasai et al. 2000). Tagging efforts suggest that between the ages of three and seven, yellowtail appear to school with others of similar size and move widely across much of their geographical range (Uehara et al. 2006). Large fish, older than 8 years, are seldom found in dense schools and are thought to move less than their younger conspecifics (Baxter 1960). Ovaries from yellowtail spanning a wide-range of sizes revealed that some individuals spawn during their second summer (~510 mm FL), and all fish spawn by their third (~630mm FL). Once inshore, adult fish are assumed to live out the remainder of their lives as highly mobile, migratory, inshore predators returning to pelagic habitats only to spawn (Baxter 1960).

Quantifying ontogenetic movement and life-history patterns is crucial to understanding the role yellowtail play in the broader southern California marine environment as well as to determine their susceptibility to recreational and commercial fishing pressure. The overarching goal of this thesis is to understand and quantify how yellowtail use the Southern California Bight and how that usage affects their biology. This will be carried out in 3 separate chapters dealing with analysis of long-term recreational catch records, conventional tagging, passive acoustic telemetry as well as spatially-explicit analysis of age, growth, diet and trophic position.

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Chapter 1:

Spatial and Temporal Patterns in the Southern California Recreational Yellowtail Fishery

Noah Ben-Aderet, Stuart Sandin

Abstract:

Yellowtail (*Seriola lalandi*) are highly-valued gamefish targeted by recreational fishermen in the Southern California Bight (SCB) since the late 19th century. State-mandated Commercial Passenger Fishing Vessel (CPFVs) catch records indicate average take is approximately 70,500 fish per year, although catch has topped 500,000 fish during exceptionally warm years. The bulk of the annual catch is assumed to be comprised of fish that seasonally migrate north into the SCB from Mexico. However, recreational anglers target and catching large yellowtail in select SCB inshore habitats during winter months. Often when ocean temperatures are significantly below those thought to be optimal for yellowtail. Despite angler interest, not much is known about current yellowtail movements in California and no fisheries-independent data exist.

This study is the first to quantify spatiotemporal patterns of recreational fishing pressure and yellowtail movement based on analysis of recreational fishing data. Here, we test the hypotheses that *yellowtail caught inshore are routinely larger than conspecifics caught offshore, that large fish are caught inshore during winter months in sub-optimal water temperatures and that yellowtail catch has distinct, seasonal, spatial patterning.*

I analyzed two sources of recreational yellowtail catch data in this study. CPFV logbook data from the California Department of Fish and Wildlife and Recreational Fisheries Information Network (RecFIN) angler survey data. Recreational catch indicates broad spatial and temporal trends exist in the SCB recreational yellowtail fishery. They are: (1) seasonal increases in juvenile fish offshore and larger, mature fish in select inshore areas. (2) Yellowtail "hotspots" with consistent, year-round, elevated catches as compared to surrounding areas. (3) Distinct seasonal catch increases (most likely correlated with

increased yellowtail abundance) are driven by ocean temperature and large-scale environmental factors (PDO, ENSO, etc.). Effective management requires understanding the drivers behind SCB yellowtail catch, movement patterns and population structure. This work is the first step in quantifying impacts to an iconic California gamefish.

Introduction

Fishermen are a good source of qualitative information often overlooked by researchers. Successful fishermen understand basic movement patterns quite well due to years spent targeting certain species (Parnell et al. 2010). This is especially true for yellowtail due to their popularity as gamefish (M. Medak *pers comm*). As evidence of their popularity with anglers, yellowtail presence increases fishing effort and CPFV ridership. Dotson and Charter (2003) demonstrated that increases in yellowtail catch reported by CPFV's increased ridership on subsequent days and as catch increased so did ridership (Dotson & Charter 2003). Anecdotally, this occurs with private vessel anglers as well, and has increased recently due largely to the prevalence of online fishing forums (*pers obs*). However, as is the case for many recreationally-targeted species without dedicated management plans, more detailed patterns in yellowtail space and habitat usage have yet to be fully quantified (Francis et al. 2007), so are essentially unknown outside of the "traditional knowledge" of dedicated commercial and recreational fishermen.

In southern California, yellowtail are highly-valued game fish that have been targeted by recreational fishermen since the late 19th century (MacCall 1996). While estimates for private boats are harder to calculate, Commercial Passenger Fishing Vessel (CPFVs) catch records indicate their average take is approximately 70,500 fish per year, although during exceptional warm water years this total has ranged as high as 500,000 fish (Crooke 1983) and the recreational catch vastly outweighs commercial take (e.g. 201 metric tons versus 18.3 tons in 2006, CA DFW). California has mandated the collection of recreational catch information since the 1930's, thus there exists a fair amount of recreational catch data for this species (Hill & Schneider 1999).

The paucity of research on yellowtail populations and movements in California is surprising considering angler enthusiasm and the existence of long-term recreational fishery surveys. However, the lack of research is better understood when considering state and federal management strategies. Yellowtail, although highly sought-after, do not fit within existing federal or state management strategies. They are not listed as a "Highly Migratory Species" by the National Marine Fisheries Service (NMFS) and so are not managed federally. Further, they are neither Coastal Pelagic Finfish nor Groundfish, as determined by the California Department of Fish and Wildlife (CA-DFW), and due largely to budgetary constraints are not state management priorities (Valle).

Fishing patterns lead to biological questions

Analyzing catch data is a cost-effective way to begin to understand broad-scale, spatial and temporal dynamics, even if it does little to elucidate finer-scale movements or habitat usage patterns. Understanding how their spatial and temporal movement patterns change over time is important because yellowtail are so widely targeted. If strong temporal or spatial size segregation exists, fishing pressure in a certain area or on a certain size class can disproportionately target a single segment of the entire stock (Hamilton et al. 2007). Given the amount of fishing that occurs in southern California (Dotson & Charter 2003), this raises questions as to impact on yellowtail populations. Other than work presented later in this thesis, there is no current fisheries-independent data for yellowtail. Therefore, analyzing existing fisheries data is the first step in quantifying fishing patterns as well as inferring yellowtail movements from patterns in catch.

This chapter was originally prompted by the realization that SCB recreational anglers often target and catch large yellowtail in select inshore habitats during winter months. Often when ocean temperatures are significantly below those thought to be optimal for yellowtail (Morita et al. 2010, Baxter 1960). The study seeks to answer the following questions: (1) Is there seasonality to when yellowtail are caught inshore or offshore? (2) Are sizes of inshore and offshore yellowtail different or are reported differences simply angler impressions? (3) Is there evidence that large yellowtail overwinter in the SCB? (4) If so, are catches confined to specific coastal areas? No existing studies have attempted to address these questions and currently no sources of fishery independent data exist for yellowtail in California; recreational and commercial fishery data are all that exist. Utilizing only existing recreational catch data, this study tests the hypotheses that *yellowtail caught inshore are routinely larger than conspecifics caught offshore, that large, inshore fish are indeed caught during winter months in sub-optimal water temperatures and that catch has distinct, seasonal, spatial patterning.*

Methods

Study area

This study focused on yellowtail catch from US territorial waters within the Southern California Bight (SCB) although the entire bight extends from Point Conception

(CA, USA) into Baja California Norte, Mexico (to Cabo Colonet). This area of coastline also encompasses three of the largest cities in the United States and Mexico: Los Angeles, San Diego, and Tijuana. The proximity of such a large human population has numerous consequences, including widespread coastal development, high levels of urban runoff, and intense recreational and commercial fishing pressure (Dotson & Charter 2003).

Fisheries Data

I used 2 sources of recreational yellowtail catch data for the analysis in this study. Commercial Passenger Fishing Vessel (CPFV) logbook data provided by the CA-DFW and angler survey data from the Recreational Fisheries Information Network (RecFIN), a data aggregation network maintained by the Pacific Fisheries Management Council (PFMC).

The state of California mandates all CPFV's to maintain a daily log of catch, fishing location and ridership. Data collection began in 1936 and has been continuous except during World War II. From 1936 to 1978, data were only provided for months with non-zero effort and catch (Hill & Schneider 1999). Prior to 1980, only monthly catch totals for each CA-DFW sampling block are available. From 1980 onwards resolution increases to the trip-level. The logs contain information on total number of anglers, coarse fishing locations (DFW spatial sampling block number (see map), total number of yellowtail caught, total number of yellowtail released, number of individual species caught, total hours fished, total angler-hours, vessel ID number, and home port location.

RecFIN data consists of information from both the Marine Recreational Fisheries Statistics Survey (MRFSS, 1980-2004) and the California Recreational Fisheries Survey

(CRFS, 2004-present). MRFSS is a National Marine Fisheries Service survey that provided the framework for CRFS. Both surveys employed the use of paid employees to survey anglers at various public harbors and on select CPFV trips. However, each survey sampled distinct locations at different frequencies as well as computed catch and effort statistics differently. This renders direct comparisons between the two impossible. However, sampler-examined catch records from each survey contain overlapping information that are immune from differences in survey methodology (fork length, date, fishing mode, inshore/offshore catch location).

List and definitions of analyzed parameters:

CPFV logbook:

• *Block* – DFW spatial sampling block number (Figure 1). Most blocks within range of CPFV's are 10 minutes (') latitude by 10' longitude. Due to inconsistencies with reporting catch from Mexican waters, all Mexican blocks were excluded from this analysis.

• *Number* – total number of fish caught in each block, for each month in each year. This was a combination of total yellowtail kept and total released

• *Angler-hours* – total number of hours fished multiplied by the total number of anglers for each block/month/year.

Parameters Derived for CPFV Analysis

• *Catch Per Unit Effort (CPUE)* – non-species specific, total number of yellowtail caught divided by the total angler-hours for each block/month/year.

• *El Niño/Southern Oscillation (ENSO) temperature anomaly* – NOAA's long-term Oceanic Niño Index (ONI). A 3 month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region ($5^oN-5^oS, 120^o-170^oW$)], based on centered 30-year base periods updated every 5 years. (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/)

• *PDO Index* - The leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period) (Mantua et al 1997, 2002).

• *Distance from nearest CPFV port* – I calculated the shortest distance to each port for each individual block in R using the Geosphere package through constructing a distance matrix of haversine distances between the center of each block to each port or marina along the SCB that has a CPFV operation. From south to north, those locations are San Diego bay, Mission Bay, Oceanside, Dana Point, Long Beach harbor, Redondo Beach, Marina Del Rey, Channel Islands Harbor and Santa Barbara Harbor.

RecFIN:

• *Year* – the year the fish recorded was caught.

• *Wave* – the CA-DFW-assigned 2-month period in which the fish recorded was caught, the lowest temporal resolution available that encompasses the entire dataset. Wave 1 = January/ February, wave 2 = March/ April, so on until wave 6 (November/December).

• *Fork Length (FL)* – Records that contained measurements of total length only were converted to FL by the conversion equation: TL =

FL(1.19)+15.45 (Baxter 1960). All lengths greater than 1600mm or less than 200mm were deemed incorrect and removed from the data set.

• *Inshore/Offshore* – Based on whether the fish recorded was captured within 3 miles or greater than 3 miles offshore (federal vs. state waters). Conveniently, this 3-mile designation generally approximates the width of the continental shelf along the San Diego coastline of the Southern California Bight (Carlucci et al. 1986).

Additional Data used in RecFIN Analysis

• *Sea Surface Temperature (SST)* – I used the Scripps Institution of Oceanography (SIO) pier daily temperature record for consistency with historical fisheries research in the SCB. SIO pier SST was used as a proxy for water temperatures in the entire bight (Norton 1999).

Data analysis

Due to differences in methods of estimation within each survey regime, I did not calculate yellowtail CPUE from RecFIN data. Subsequently, all results from RecFIN are reported in relative proportion to the overall catch. To account for some measure of recreational fishing effort, I used a measure of SCB-wide yellowtail CPUE calculated from the Los Angeles Times Daily Catch Report database as well as also calculating block-specific CPUE using angler-hours and total yellowtail catch per year/month/block combination. However, this block-specific measure of CPUE has several caveats. First, effort (as cumulative angler-hours) is not species specific, so therefore greatly under-estimates catch per hour when divided by the total number of yellowtail caught. Second, it also does not account for yellowtail catch from private vessels or kayaks, which, especially in recent years, account for an increasingly significant portion of overall take (RecFIN, *pers obs*).

To visualize temporal differences in the sizes of yellowtail caught in southern California, I generated multiple histograms with 2cm length bins. First in aggregate, then divided by inshore/offshore designation, sampling wave and year/wave combinations. The numbers of inshore and offshore yellowtail in each specific size-bin are represented as a proportion of the overall catch, either within the entire 1980-2015 data range or summed within each wave (2-month sampling unit) across all years. I also constructed a length-frequency bubble-plot (5cm length bins) for all years by individual sampling wave to visually determine if there was evidence for variations in catch sizes to be the result of specific year classes of fish moving through the fishery. Individual year/wave combinations needed a minimum of 20 measured fish to appear on the plot to control for over or under-representation of specific size classes and sampling waves. Additionally, I used linear regression to examine the relationship of water temperature on both the mean and 90th percentile sizes of yellowtail landed.

I examined spatial differences in the fishery using the CPFV logbook data. I aggregated CPFV logbook records into unique records of year/month/block combinations. Records were then either plotted individually or further summed to attain historical totals and means for each block throughout the bight. To visualize seasonal and long-term spatial trends in catch, I generated maps of log-transformed catch as well as effort and CPUE for all blocks by season in R using the ggmap package.

I also looked at the influence of local oceanographic conditions on yellowtail catch. I constructed a series of general additive models (GAMs) to test the effects of several spatial and environmental parameters on the patterning of block-specific CPFV yellowtail catch totals within the SCB (Wood 2012). The predictor variables used in the models, either alone or in combination, were SST (as measured from the SIO pier), spatial situation (Block location), distance (from nearest CPFV landing), ENSO index anomaly, PDO index on block-specific, log-transformed CPFV yellowtail catch. Note that block location and season were considered as random factors to account for both spatial and temporal autocorrelation. Predictor variables were investigated for co-linearity (with a threshold correlation for inclusion set at 0.50. GAM's were fit in R using the lme4 and gam packages. Candidate models were ranked based on AICc relative-importance weights; the model with the highest explanatory power having the highest weight (Williams et al. 2015).

To further examine the influence of ENSO, I computed block-specific Z scores by subtracting the overall mean catch per each individual block from the total catch for each unique year/month/block record and dividing that number by the standard deviation of catch for each block. The farther the Z-score was from zero, the greater the total catch for each year/month/block combination differed from the mean for that block

Results

Spatial Trends

Fish Size – RecFIN contained length data for 17,756 yellowtail with a known catch location caught between 1980 and 2015. Approximately twice as many fish were caught inshore (within 3mi of shore) as were caught offshore (inshore = 11,650; offshore = 6,106,

Table 1). Lengths are normally distributed, made up of a large amount of intermediate-sized fish and smaller amounts of larger, sexually-mature fish as well as smaller, immature fish (Figure 2). Mean lengths between inshore and offshore catch were significantly different ($p<0.001$, inshore mean FL = 701 mm and offshore mean FL = 682mm). While only an 8 cm difference in mean sizes between inshore and offshore fish, the very largest size classes are represented solely within the inshore catch.

CPFV Catch – CPFV yellowtail catch is not evenly distributed across the SCB. 6 blocks account for 40.98% of total SCB yellowtail catch (blocks: 860, 756, 740, 849, 720, 761; see SCB block map). These blocks cluster around islands, inshore rocky headlands and kelp forests in the southern SCB. Effort (in the form of total non-specific angler-hours) follows similar spatial patterns (cumulative angler-hours figure) as well as defined seasonal patterns, with highest fishing effort during the summer and the lowest during winter months. Although the highest yellowtail effort is in the summer, CPUE peaks in late spring, drops during summer and then increases again in the fall (Figure 3).

Seasonal Trends

Fish Size – Proportionally more large fish (>800 mm FL) were caught inshore throughout all waves, and size distributions were relatively consistent between waves. The exception was wave 5 (September/October) where significant differences between inshore and offshore catch sizes were seen at every point along the entire size distribution (Table 2). Wave 5 differences were largely because 39% of all offshore fish caught were smaller than 500mm FL and 28.4% of all fish caught inshore over 800mm FL (Figure 4).

Inter and intra-annual variation in recreational catch lengths is better represented by figure 5, which displays the amount of yellowtail caught in each 5cm size-bin as a proportion of the total amount caught during that individual year/wave. For waves with high catches (3,4,5 – which correspond to warmer water and increased effort), visual inspection of bubble size and frequency shows clear evidence of year-classes of yellowtail moving through the fishery. Certain year/wave combinations (wave 6, 2013; wave 1, 2014) demonstrate an increase in the proportion of large fish, and other year/wave combinations (waves 4/5 in 1983 and 1998) showing proportionally more smaller fish.

CPFV Catch – Distinct seasonal spatial patterns exist in CPFV catch totals. When log-transformed catch-by-block is plotted by season, three distinct patterns emerge; a summer pattern with yellowtail caught widely throughout the SCB, a winter pattern with lower catch and catches clustered in inshore and island blocks and a spring/summer pattern that appears to be a blend of winter and summer patterns. In all seasons, however, the select blocks with highest catch (“hotspots”) remain consistent (Figure 6).

Environmental Influences

In addition to specific year/wave combinations favoring certain length classes, larger fish are indeed more often caught in cooler water temperatures. As subsequent analysis of length as a function of water temperature (Figure 7) reveal a noisy, but significant negative correlation between water temperature and mean and fish size (r^2 = 0.128, $p < 0.01$), with fish length generally decreasing as water temperature increases. GAM output supports the assumption that these visual patterns in yellowtail catch are driven by physical and environmental factors as well as by angler behavior. All factors tested (SST, season, block location and distance from nearest port) significantly affected catch-by-block (Table 3). While not a significant driver of seasonal catch totals, ENSO phase had a distinct effect on block-specific Z-scores. Block-specific Z-scores on 3 separate SCB maps divided by ENSO-phase indicate increased anomalous catches in the outer bight blocks during ENSO negative years and in the nearshore blocks during ENSO-positive years (Figure 8, $p < 0.001$).

Discussion

Utilizing recreational fisheries data, this study aimed to test the veracity of common angler impressions that smaller fish are only caught offshore in summer, large fish are winter SCB residents and that most yellowtail catch is driven by water temperature. While not all impressions are accurate, it is safe to conclude that broad spatial and temporal trends exist in the Southern California Bight recreational yellowtail fishery. These trends are (1) the seasonal increase in catch of smaller, juvenile fish in offshore waters and larger, mature fish in select inshore areas. (2) The existence of consistent yellowtail "hotspots" with consistently elevated catches as compared to surrounding areas, both in summer and in winter; and (3) distinct seasonal increases in catch driven by environmental factors that, most likely, correlate with increased yellowtail abundance.

Spatial and Temporal patterns in size-frequency distributions

The size distribution of Southern California's recreational yellowtail catch is normal, containing large numbers of intermediate-sized fish and smaller amounts of both larger, sexually-mature fish as well as smaller, immature fish (Figure 2). Even when divided into inshore vs. offshore, sizes remain distributed relatively normally although with small differences in proportion and mean size (701mm vs. 682 mm). Interestingly, despite fishing pressure, mean and median (679mm vs. 670mm) sizes of inshore and offshore catch indicate that most yellowtail caught are sexually mature (Baxter 1960). Despite the statistical significance in size difference between inshore and offshore fish, 8cm is quite small. Both 682mm and 701mm fish are sexually mature as well as in the same year class (California yellowtail mature sexually between 510mm - 635 mm FL, usually their 2nd to 3rd summer post-hatching (Baxter 1960; Gillanders et al. 2001; Ben-Aderet *unpublished data*). This trend of mean and median catch sizes approximating minimum reproductive size repeats across many targeted species along the California coast that have minimum established catch sizes (Schroeder & Love 2002); (Coleman et al. 2004); (Hamilton et al. 2007). Considering recreational anglers generally want to catch the largest individuals of a given species, this relationship is straightforward (Hilborn 1985); (Lewin et al. 2006).

Inshore and offshore size distributions remained relatively consistent when catch was divided into 2-month sampling waves. The exception being wave 5 (Table 2), which showed higher proportions of both smaller offshore fish and larger inshore fish as well as waves 2 and 3 where larger fish (>800mm) were proportionally greater inshore. The pattern of larger fish inshore in waves 2 and 3 could be due to seasonal northward movements of yellowtail (Brodie et al. 2015) from Baja California or from larger fish simply feeding more inshore in preparation to spawn, so thus being captured by the fishery at a greater rate. Wave 5 (September/October) often has the warmest inshore and offshore water temperatures as well as the highest catches of other highly migratory species (tuna, striped marlin, dorado, (Dotson & Charter 2003)).

The spike of catchable-sized juvenile yellowtail seen in wave 5 could be due to association with yellowfin tuna (*Thunnus albacares*) and dorado (*Coryphaena hippurus*) around drifting kelp mats. During those months (September/October) offshore fishing pressure is at its peak (Dotson & Charter 2003). Many anglers are lured by the opportunity to catch large, charismatic fish with the added benefit of often light winds and favorable weather. Increased offshore fishing effort leads to increased pressure on drifting kelp mats, which are habitat for juvenile yellowtail (Uehara et al. 2006), and probably the reason for the sharp increase of "catchable-size" juveniles. Conversely, the increase of larger fish in the inshore catch during that same time-period is potentially due to mature fish returning to nearshore waters after spawning offshore, where they are more easily targeted by a greater number of anglers (*pers comm, pers obs*).

RecFIN data collection, sporadic yellowtail catch and angler behavior

There is a stark difference in cumulative yellowtail catch totals between RecFIN and CPFV-logbook data-sets. RecFIN reports only physically measuring approximately 22,000 yellowtail for the entire 35 years of data I analyzed in this study, in contrast to CPFV logbooks. For example, just one San Diego-based CPFV reported catching over 15,000 yellowtail in 2015 alone (CPFV "San Diego", sportfishingreport.com) and many long-term cumulative block totals are in the hundreds of thousands to millions of fish. This discrepancy is due in part to how the CA-DFW assigns CRFS sampling personnel to various public launch-ramps and CPFV landings. While these samplers visit almost every public boat-launch and sportfishing landing in the state, they only visit each location once or twice per month. This means their data collection is biased towards species caught consistently throughout the year instead of during specific or intermittent time periods. Therefore, the likelihood of missing intermittent pulses of yellowtail landings is quite high, especially during winter months when yellowtail fishing and catch is confined to certain regions, fish are caught in pulses, and fishing effort is significantly lower (*pers obs*, RecFIN data manual)

Spatial designations and angler behavior effect yellowtail size distribution

Recreational anglers have long attested to seasonal increases or decreases in the numbers of large, inshore, yellowtail. At the onset of this study, I assumed these claims would be supported by recreational fisheries catch data collected by the state of California. Indeed, length-frequency data indicates that in general, inshore yellowtail are larger than their offshore conspecifics. However, I was surprised that the difference in mean length of inshore versus offshore yellowtail was so small (8 cm) as to be largely inconsequential. This could be due to the coarse spatial designation used by RecFIN which I also used for the purposes of this study. 3 miles from land, which includes islands, means that much of the catch is considered inshore even though the marine environment 2-3 miles offshore from any of the islands in the SCB is essentially pelagic habitat. Especially compared to areas the same distance from the mainland which are subject to a host of physical and environmental factors not seen further offshore.

Additionally, angler behavior likely plays a significant role in the patterns seen in catch records. During the colder-water winter months, most recreational fishing, especially CPFV's, target rockfish (*Sebastes spp.*) on deeper-water (60-120m) rocky-reefs, both inside and outside of the 3mi designation. Large yellowtail are occasionally caught (often incidentally), however, most SCB winter yellowtail are caught by a small number of generally highly-skilled anglers (*pers obs*). This marked drop in fishing effort and spatial coverage is in stark contrast to the widespread offshore fishing effort in the summer months when warmer water brings with it seasonally migrating pelagic species such as tuna and marlin (Love 2006). During those winter months, smaller yellowtail might still be present offshore, but not pursued or captured by the recreational fishery. The above points illustrate the need for fisheries independent sampling and tagging efforts to truly understand yellowtail movements, behavior and population structure in the SCB offshore environment.

Environmental Influences on catch size

Increased frequency of SCB spawning as driver of offshore catch?

Anglers often cite spawning patterns as a primary factor behind encountering large yellowtail far offshore in the SCB. According to the available literature, yellowtail are thought to spawn offshore in the SCB only during warmer-than-average years (Baxter 1960), although many commercial fishermen and CPFV captains disagree and claim to observe regular summer spawning (Markus Medak *pers comm*). During the study period, the following years were listed as anomalously warm (ENSO 3.4 >0.5ºC above the long-term average): 1982-83, 1986-87, 1991-92, 1994-95, 1997-98, 2002-2004, 2006, 2009 (NOAA Climate Prediction Center). Perhaps the increase in large yellowtail caught offshore during the warmest sampling waves could be due to increased spawning activity, although what proportion of the spawning fish are either year-round SCB residents or northward migrators from Baja California is unknown.

The size-frequency trends seen in my analysis repeat across numerous years, and elevated catches of larger fish offshore often coincide with noted warm years (Baxter 1960; Collins 1973; MacCall 1996; Dotson & Charter 2003). However, with the past several years markedly warmer than average (NOAA – National Centers for Environmental Information) and mean SCB sea-surface temperatures projected to increase due to global climate change (Sydeman et al. 2014), perhaps yellowtail are spawning in the outer SCB more frequently than previously assumed? While this hypothesis has yet to be formally tested, Kimura et al. (Kimura et al. 1994) reported changes in the seasonal occurrence and migrations of Japanese yellowtail (*Seriola quinqueradiata*) due to intrusions of warm water from the Kurishio current. This trend appears to be analogous to the increases of yellowtail catch totals and estimated abundance within the SCB during El Niño years (Dotson & Charter 2003) as well as to substantial catch increases in another tropical species, dorado (*Coryphaena hippurus*) by the southern California CPFV fleet over the last 50 years. This poleward shift in seasonal abundance could be due to increasing ocean temperatures (Norton 1999; Brodie et al. 2015).

Physical factors influencing year-round residency of SCB yellowtail

Consistent winter catch of yellowtail in certain areas of the SCB support the theory that some fish do not migrate south during the coldest months and are year-round residents. This idea is not particularly new, in 1960, Baxter reported that most tagged, large, yellowtail (>1000mm TL) were recaptured much closer to the location of their initial capture than younger, smaller fish. Maccall (1996), in a study using historical records of the Avalon Tuna Club on Catalina Island (records maintained since 1898), postulates that the SCB's yellowtail population is probably re-established or strengthened during periods of prolonged warm water and that during cooler periods, "these populations would no longer be self-sustaining and would slowly decline due to lack of recruitment." Without fishing, adult yellowtail have relatively low mortality rates, and a large enough population could remain resident for many years (maximum lifespan is between 14-20 years (Baxter 1960, Stewart et al. 2004). However, during cooler periods, even a moderate fishery would have the capacity to rapidly deplete a less migratory population (MacCall 1996). Current tagging work (Ben-Aderet, Chapter 2), provides support for Maccall's idea that subset of large fish (>100cm FL) do not seasonally migrate and instead demonstrate some degree of residency within certain SCB rocky-reef environments (Baxter 1960).

However, if the catch of large yellowtail in inshore waters during cooler months is due to the presence of fish that arrived during warm-water and remained in the area (i.e. hold-over fish), a marked increase in the catch of yellowtail should be seen both in pronounced warm-water years as well as in the winter months immediately after that year. Winter catch should decline each subsequent cool year as fishing pressure takes its toll and stocks are not seasonally replenished during the summer months. While El Niño years do see large increases in the total amount of yellowtail landed by CPFV anglers, subsequent years do not reveal a gradual return to pre-El Niño levels. In fact, as soon as water temperatures return to normal levels, so does catch (L.A. Times CPFV landings; although there is a pattern of anomalously cooler La Niña conditions developing immediately post El Niño). The pattern of catch quickly dropping off post El-Niño is one reason why anglers assume that yellowtail primarily move in from the south as a response to seasonal increases in water temperature and are not local residents, CPFV-logbook data corroborate this intuition

Influence of large-scale oceanographic trends

SST was a primary driver of the seasonal spatial patterns seen in CPFV yellowtail catch. In fact, if satellite-derived SST for the SCB (which did not exist for until the mid 1980's) is binned by similar sized blocks as catch, the seasonal patterns appear qualitatively similar. Qualitative appearances aside, SST, when coupled with season and the distance each block was from the nearest port, accounted for much of the variance in block specific catch totals. Although the difficulty of determining what factors drive SCB yellowtail catch patterns is evident from the significance of all the parameters in the model as well as it's relatively low percentage of deviance it explained (mod.6d, 11.5%).

While yearly variations in SST accounted for differences in SCB yellowtail catch, ENSO-phase as well as PDO-phase (both of which have significant background effects on ocean temperatures and fish populations throughout the north Pacific (Mantua & Hare 2002), did not significantly affect the model's ability to explain patterns in seasonal block-catch totals. The lack of significant effect could be due to the low-frequency of ENSO events, and therefore the relatively few marked El Niño years in the data analyzed. I assume, however, that if the analysis was expanded from seasonal (intra-year) to multiple years, these larger-scale processes would more significantly impact yellowtail catch totals (Dotson & Charter 2003, Squire 1987) .

Summary

SCB yellowtail catch is cyclical and affected by multiple factors. Ocean temperature appears to be a primary driver of increased catches in the SCB, which probably stem from greater numbers of yellowtail from Mexico moving north into U.S. waters and into the range of recreational anglers. The effect of SST also explains elevated catch during ENSO-positive (El Niño) years, which have anomalously warm water as well as depressed catches during ENSO-negative (La Niña) years. Although spatial catch patterns vary consistently with changes in water temp, certain areas appear to be “hotspots”, with consistent catch despite seasonal temperature fluctuations. These hotspots could be due to both constant yellowtail presence as well as consistent fishing pressure. Further work to understand why these areas are more productive for yellowtail and what drives this increase in productivity and associated fishing success is a necessity. Especially for successful ecosystem-based management policies.

The sizes of recreationally-caught yellowtail appear vary temporally and spatially as well. Albeit with consistent trends of bigger fish in cooler water and smaller fish more prevalent offshore. The year-to-year variation in size-frequency distribution points to variation in the recruitment success of certain year-classes as well as to the potential for successful spawning in the outer-SCB. Understanding the nature of this variation is critical for determining SCB yellowtail abundance and population structure, further investigation is needed.

The large amount of variability in RecFIN size data as well as CPFV logbook catch totals suggests that SCB yellowtail catch is influenced by a myriad of factors; everything from economic issues and recreational angler preferences to oceanographic and climactic processes. Analyzing recreational catch records is a good way to understand the basics of the fishery and potentially to illuminate larger-scale trends in catch and abundance. However, without concentrated research efforts to collect fishery-independent data, completely understanding yellowtail population structure as well as the drivers behind SCB yellowtail catch patterns is impossible.

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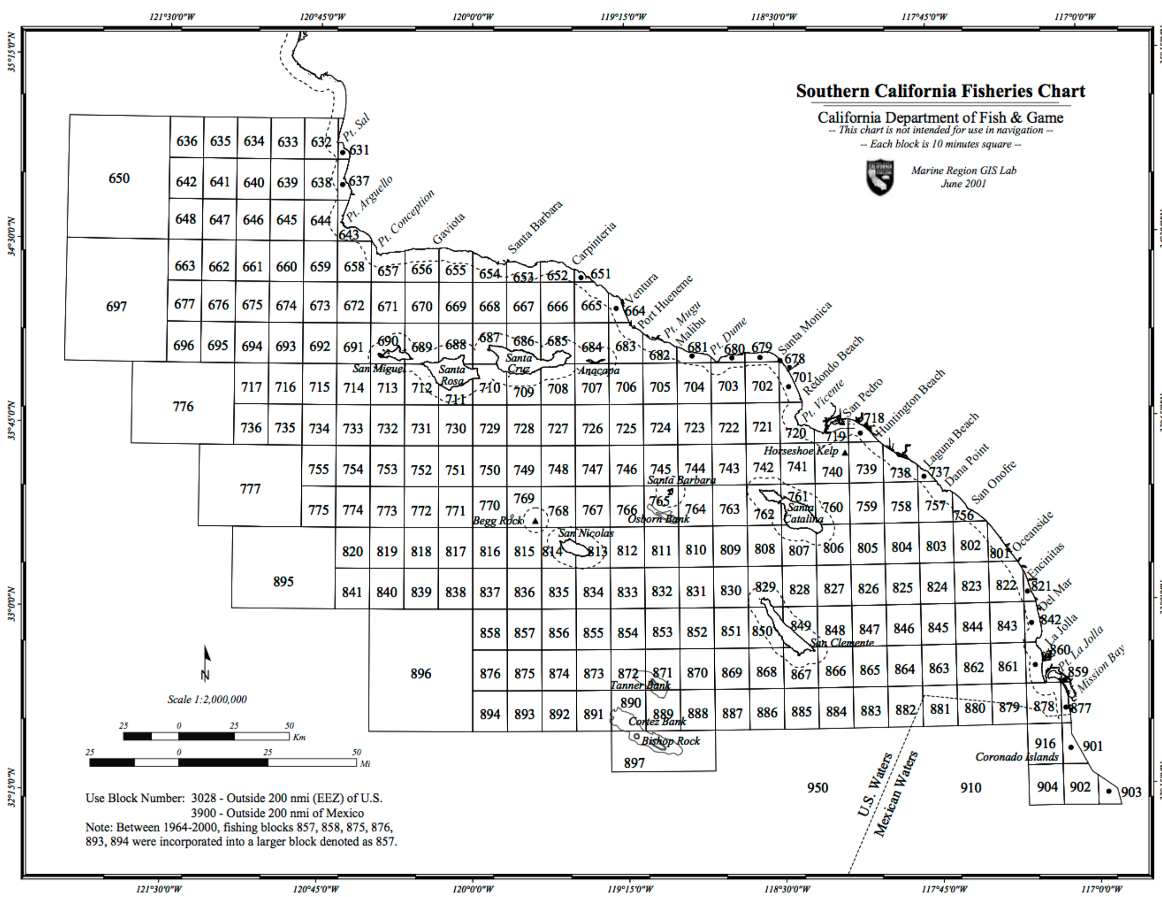

Figure 1-1. California Department of Fish and Wildlife map of the Southern California Bight and associated fisheries sampling blocks. Blocks are 10 minutes square in most areas except in Mexican waters and far offshore. (source: CA-DFW)

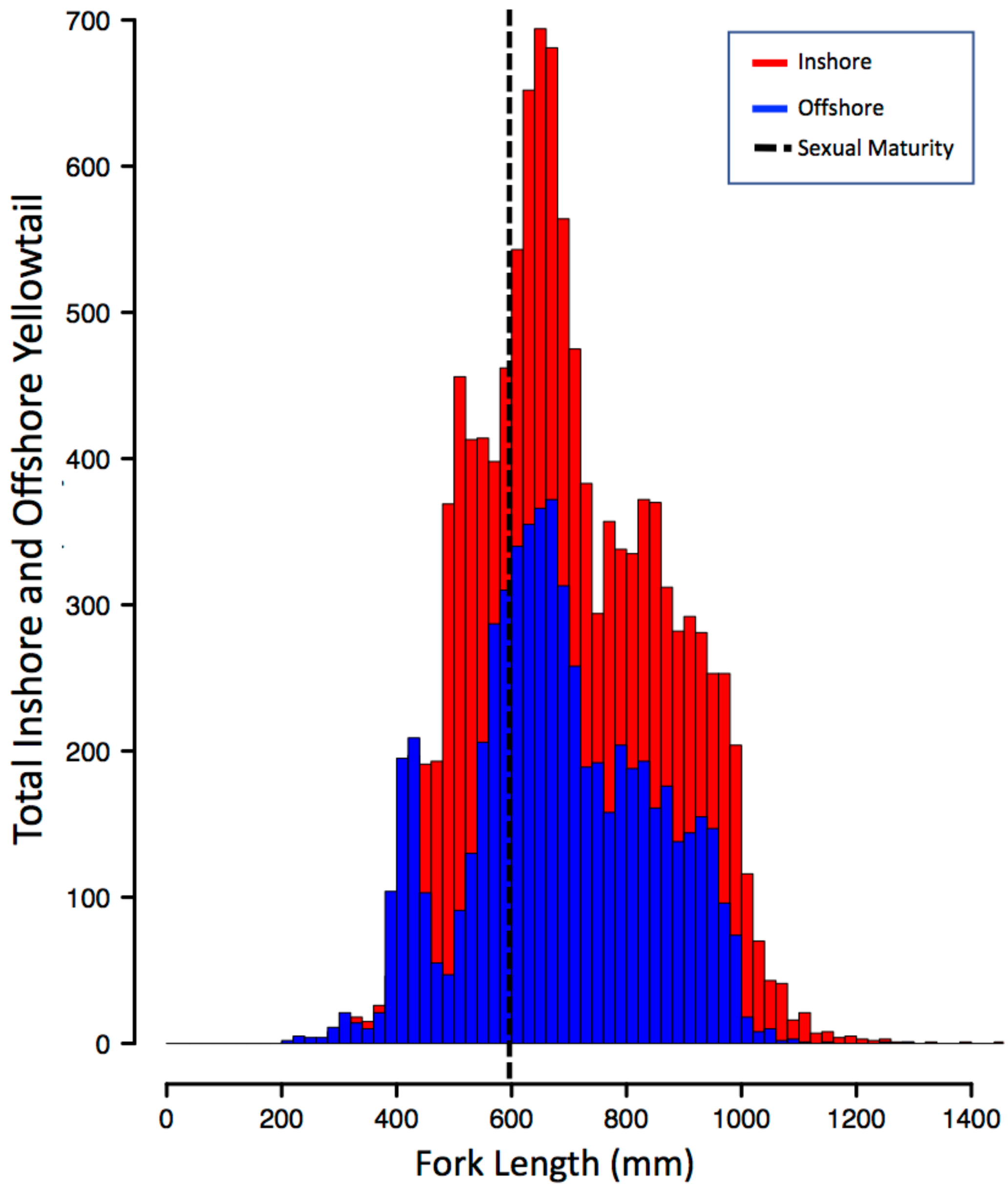

Figure 1-2. Size frequency distribution of inshore and offshore yellowtail catch sampled by CA-DFW surveys in the Southern California Bight between January 1980 and December 2015, 2 cm size bins, N= 17,756 (11,650 inshore, 6,106 offshore). Inshore mean FL = 701mm. Offshore mean FL = 682mm. Dashed line denotes approximate size at sexual maturity.

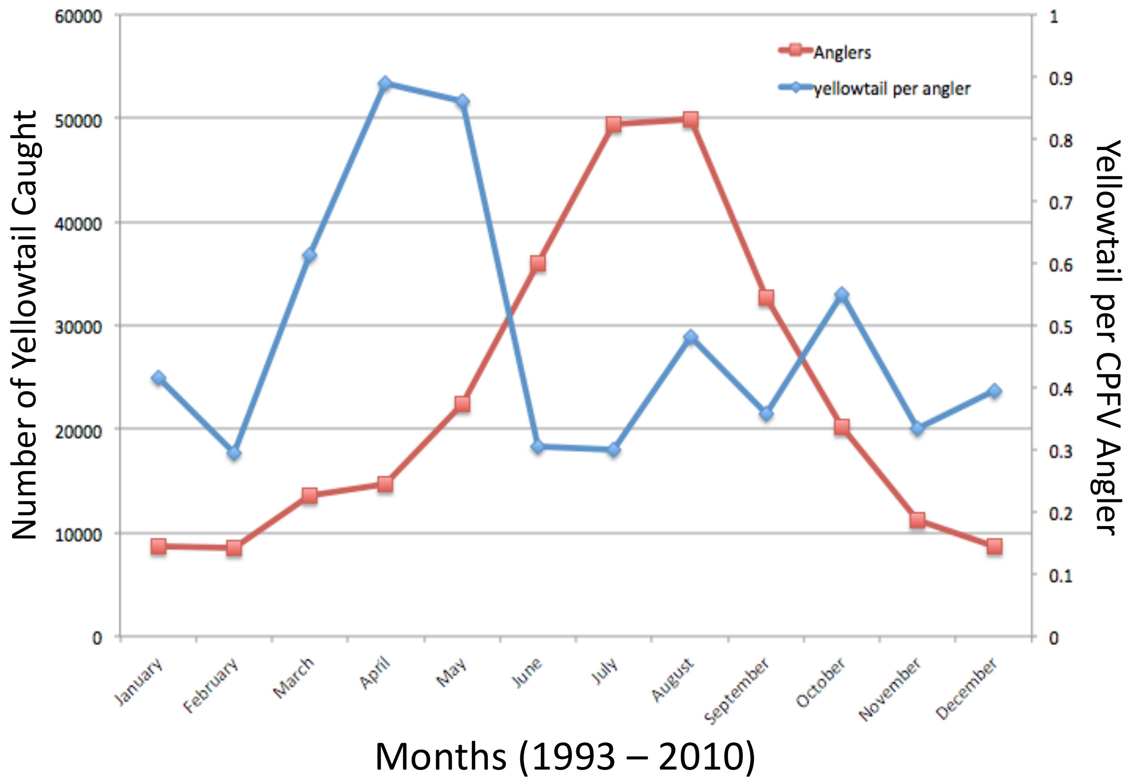

Figure 1-3. Total number of southern California CPFV anglers per month (blue line) and number of yellowtail per individual CPFV anger per month (red line). Data averaged across years 1993 – 2010, reported by the Los Angeles Times daily CPFV landings database.

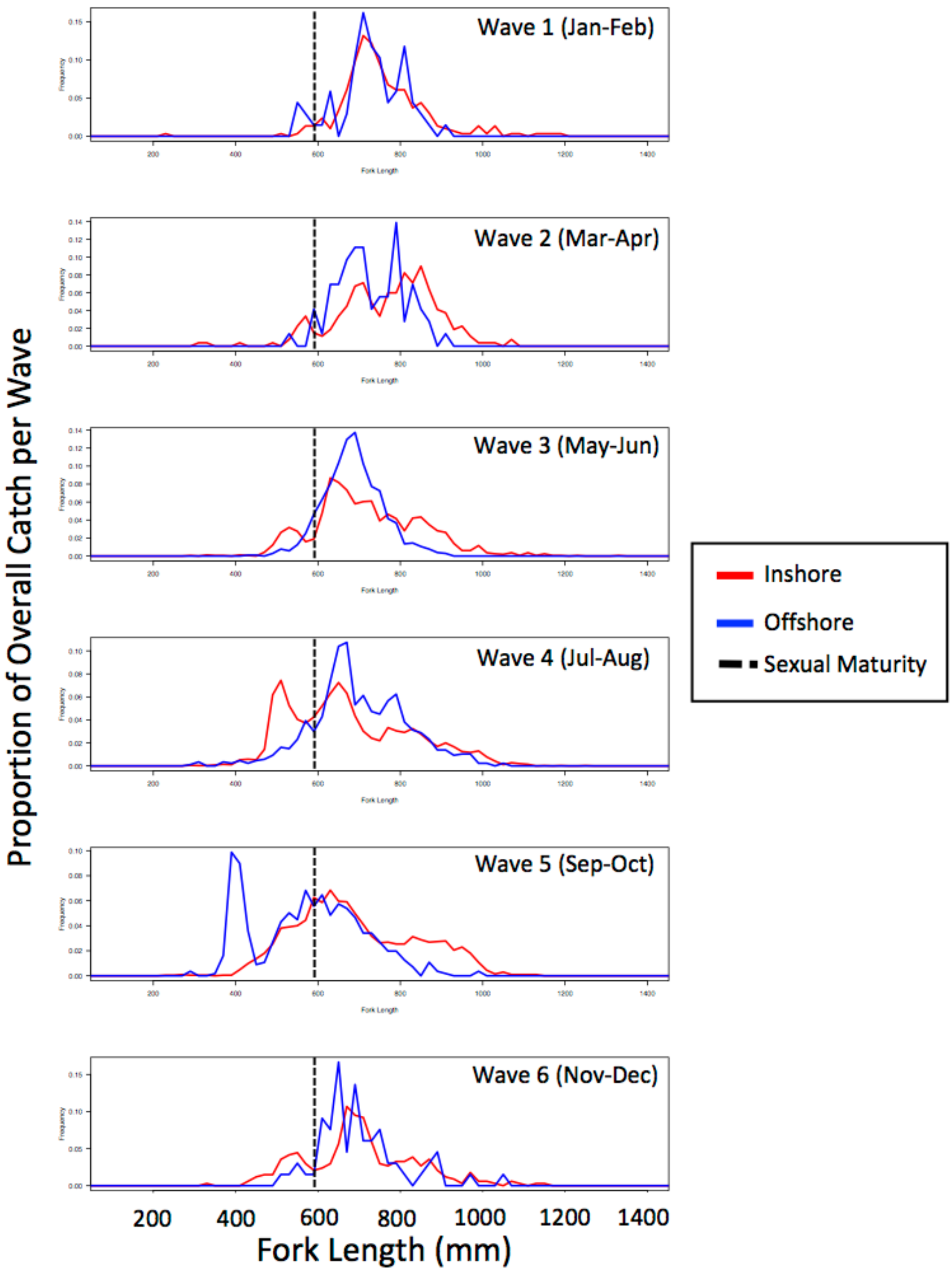

Figure 1-4. Size-frequency plot representing each 2-month sampling wave's relative contribution to overall catch for all years (1980-2015). Blue lines = fish caught offshore, red lines = inshore fish; vertical dashed-lines denote approximate size at sexual maturity.

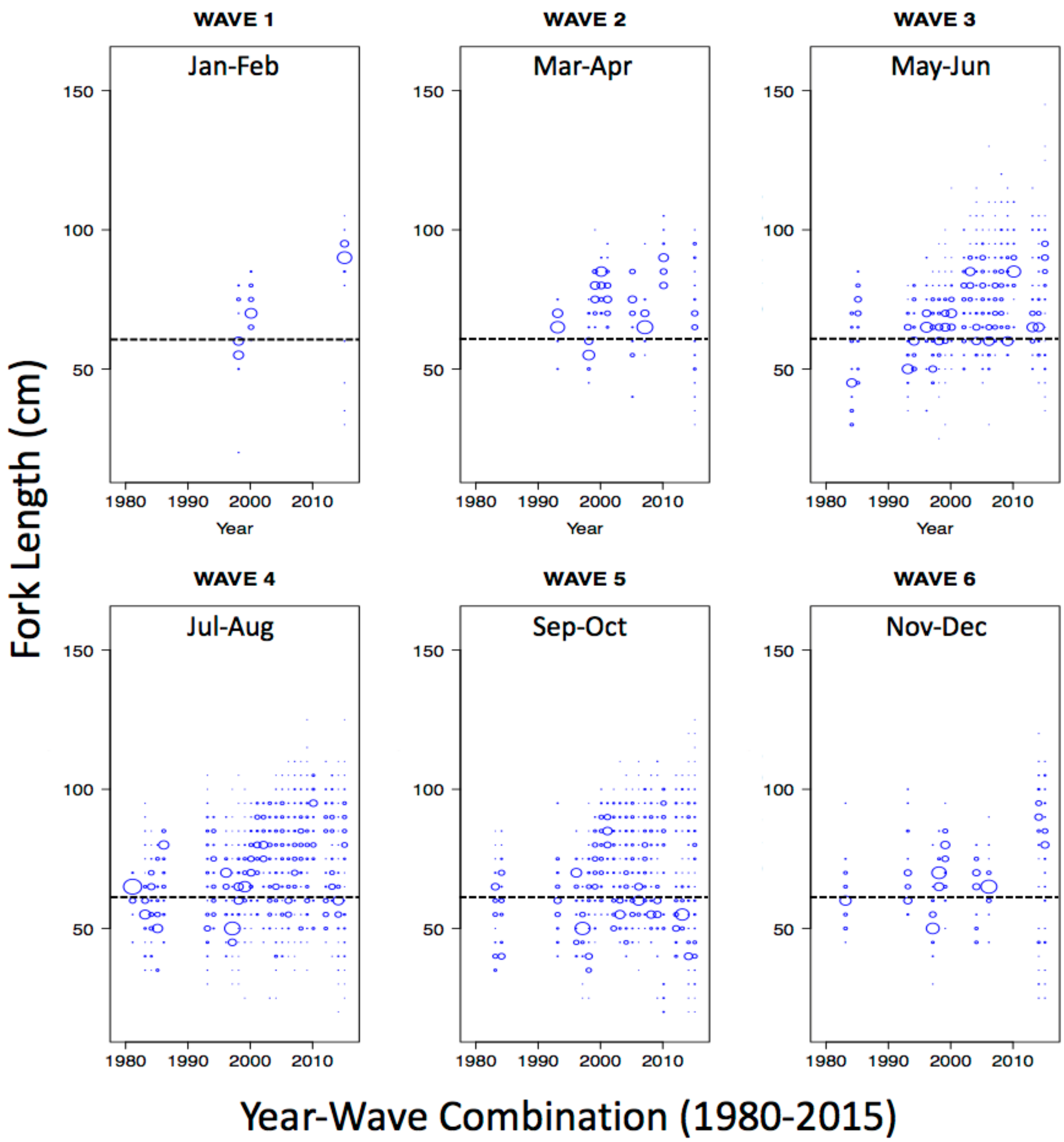

Figure 1-5. Length-frequency bubble plot representing fork lengths of yellowtail caught per individual wave per year. Bubble size is proportional to the amount of fish caught in that individual size class per each year and facilitates visualizing the relative effects of recruitment and year-classes on the overall yearly catch. Dashed-lines denote approximate size at sexual maturity.

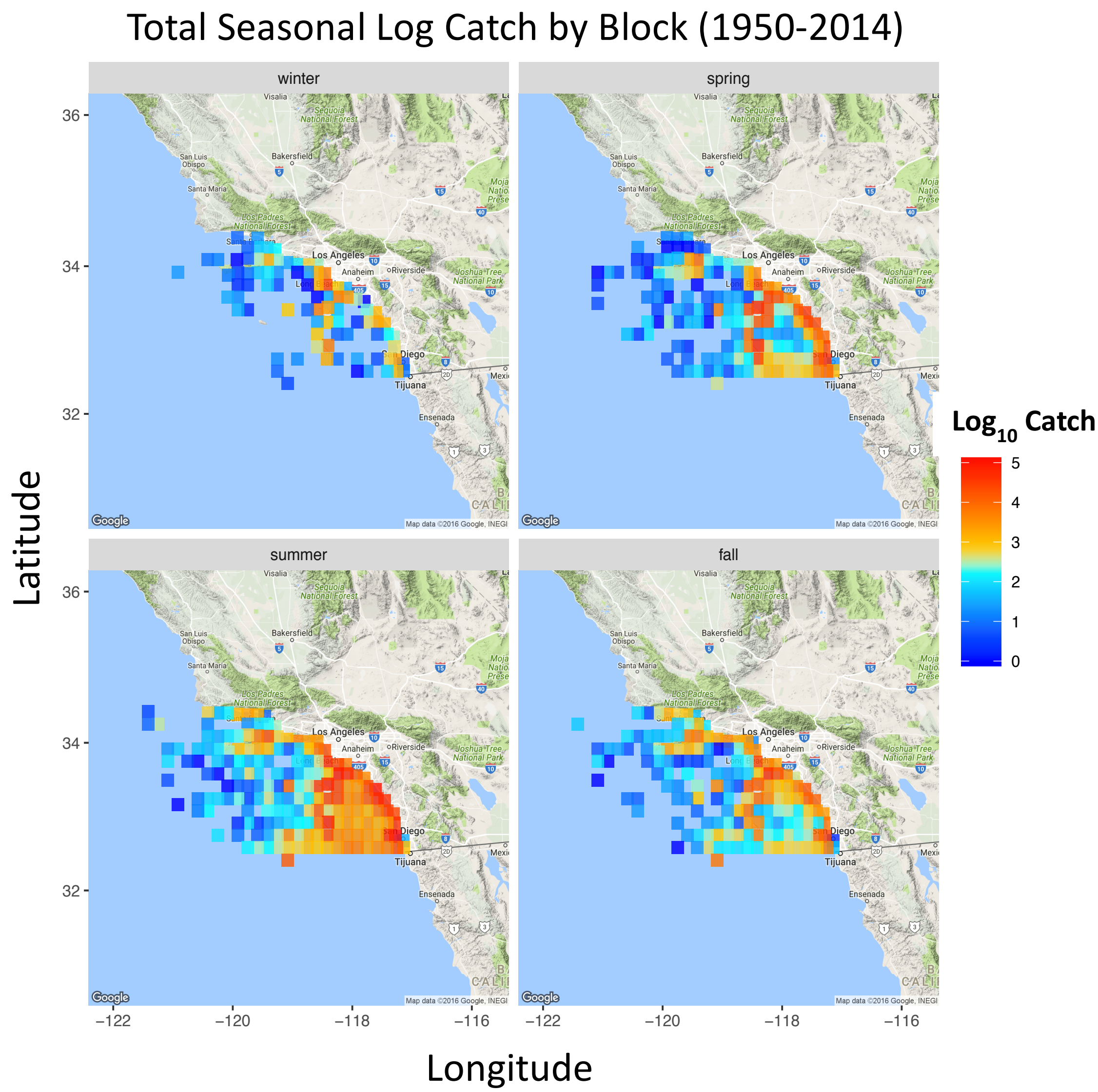

Figure 1-6. Log-transformed seasonally-cumulative yellowtail catch totals (1950-2014) for each individual CA-DFW sampling block in the SCB. Despite 6 blocks (860,756,740,849,720,761) accounting for 40.9% of all yellowtail recorded, there is a clear pattern of elevated yellowtail catch in the summer as well as months immediately pre- and post-summer.

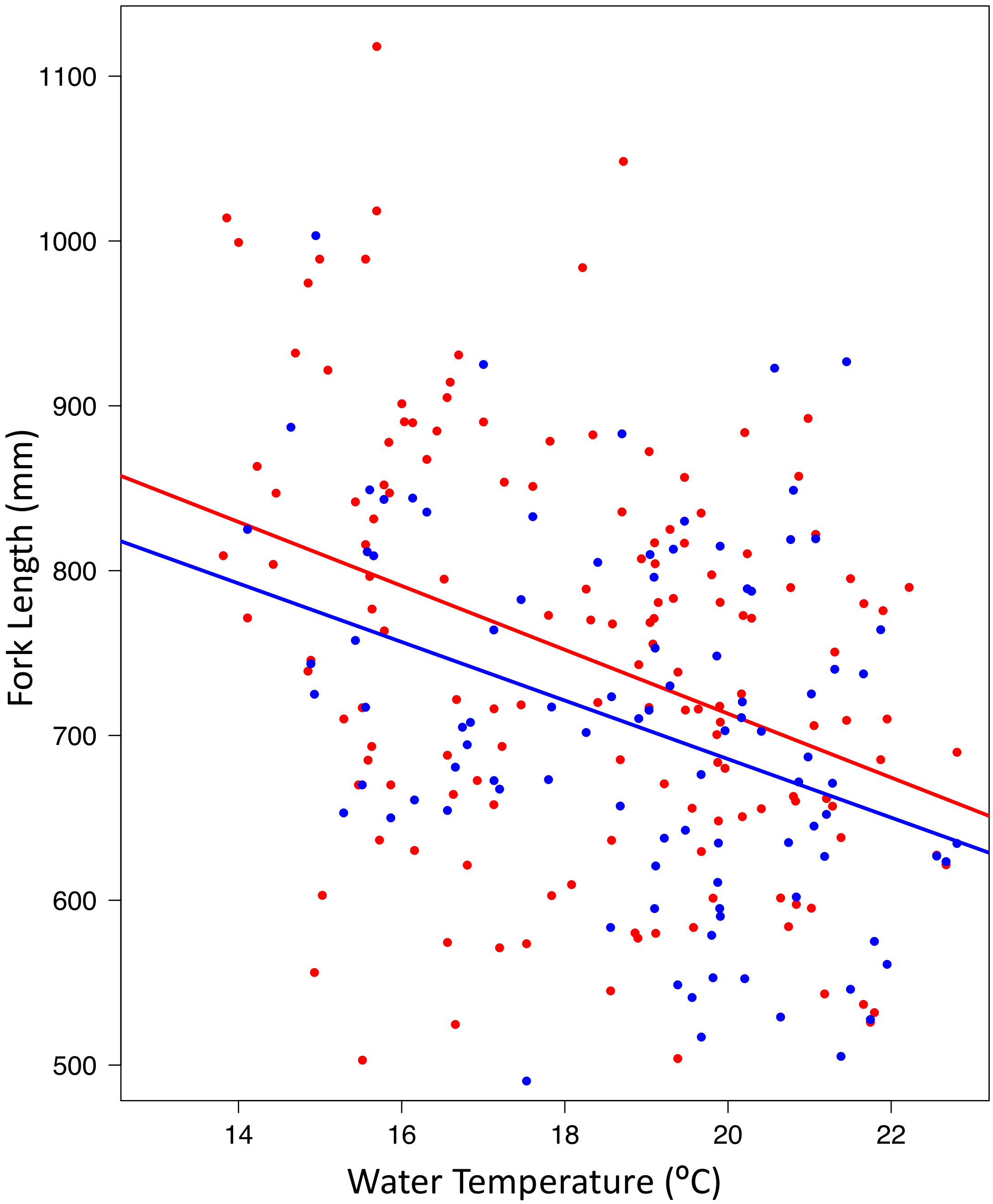

Figure 1-7. Mean fork length by month of all SCB yellowtail (1980-2015), versus monthly mean sea-surface temperature measured at the Scripps Institution of Oceanography pier. Although noisy (inshore $r^2 = 0.123$, offshore $r^2 = 0.129$), fish size significantly correlates with SST ($p < 0.001$ (inshore and offshore)).

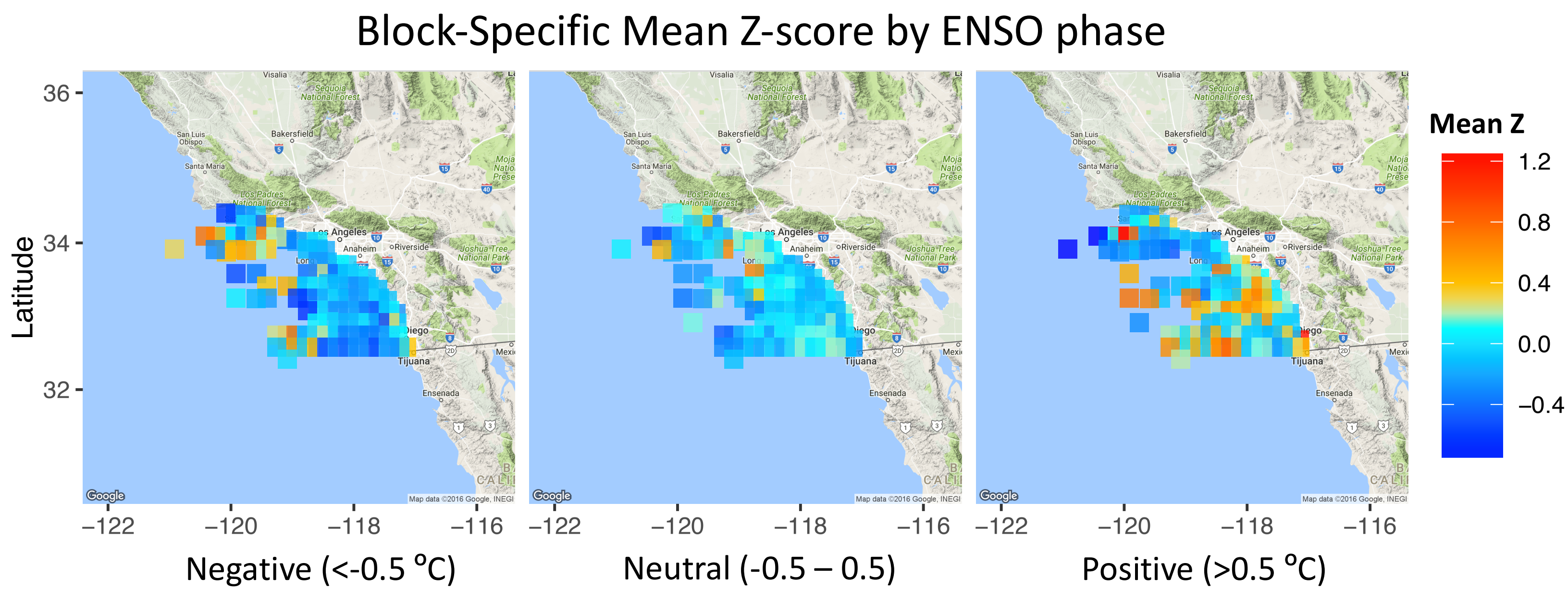

Figure 1-8. Block-specific Z-scores on 3 separate SCB maps divided by ENSO-phase indicate increased anomalous catches in the outer bight blocks during ENSO negative years and in the nearshore blocks during ENSO-positive years. Z-scores indicate increased anomalous catches in the outer bight blocks during ENSO negative years and in nearshore blocks during ENSO-positive years ($p < 0.001$). ENSO negative is Niño 3.4 anomaly of less than -0.5ºC, neutral is between -0.5ºC and 0.5ºC, positive is greater than 0.5 ºC.

Tables:

Table 1-1. Summary of all yellowtail caught inshore and offshore recorded within the RecFIN database. All fish are Type 3 (sampler-examined) records, from all fishing modes within southern California.

RecFIN Data Summary: Sampled Yellowtail Catch: 1980 – 2015							
Catch Location	Sample size (n)	Min. FL (mm)	25th Percentile	Median FL (mm)	Mean FL (mm)	75th Percentile	Max. FL (mm)
Inshore	11650	211	582.2	680	701.2	825	1450
	6106	209	581	670	682	802	1300

Table 1-2. Relative differences between inshore and offshore fish sizes along a gradient of size-class percentiles. Bold type indicates significance ($p < 0.05$). Table should be read as: 50^{th} percentile (median) sizes were significantly different between inshore and offshore catch during waves 1, 4, 5, 6.

Sampling Wave (Months)	**P-value of Difference Between Inshore and Offshore Catch Sizes at Corresponding Size Percentile**										
	1%	2.50%	5%	10%	25%	50%	75%	90%	95%	97.50%	99%
Wave 1 (Jan-Feb)	0.226	0.299	0.346	0.095	0.215	**0.026**	**0.019**	0.174	**0.028**	**0.003**	**0.002**
Wave 2 (Mar-Apr)	**0**	**0**	**0.002**	**0.007**	0.294	0.423	0.307	0.107	0.068	0.255	0.304
Wave 3 (May-Jun)	**0**	**0**	**0**	**0**	**0**	0.059	0.066	**0**	**0.011**	**0**	**0**
Wave 4 (Jul-Aug)	0.387	0.318	**0**	**0**	**0**	**0**	0.322	**0**	**0**	**0**	**0**
Wave 5 (Sep-Oct)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Wave 6 (Nov-Dec)	**0.047**	**0**	**0**	**0**	**0.009**	**0.001**	**0.049**	0.067	0.168	0.316	0.182

Table 1-3. Candidate general additive models (GAMs) testing effects of temperature, month, season, block location (latitude/longitude) and block distance from nearest CPFV port on block-specific yellowtail catch.

Model	**% deviance explained**	**AICc**	**w_i**
mod.6 = gam(log catch ~ 1 + temp*month + s(latitude, longitude, by=season),family=gaussian)	11.40%	2.38E-37	0.004
mod.6d = gam(log catch ~ 1 + temp*month + s(latitude, longitude, by=season) + distance, family=gaussian)	11.50%	1.00E+00	0.996

Chapter 2:

Local and Regional Movements of Yellowtail (*Seriola lalandi*) in the Southern California Bight through Acoustic Telemetry and Conventional Tagging

Noah Ben-Aderet, Brice Semmens, Stuart Sandin

Abstract

Despite their economic value and iconic status as a gamefish, yellowtail (*Seriola lalandi*) regional and local movement patterns in the Southern California Bight (SCB) are unknown. This lack of information has implications for California's use of Marine Protected Areas (MPAs) as management tools, since spatial management strategies designed without detailed, species-specific, spatial data are less effective. Here, I quantify space-use by yellowtail within the La Jolla area and throughout the SCB, as well as obtain a measure of recreational fishing pressure through conventional tagging and passive acoustic telemetry.

I tagged 182 yellowtail with external dart tags in various inshore and offshore areas throughout the SCB aboard CPFVs and skiffs. Of the 182, 22 yellowtail between 82 – 107 cm Fork Length were fitted with Vemco acoustic transmitters. 36 tagged fish have been returned to date, a 21.4% recapture rate. Timing of tag returns coincides with periods of higher fishing effort and there was a significant positive relationship between time at liberty and recapture distance. Of the acoustically-tagged yellowtail, larger fish were more likely to be detected in La Jolla throughout the year and in winter specifically, lending some credibility to claims by recreational anglers that large, inshore, fish in La Jolla are year-round residents.

The 21.4% tag return rate is the clearest finding of this study, it indicates extremely high fishing pressure on yellowtail in the SCB. Potentially, the SCB is a net population-sink for yellowtail, who's population needs to be constantly replenished to maintain such catch-rates , most-likely with fish moving north seasonally from Mexico.

Introduction:

Yellowtail (*Seriola lalandi*) are one of the most sought-after gamefish in southern California and significantly affect local fishing effort; Commercial Passenger Vishing Vessels (CPFVs) ridership significantly rises on days following increases in yellowtail catches (Dotson and Charter 2003). Despite their economic value (Haab et al. 2006), yellowtail movement patterns in California remain virtually unstudied. In the Southern California Bight (SCB), yellowtail catches generally increase as the ocean warms in the spring and decrease along with water temperatures in the fall (Dotson and Charter 2003). While winter catches are much lower and generally sporadic, yellowtail, especially individuals larger than 95cm fork length (FL), are routinely caught in the SCB during winter (Ben-Aderet, chap 1). In the southern SCB, the La Jolla region, encompassing the La Jolla kelp-forest and adjacent submarine canyon, is one such area of consistent winter catch of large yellowtail. These fish are commonly called "homeguards" by anglers, implying they are non-migratory residents although this theory has never been investigated.

In addition to determining whether large yellowtail are indeed winter residents, understanding general movements and habitat usage patterns is important in determining the efficacy of marine protected areas (MPAs) as a management tool for yellowtail and other migratory species (Shumway 1999). The primary issue is the relatively small size of existing MPAs (74% < 10km, (Halpern 2003) because yellowtail and many other recreationally-targeted species have relatively large daily or seasonal ranges. This is especially relevant in southern California due to the state's ambitious program of marine spatial management mandated by the Marine Life Protection Act passed in 1999 (MLPA, CA-DFW). Effective spatial management, however, depends upon understanding how species of concern use space throughout their life (Kramer 1999, Grüss et al. 2011). While spatial data exist for some fish species in the SCB (Mason and Lowe 2010) (Topping et al. 2006), no such data are available for yellowtail. This is partially because yellowtail, although highly sought-after, do not fit within existing federal management strategies. Their presence in nearshore environments mean they are not managed federally, and they are not a state management priorities due to their large seasonal movements throughout the SCB as well as budgetary constraints (CA-DFW pers comm.).

To date, there has only been one other study on California yellowtail movements, a California Department of Fish and Game (now Fish and Wildlife, CA-DFW) fisheries bulletin published by Baxter in 1960. Baxter tagged over 15,000 yellowtail with conventional dart tags, predominantly off central Baja California, Mexico. Baxter presented two main findings: (1) most fish tagged north of Punta Eugenia migrated northward during the spring and summer, many into the Southern California Bight (SCB), and (2) intermediate sized fish (between 60 – 90 cm FL) were recaptured significantly farther from their tagging locations than either smaller (<60 cm FL) or larger (>90cm FL) yellowtail. While northward migration from Mexico may explain the higher summer catch rates, the winter catches of large yellowtail in the SCB are unexplained. Previous analysis of long-term catch data reveals historically consistent spatial and temporal patterns in yellowtail catch, with certain locations in the SCB accounting for the bulk of both the summer and winter recreational catch (Ben-Aderet, Chap 1). Such patterns imply the existence of complimentary patterns in yellowtail movements and populations.

In this study, I attempt to quantify local and regional yellowtail movement patterns through a combination of conventional tagging and acoustic telemetry. The combination of tagging methods provides both fine- and coarse-scale spatial data. Conventional tagging facilitates estimation of catch rate, basic movement patterns, and with adequate sampling, population size (DeLury 1951, Cormack 1964, Pine et al. 2003). As an additional benefit and broader impact, cooperative tagging studies directly engage the angling public, provide stake in the research and increase participation (Lucy 2000). In complement, acoustic tagging provides local-scale, short-term, movement information as well as a method to determine if large yellowtail are indeed residents in area surrounding the La Jolla kelp forest (Meyer 2007).

The study objectives are (1) to determine if trends in size-specific tag-return rates and recapture distances seen by Baxter (1960) are consistent across space and time, using conventional tag methods from CPFVs and private fishing vessels; (2) to quantify differences in amount of time spent off La Jolla between fish tagged in winter and fish tagged in summer, using the La Jolla acoustic telemetry array; (3) to examine overall patterns of yellowtail space-use and movements in the La Jolla kelp-forest area. Furthermore, by accessing detection data from acoustic receivers in other areas in the SCB, this study has a regional perspective on dispersal patterns of yellowtail tagged in La Jolla.

Methods:

Study Area -

I used a network of acoustic receiver arrays during this study, the primary array was the La Jolla Acoustic Array. The array consists of 43 Vemco^{TM} VR2-W receivers moored along 2 transects roughly parallel to shore between 10m to 25m deep. The receiver array stretches along Pt. La Jolla from La Jolla Cove south to Crystal Pier and spans two no-take reserves (Matlahuayl State Marine Reserve and South La Jolla State Marine Reserve CA-DFW 2012). Between the two reserves lie some of the most heavily fished areas along San Diego's coastline (Parnell et al. 2010) as well as as the premier yellowtail fishing location in San Diego county (Figure 1).

Through data sharing relationships with other SCB researchers (Southern California Acoustic Telemetry Tracking Network (SCATTN)), I accessed data from other SCB receiver arrays (Figure 1). Since any tagged yellowtail would be detected by any VR2 receiver that it swam within range of, this greatly increased the potential for yellowtail detections outside the La Jolla array. These detections allowed me to gather information on broader movements within the SCB beyond the La Jolla acoustic array.

Acoustic Tagging –

I tagged a total of 22 adult yellowtail between 82 - 107cm FL in both summer and winter months with V16-4x passive acoustic transmitters (high power, battery life = 854 days, range = approx. 1000m) between August, 2014 and December, 2016. The acoustic transmitters emit an unique "pulse train" of closely-spaced pings at 69kHz randomly once every 30-90 seconds with a 60 second nominal delay. Of the 22 fish, 17 were tagged in La Jolla and another 5 in western Ventura county (approx. 34.07º x -119.029º) in September, 2015 to take advantage of acoustic receivers situated in the northern Channel

Islands (Santa Cruz and San Miguel islands) as well as to determine if fish caught in late summer in the northern SCB would be detected further south as the year progressed and the water cooled.

I caught yellowtail using hook and line with either live pacific mackerel (*Scomber japonicus*) or jack mackerel (*Trachurus symetricus*) as bait. After a successful landing, an assistant kept the fish in the water until lifting it onto a custom tagging cradle. Once in the cradle, we fit a split-hose into the fish's mouth to irrigate the gills. I surgically implanted the transmitters into the fishes' peritoneal cavity using methods outlined in previous telemetry studies ((Topping et al. 2006), (Meyer 2007)). I used anti-biotic infused, dissolvable sutures (18ga PDS-gut) to speed wound healing. Surgeries lasted approximately 3 minutes, after which the fish was returned to the water and revived boat-side until able to strongly swim away. Mortality was extremely low with only one fish dying post-tagging (due to a water-pump failure), all other fish survived and were successfully detected at least twice post-tagging. I performed all tagging work under animal care use protocol # S12116.

Conventional Tagging –

I tagged an additional 160 yellowtail with Floy FIM 96 conventional tags in various inshore and offshore areas throughout the SCB (Figure 2). Most of the fish were tagged aboard CPFVs, or on board various private fishing vessels through local guides or other interested anglers. Fish were caught by hook and line, with either live bait or artificial lures. After landing with a soft-mesh landing net, we placed the yellowtail on a measuring board or tagging cradle, recorded the fork length and tagged the fish. Tags were inserted into the connective tissue that anchors the dorsal spines at the base of the first dorsal fin. After landing, the entire process lasted approximately 1 minute or less, with the fish being out of the water for less than 30 seconds. Fish hooked deeply or bleeding from gills were not tagged.

Tags had reward and contact information printed on them so anglers could notify me of successful recaptures. Anglers calling in with recaptures were rewarded with a "Southern California Yellowtail Tagging Program" t-shirt. I chose to use shirts instead of a cash reward due to the inclusive, non-monetary value that a t-shirt has as a symbol of membership of a select group (Gneezy 2000). CPFV crew members and anglers who wore these shirts advertised the tagging program, and the fact that the only way to receive a shirt was to either tag and release an adult yellowtail, or report a successful recapture, only served to enhance the shirt's value.

Public participation and outreach –

Anglers with prior knowledge or otherwise involved with tagging are far more likely to subsequently report re-captured fish (Lucy 2000). To educate the southern California angling public, I worked in conjunction with the Coastal Angler Tagging Cooperative and National Marine Fisheries Service (NMFS), on outreach activities at the Fred Hall Fishing and Boat Show and "Day at the Docks", a San Diego sportfishing fair. Additionally, I gave presentations to fishing clubs, 2 radio interviews with "Rod and Reel Radio" and was featured in an article in "*Pacific Coast Sportfishing*" magazine. This was all in addition to routine discussions with CPFV anglers and crew members while tagging yellowtail aboard various vessels.

Data analysis –

Both conventional tag-recapture methods and acoustic telemetry provide measurements of movement patterns. Conventional tag-recapture data provided coarse movement patterns and dispersal measurements for all fish successfully recaptured. Passive acoustic telemetry facilitated measurements of seasonal differences in site fidelity as well as quantifying differences in total detection time.

Acoustic Telemetry –

I used VUE (v 2.2.7), Vemco's proprietary acoustic telemetry software for maintenance, management, and preliminary visualization of acoustic detection data. I used R (v 3.3.1) for most analyses of conventional and acoustic tag data. I imported detection data as comma separated value (.csv) files into R from VUE and computed the parameters listed below using the Vtrack package (Campbell et al. 2012). I analyzed data from a fish only if it was successfully detected 30 days or more post-release. This ensured that fish recaptured soon after tagging weren't included and that subsequent analysis was only on fish at liberty longer than 30 days.

By quantifying the time spent within detection range in La Jolla, as well as time detected elsewhere in the SCB, I attempt to determine if large, winter-caught yellowtail spend more time in the La Jolla area than smaller, summer-caught fish. While I quantify time spent either undetected, or detected on SCB VR2 arrays, definitively determining if such fish are permanent residents within the La Jolla region as well as estimating their home range size is not feasible given the scope of the current LJ VR2 array. Estimating residency and home range size is not possible due to the lack of receiver coverage throughout the SCB's offshore islands, shallow-reefs as well as a complete lack of receivers in Mexican waters. The lack of receiver coverage is compounded by the yellowtail's rapid swimming speed as well as variable and wide-ranging seasonal migration patterns (Clark 2006, Baxter 1960). La Jolla's bathymetry adds an additional complication, as yellowtail can still be in the area, but invisible to most receivers due to the submarine canyon adjacent to the north-west portion of the receiver array. Therefore, we treat any hour that a fish was detected as a "residence hour" with the same definition holding true for "residence days". Definitions for all other parameters are found below.

Parameters:

- Total detections per fish: sum of all detections, at all receivers, for each fish. A detection is the unique combination of time/date and tag number recorded when a tagged fish passes within range of a receiver.
- Detections per each receiver: sum of all detections for each fish at each receiver.
- Residency time at each receiver: Cumulative number of detection-hours at each receiver per individual fish, standardized for tagging duration.
- Minimum swimming distance: minimum great-circle distance in kilometers traveled by each fish, computed as a sum of all minimum distances between all sequential receiver/detection combinations for each individual fish.

- Percent Total time detected: sum of all detection hours divided by total time each fish was at liberty.
- Percent Total time out of range: difference between total time at liberty and total time detected divided by total time at liberty.

Detection regions:

The location of each receiver array in the SCB determined the individual detection regions. La Jolla was the exception. Although the La Jolla array is comprised of a continuous network of overlapping receivers, it was treated as two regions for analytical purposes due to distinct areas of concentrated fishing effort at the northwest and southwest corners of the La Jolla coastline.

- South La Jolla: considered a separate region to compute total time spent in the South La Jolla State Marine Reserve for better comparison to north La Jolla (outside of any MPA).
- North La Jolla: Majority of receivers located outside of any MPA, with several along the western edge of the Matlahualyl SMR.
- North San Diego: Receivers located at the Del Mar Mooring and Cardiff reef (southern edge of the Swamis SMCA)
- San Onofre: Receivers located offshore from San Clemente, CA south along the Wheeler North artificial reef as well as adjacent to the San Onofre Nuclear Generating Station, maintained by researchers at CSU Long Beach.

- Catalina Island: 3 receivers on the leeward (east) side of the island, maintained by researchers at CSU Long Beach.
- Northern Channel Islands: Receivers on north and south sides of San Miguel and Santa Cruz islands. Receivers maintained by National Park Service

Conventional tags –

When anglers called with a recapture, I noted catch location (as specific as possible), catch date, fish size at recapture as well as method of catch. Using R, I calculated time at liberty (TAL) and great-circle distance travelled between tag and recapture locations. Due to low sample size and seasonal variations in recaptures, further population analysis using mark-release-recapture analytical techniques was not attempted. Sample size was low due to inability to fund dedicated tagging trips aboard CPFVs as well as most recreational angler's proclivity to keep and eat, rather than tag and release, adult yellowtail.

Results

Conventional tagging

I tagged 182 yellowtail ranging in size from 23 to 107 cm fork length between September, 2014 and January 1, 2016 with assistance from several volunteer anglers, fishing guides and CPFV captains and crew. Of those 182, 36 were reported recaptured, a 21.4% recapture rate (Table 1). Time at liberty (TAL) ranged from 0-414 days with a mean of 103.7 and a median of 30 days (95% confidence = ±44.6 days). TAL was bimodal, with recaptures occurring from 0-121 days post-tagging or greater than 299 days post-tagging (Figure 3). Interestingly, since all recaptured fish were tagged between April and October of 2014 and 2015, the lack of recaptures between 122 and 299 days post-tagging corresponds to the proximate cold-water (winter) season and a corresponding seasonal decrease in recreational fishing effort. Thus, fish that were tagged in the warmer months of 2014, if not recaptured during that same season (May – October, 2014), were only recaptured in the next warm-water season (May – October, 2015) (Figure 3).

Tagged fish were recaptured anywhere from 0.0km to 420km from their original tagging location, mean distance = 96.8km, median distance = 73.9km (Figure 4). There was a significant positive relationship between TAL and recapture distance ($p < 0.001$), although the effect of fish size on either TAL or distance from original tagging location was less clear (Figure 5). Recapture locations were spread throughout the SCB from south of Punta Baja in Baja California Norte, Mexico north to the Ventura county coastline, as well as scattered throughout offshore waters of the central SCB (Figure 6). Visually, larger fish tended to be caught inshore or near islands although no trends were quantified (Figure 6).

Acoustic Telemetry

Recapture rate – I tagged 22 yellowtail with acoustic transmitters, 6 were recaptured, a 27.3% recapture rate. TAL ranged from 9 to 299 days, median TAL = 20.5 days (95% confidence = 90.4 days). The distance between tagging and recapture locations ranged from 0.2 – 310.2km, median = 31.3km although 3 fish were caught less than 1.7km from their tagging location while the other 3 were further away (61km, 125.4km and

310.2km). As with conventional-tagged fish, no winter-tagged fish were recaptured although recapture rates were over 25%.

La Jolla Acoustic Array – Between August, 2014 and September, 2016, 17 of the 22 (77.3%) acoustically tagged yellowtail were detected in La Jolla on at least one receiver. Of those 17, 1 fish (ID# 27077) most likely died post-tagging and 4 others were recaptured. I assume the one fish died due to both the condition of the fish upon release as well as that it was only detected briefly on one receiver immediately post-release and never detected again. All other fish released in better condition in that area of the La Jolla array were detected multiple times on multiple receivers. As of this writing, 12 fish are assumed to still be at liberty (Figure 7).

Receivers on the ocean-side of the array detected the most fish (>7), with the 2 receivers moored in the deepest water, outside the main body of the array, on the north-western and south-western corners detecting the most fish by far (NW = 15, SW = 12, Figure 8). No other receiver anywhere in the SCB recorded more than 7 individual yellowtail during the duration of the study. Of the 17 fish detected by La Jolla acoustic receivers, I tagged 4 during winter months (December – March, SST < 16.5ºC), and the remaining 13 in summer (May - October), when the water was warmer (SST > 20.5ºC). Only 3 out of the 13 fish tagged in summer were detected in La Jolla the following winter, while 3 of 4 winter fish were detected the following summer. Fish tagged in winter were larger (mean FL 103.5cm vs. 90.9cm), and detected significantly more within the La Jolla region than summer fish ($p = 0.015$, Figure 9a). However, as a continuous variable, size effected detections within the La Jolla region more than tagging month and larger fish were more likely to be detected in general ($p = 0.02$, Figure 9c), although after filtering out La Jolla detections, there was no significant effect of size on detection time in all non-La Jolla regions (Figure 9b). Additionally, although detection rates for all fish varied widely between individuals (Appendix 1: pie chart), fish size, rather than tagging season, remained a better determining factor for the total percentage of time detected in La Jolla.

Regional detections throughout the SCB – Using a cluster analysis technique (Chateau 2006), tagged fish divide into 3 groups based on their patterns of detection among the different SCB receiver regions. The first group was fish detected primarily in La Jolla, second group were fish detected in La Jolla and one other region (either North San Diego or the Northern Channel Islands) and the third group were fish primarily detected in an area other than La Jolla (North San Diego, in this case); (Figure 10). There was no significant effect of size on the amount of time detected outside of La Jolla (figure 9b).

Local and Regional Movements – More frequent detections led to higher total distances traveled ($p<0.001$, $r^2=0.635$, Figure 12). However, this finding is somewhat misleading, since distances are computed as straight lines between receivers. Thus, if a fish is out of range, there is no distance measured and that individual will have a lower recorded distance even if the actual swimming distance was quite large. Additionally, proximity of tagging location to the nearest receiver affected the total amount of detections recorded, with fish detected more frequently by receivers closer to their tagging locations ($p<0.01$, Figure 11). Although the relationship was significant, the explanatory power was quite low ($r^2 = 0.027$), this is likely due to fish tagged in La Jolla being detected in the northern Channel Islands as well as fish tagged in Ventura going undetected until arriving in La Jolla several months later.

Discussion

This study is the first to acoustically track yellowtail in the SCB as well as in North America. Higher than expected conventional tag return rates, in addition to seasonal differences in regional acoustic telemetry detections, point toward potentially significant but unquantified fishery impacts on a migratory species with poorly understood seasonal movement patterns.

Conventional Tag Returns –

21.7% of all tagged fish were recaptured during this study. This is an extraordinary return rate for only tagging 182 fish. In contrast, a state-funded cooperative yellowtail tagging program in New South Wales, Australia tagged approximately 17,000 fish between 1974 – 1994 with an overall return rate of 8% (Gillanders et al. 2001). A California Department of Fish and Game study tagged 15,121 fish off Baja California, Mexico between 1951-1957 and reported subsequent returns between 2-7% depending on tagging method and handling times (Baxter 1960). The only other SCB tagging work to have a return rate as high was Aalbers and Sepulveda (2015), they recorded a 24% return rate for electronically tagged white seabass (*Atractoscion nobilis*). However, the bulk of their fish were returned by commercial fishermen and the return rate due to recreational fishing was only 7%.

Although 182 tagged fish is not robust enough for a population assessment (Pine et al. 2003), several conclusions can be drawn from both the return rate as well as time at liberty (TAL) and distances between tagging and recapture locations:

(1) The high return rate points to high recreational fishing pressure on SCB yellowtail. This is especially true during summer months in offshore waters when yellowtail school around drifting kelp mats (kelp patties). At multiple instances during this study, fish were tagged on a kelp mat only to be recaptured within the week by private boats or CPFVs that were most likely fishing the same kelp mat. Baxter also reported very high tag-return rates in the SCB, 60 of 167 fish tagged between Santa Catalina Island and the Coronado Islands were recaptured, a 35.8% return rate. In 1960, he wrote, “The tag recoveries indicate that fishing in California takes a high toll of the available fish.” This conclusion is still valid today, 56 years later.

(2) Southern California angler effort is most likely the explanation for the temporal pattern in tag returns. Fish were either recaptured within the first 120 days or not until 300 days post tagging, with 414 days the maximum TAL. Although yellowtail were detected throughout the year, fish were only recaptured between June and October during all study years, a period that coincides with highest angler effort in the SCB (Dotson and Charter 2003). As the water cools during the fall months, yellowtail catch as well as angler effort drops. Fewer people fishing means a lower chance of encountering a tagged fish, especially if most fish are assumed to migrate south during that time (Baxter 1960).

(3) Fish size had no effect on either TAL or distance between tagging and recapture, even though Baxter noted that intermediate sized yellowtail (60-90cm FL)

were recaptured significantly further away from their tagging site than either larger or smaller fish. In this study, TAL best explained recapture distance, even though close to 15% of all tagged fish were recaptured within 100 days of tagging. Recapture distances encompassed the entire recorded range from 0 - 420km. 3 fish were re-captured south of Ensenada, Mexico and those fish were all over 80cm and tagged in US waters north of San Diego. The discrepancy between this study and Baxter's is probably due to several factors: tagging predominantly in the SCB as opposed to Baja California, a smaller sample size and our size distribution weighted towards either fish smaller than 60cm or greater than 80cm fork length (likely due to tagging aboard CPFVs).

Acoustic telemetry

La Jolla – Southern California anglers often refer to the largest yellowtail (FL > 95 cm) as "homeguards" (meaning they don't stray far from home) and claim that they are residents on the reefs where they are caught. Besides tagging evidence from Baxter (1960), the idea that larger yellowtail move less than smaller fish was hypothesized by Maccall (1996) based on historical records of southern California fishing clubs dating back to the 1890's. In a study of low-frequency variability in recreational catch, he presents the idea that perhaps yellowtail cease to seasonally migrate after reaching a "critical" size and remain in the general vicinity of wherever they were upon attaining that size. Patterns in La Jolla detections potentially support this claim, in that the gaps between detection events are shorter for larger fish (FL >98cm) than for fish smaller than 95cm.

Yellowtail size seems to drive the frequency with which tagged fish are detected by receivers in La Jolla. While both winter and summer tagged fish were detected by receivers throughout the SCB, larger fish were detected less sporadically, and tended to spend more time in La Jolla during periods of detection (Figure 7). I originally assumed a seasonal effect on percent time detected in La Jolla because of seasonal yellowtail movements in response to water temperature. However, fish size is probably a more important driver, considering larger body sizes better tolerate lower temperatures (Beitinger and Fitzpatrick 1979). Recreational fishery data also shows that larger fish are most often caught in winter (chap 1). In La Jolla, these fish are often caught along the southern rim of the La Jolla submarine canyon (*pers obs*), within range of the northern edge of the acoustic array.

Regardless of size or season, yellowtail appear to prefer the deeper, outer edge of the kelp forest as opposed to shallower, denser areas. The number of individual fish detected was highest at the northern and southern extremes of the LJ array as the benthos shifted from rocky-reef to deeper canyon slope (Figure 8a). All receivers on the deeper, outer, side of the array had elevated detections as compared to inner, shallower receivers (Figure 8b). When yellowtail were detected in La Jolla, detection patterns point to a potential "patrolling" behavior, where fish will hit multiple receivers in a short period then disappear only to return and again pass by multiple outer receivers. This is consistent with reports of yellowtail foraging behavior where they use kelp-forest or reef edges to corral or ambush prey (Schmitt and Strand 1982). However, greater spatial receiver coverage of all associated La Jolla habitats is needed to further understand the drivers behind the patterns seen here.

Regional Detection Trends

Yellowtail tagged in La Jolla can be divided into 3 groups based on their detection patterns: (1) fish detected primarily in La Jolla, (2) fish detected in La Jolla and one other region and (3) fish detected primarily outside of La Jolla. There were no clear size-based trends in regional detections, as both larger and smaller fish were detected throughout the SCB. The majority of yellowtail detected outside of La Jolla were picked up by Wheeler North Artificial Reef (WNAR) acoustic array in San Onofre. I assume both number of receivers as well as proximity to La Jolla drove this trend, as this array was the second largest in the network of receivers used in this study (besides La Jolla) as well as closest to La Jolla (~60km north, Figure 13). Overall, regional detection trends are supported by spatial trends in recreational catch data, where several "hotspots" contribute the majority of SCB yellowtail catch (Chap 1, CA-DFW).

Tagged yellowtail traveled throughout the SCB and were detected as far north as San Miguel island (the northern limit of VR2 receivers in the SCB). I assume these northward movements are SST-mediated due to El Niño driven, anomalously-high, SST's in the SCB during 2015. Yellowtail and other SCB fish species are known to expand northward during El Niño years (Squire 1987). SST-mediated northward movements are further supported by consistent anecdotal reports that yellowtail were caught between Point Conception and Monterey during summer and fall 2015 as well as several confirmed catches offshore of southern Washington state (*pers obs*, BDOutdoors.com).

Confounding the idea of SST-driven northward movements, tagged yellowtail also traveled south during the same period. Several tagged fish, including one with an acoustic transmitter (tagged in La Jolla) were recaptured by San Diego-based long-range CPFVs fishing off central Baja California. The acoustic-tagged fish was caught near Isla

San Geronimo, approximately 350km south of La Jolla. Unfortunately, there are no acoustic receivers south La Jolla, besides a small array at Isla Guadalupe (O. Sosa, *pers comm*), so southern movements of La Jolla tagged fish remain a mystery. This is unfortunate, since Baxter surmised that the center of abundance for west-coast yellowtail was central Baja California (between Punta Eugenia and Punta Baja) and that the bulk of yellowtail caught in the SCB were seasonal migrators from Mexican waters (Baxter 1960).

Implications for Yellowtail Management

Yellowtail range throughout the SCB and even large, “homeguard”, fish move constantly, 10s of kilometers per day. This has strong implications for management as California is heavily invested in spatial management. The Marine Life Protection Act mandated that 10% of the state’s coastline be protected through various no-take and limited-take marine reserves (CA-DFW). Unfortunately for yellowtail, their daily movements alone greatly exceed the scope of almost every MPA in the SCB (mean area = 18.4 km^2, CA-DFW). This issue is compounded by their fast swimming speed (Clark 2006) and extensive seasonal movements (Baxter 1960). Furthermore, the coastal nature of MPAs results in spatial protections that miss offshore drifting kelp mats, which act as sites of recruitment for juveniles and spawning for adults (Hobday 2000, Uehara et al. 2006). In the case of yellowtail, I surmise that size and season-based management strategies will prove much more effective at maintaining the sustainability of the recreational fishery.

The high tag return rate is the clearest finding of this study. It indicates that fishing pressure on yellowtail in the SCB is extremely high and the SCB is probably a net population sink for yellowtail along the west-coast of North America (MacCall 1996, Dotson and Charter 2003). Thus, to maintain consistent catches, the population needs to be constantly replenished, most-likely with fish moving north from Mexico (Baxter 1960). The historical pattern of seasonal winter cooling and a lack of recreational yellowtail fishing in Baja California has allowed the system and catch-rates to remain relatively stable. However, if the shifting patterns seen during the 2015 El Niño as well as previous events are any guide to the future, warming seas could cause yellowtail to move further north. This will put yellowtail in year-round range of SCB anglers and negate the "seasonal refuge" that wintering off central Baja could provide. To further complicate things, this scenario does not account for ongoing population growth and associated rises in fishing pressure in Baja California (Young 2001). However, forecasting future effects on SCB yellowtail movements and populations is next to impossible without designated tagging programs and more comprehensive research.

Acknowledgments:

Chapter 2, in full, is currently being prepared for submission for publication of the material. Ben-Aderet, Noah J.; Semmens, Brice X.; Sandin, Stuart A. The dissertation author was the primary investigator and author of this material.

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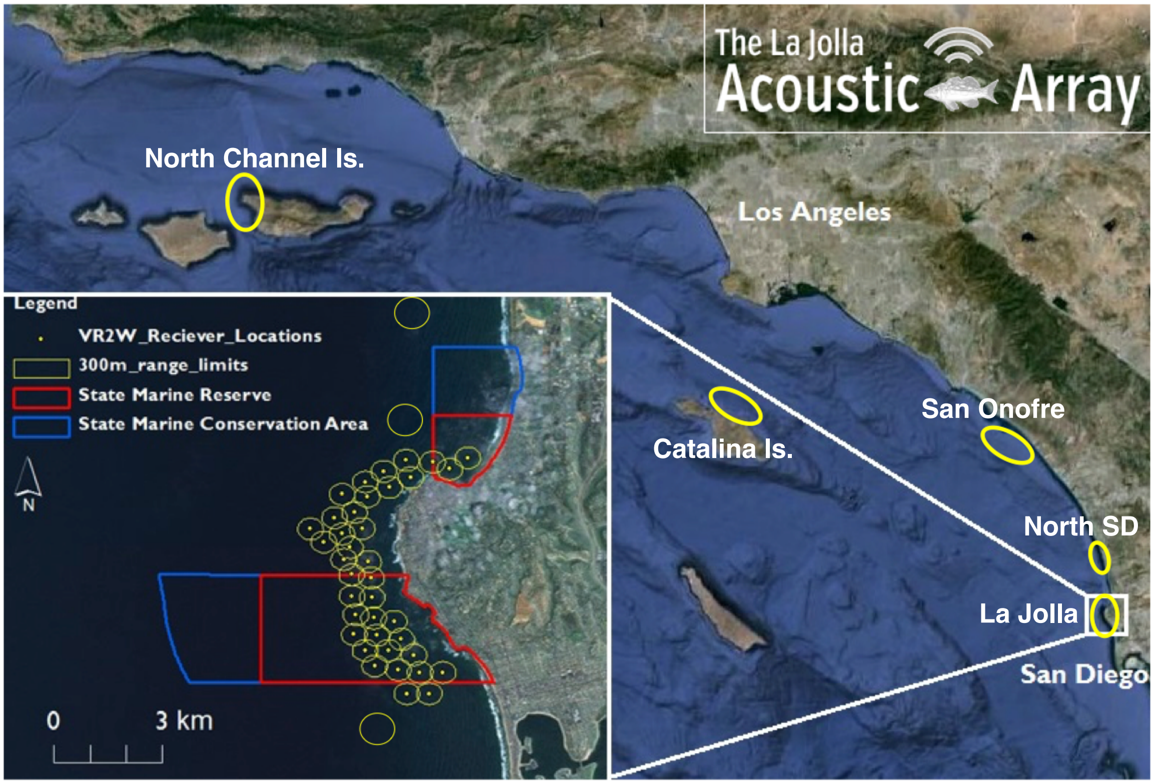

Figure 2-1. Map of La Jolla Acoustic Array inset in a map of the Southern California Bight (SCB). Yellow ovals in SCB map denote other SCB acoustic receiver locations.

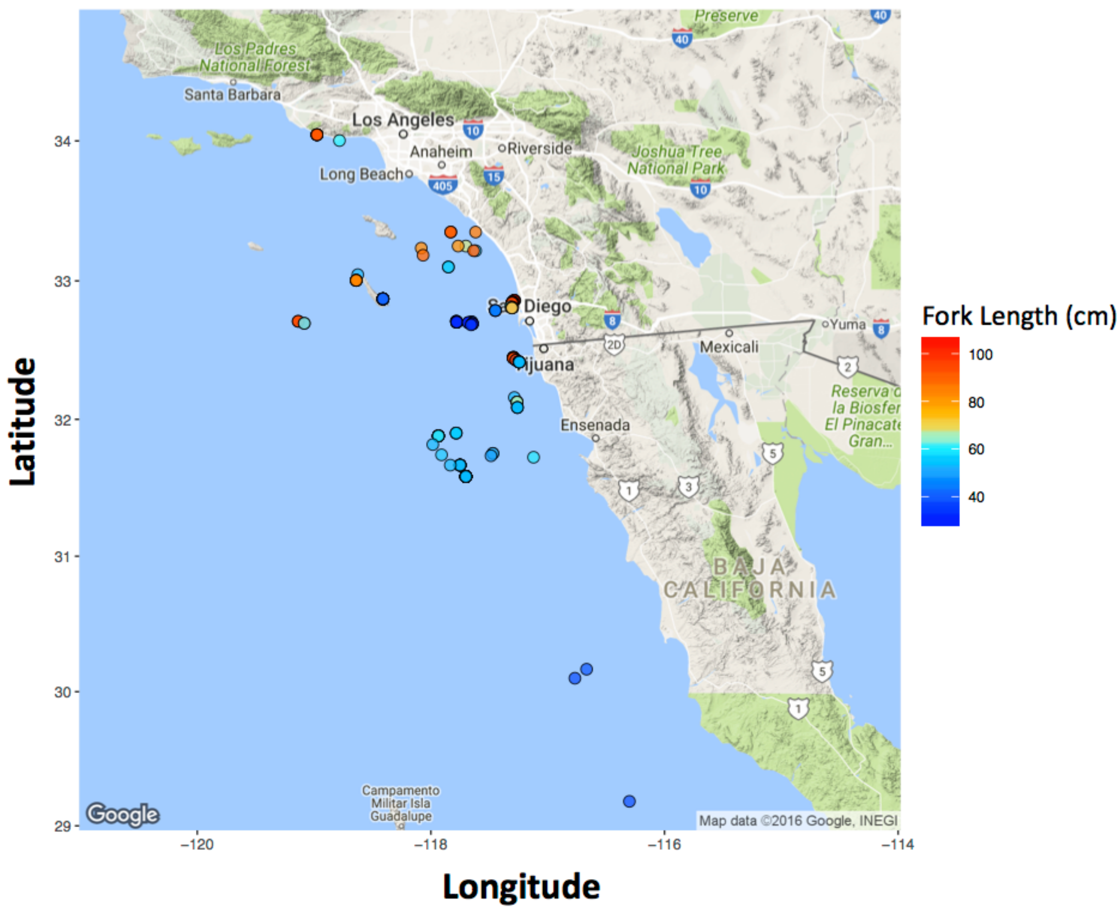

Figure 2-2**.** Map of all yellowtail tagging locations color-coded by fish size (cm). Warmer colors correspond to larger fish. In general, larger fish were tagged in areas associated with islands or reefs, usually further north or nearer to shore in the SCB.

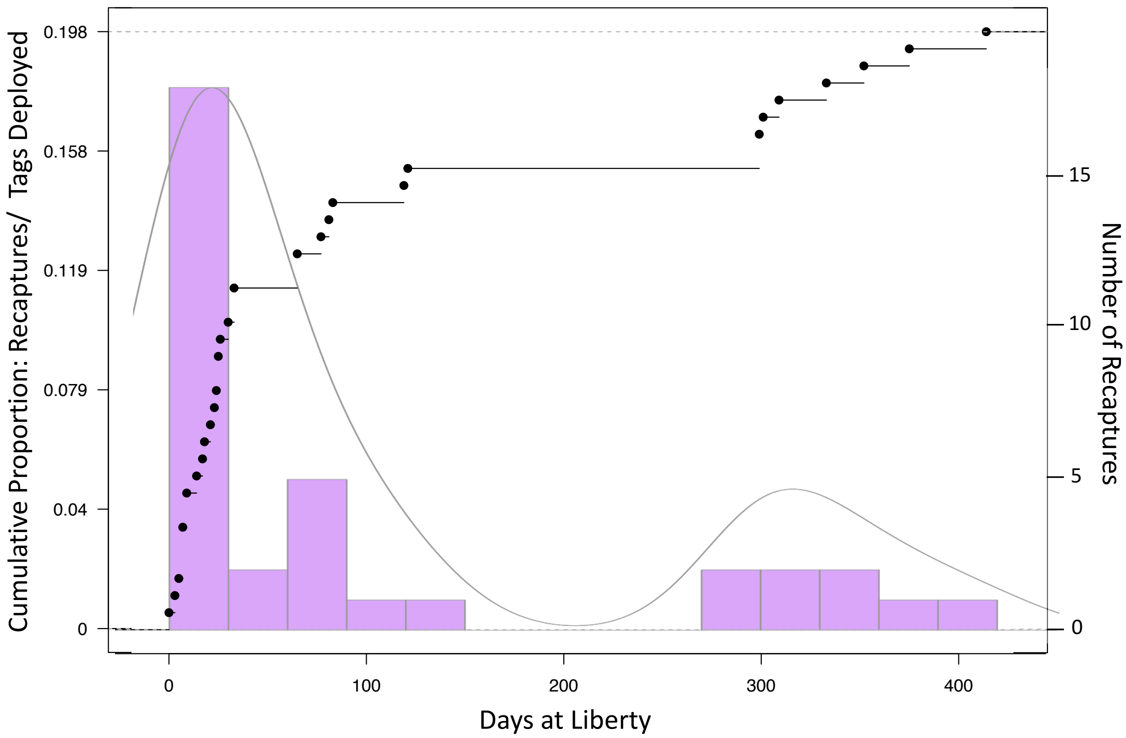

Figure 2-3. Black dots represent proportion of recaptures versus days at liberty. Histogram represents number of tag-returns per 25 day bin. Approximately 15% of all tagged fish were recaptured in the first 100 days post-tagging. No fish were recaptured between 121 and 299 days post-tagging. Recaptures resumed at a lower frequency after 299 days at liberty. Min = 0 days, Max = 414 days, Mean = 103.7 days, Median = 30 days

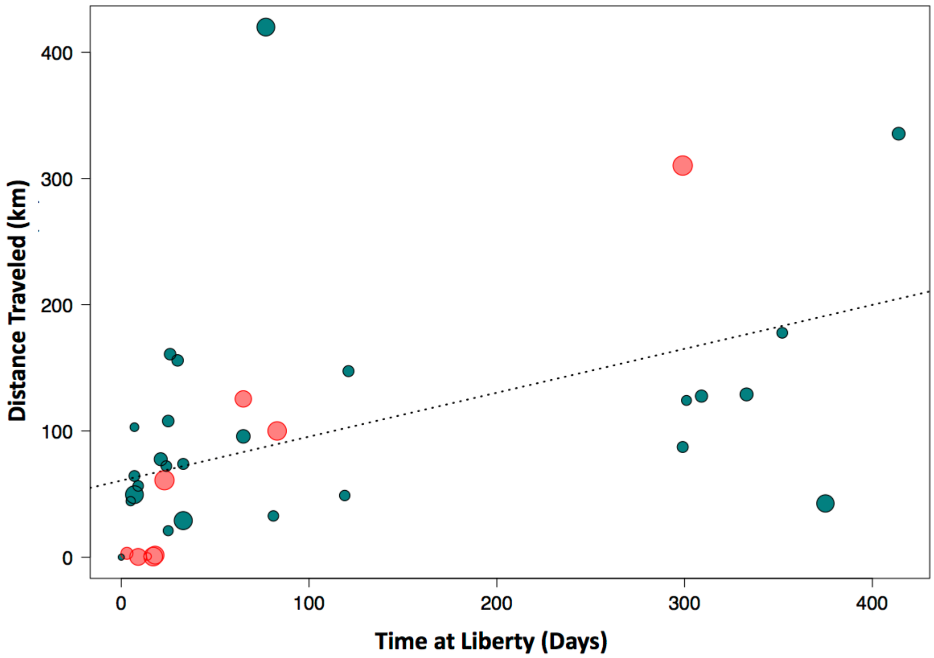

Figure 2-4. Relationship between days at liberty and recapture distance ($p < 0.005$). Red bubbles are fish tagged inshore, Blue is fish tagged offshore. Bubble size is representative of fish size.

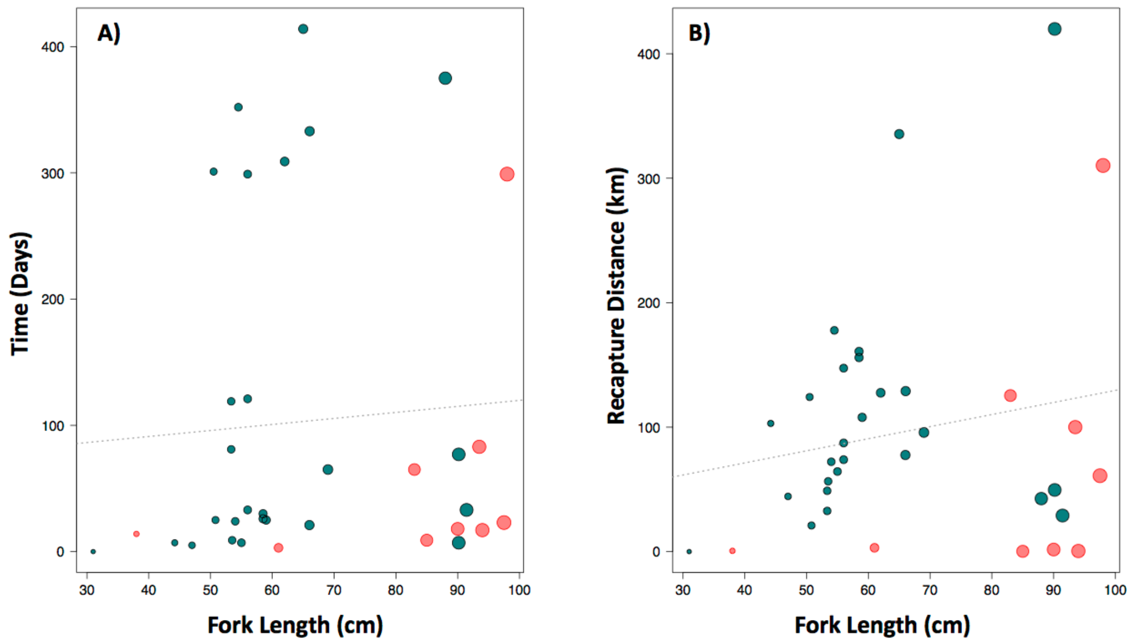

Figure 2-5. A) Time at liberty (TAL) and B) Recapture distance, both vs. fork length (cm). Red bubbles are fish tagged inshore, Blue is fish tagged offshore. Bubble size representative of fish size. Neither time nor distance significantly related to fish size.

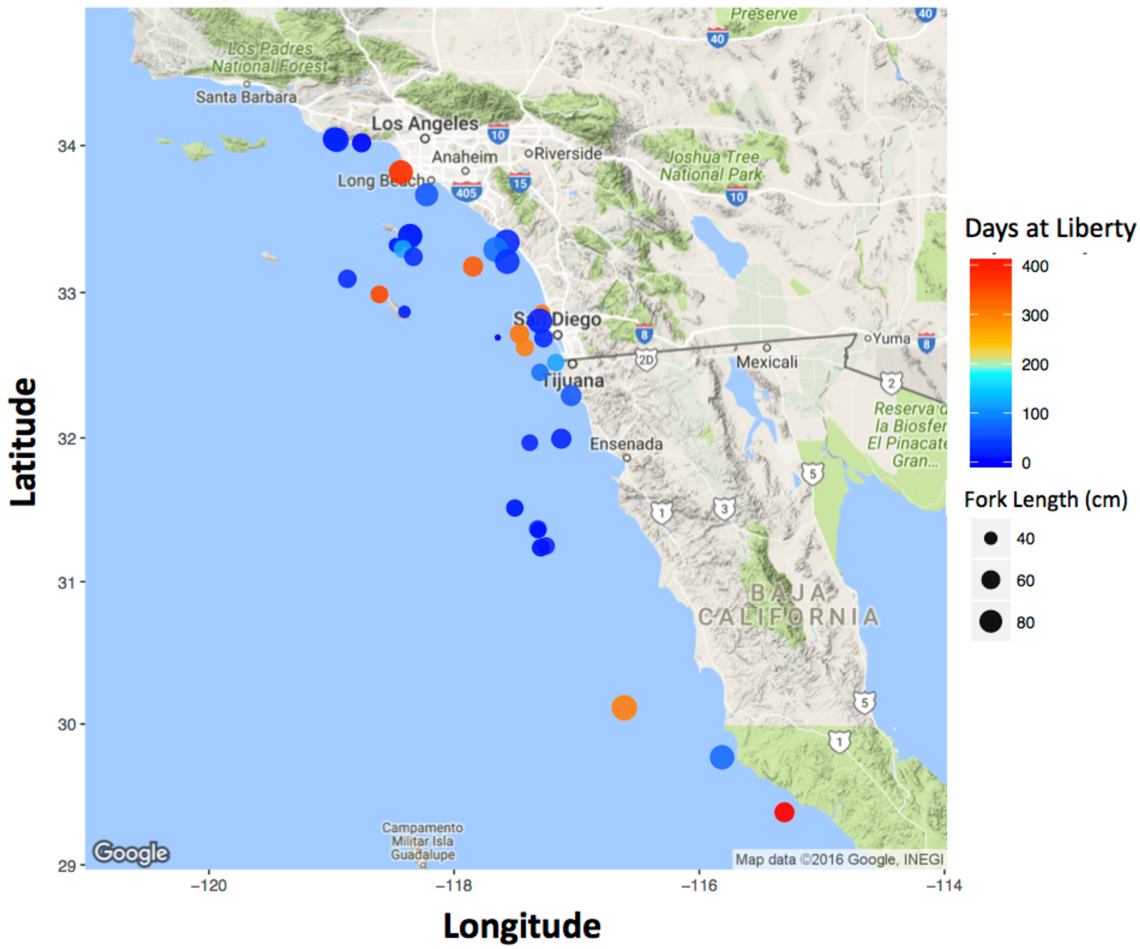

Figure 2-6. Map of yellowtail recapture locations color-coded by time at liberty. Warmer colors correspond to longer times, bubble-size is relative to fish size at capture (cm).

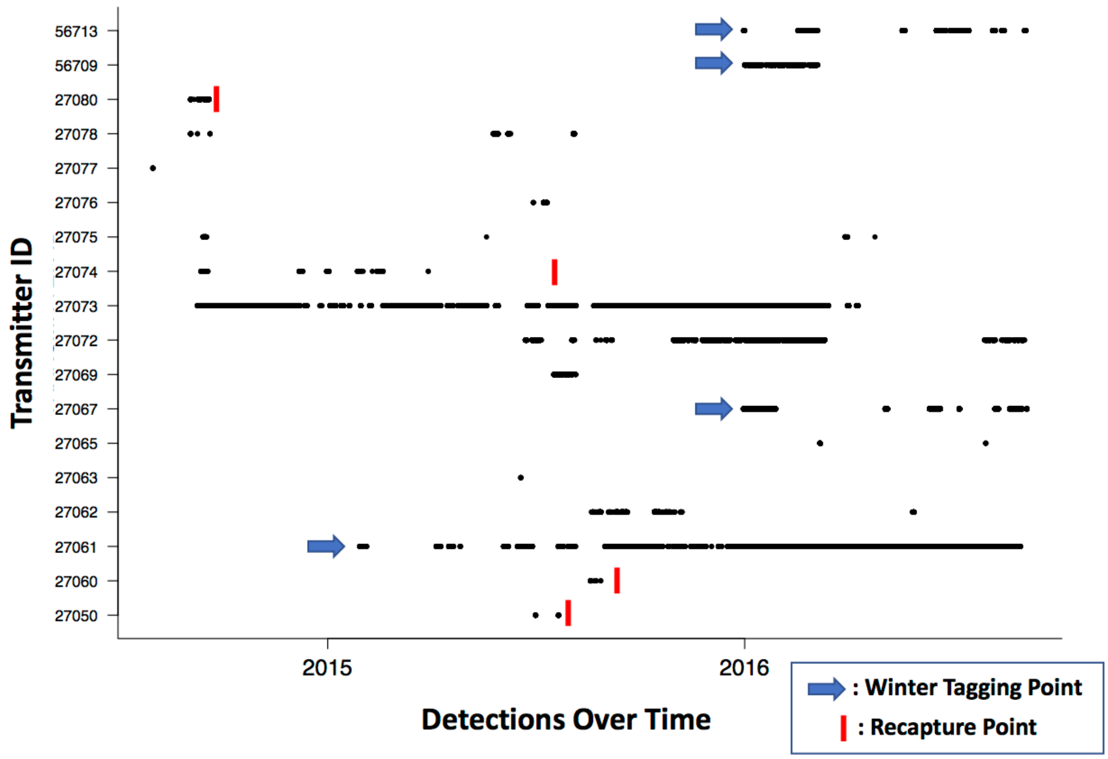

Figure 2-7. Detections over time for all fish detected. Of 22 fish tagged, 6 were recaptured, 17 fish were successfully detected with 4 detected fish subsequently recaptured. Time at liberty for recaptured fish ranged from 9 to 299 days, median = 21 days. First detection is approximately the tagging date for all fish except 27065 (tagged in Ventura 9/2015, detected in La Jolla 3/2016) and 27063 (spurious detection). Red bar indicates recapture date. Blue arrows denote fish tagged in winter.

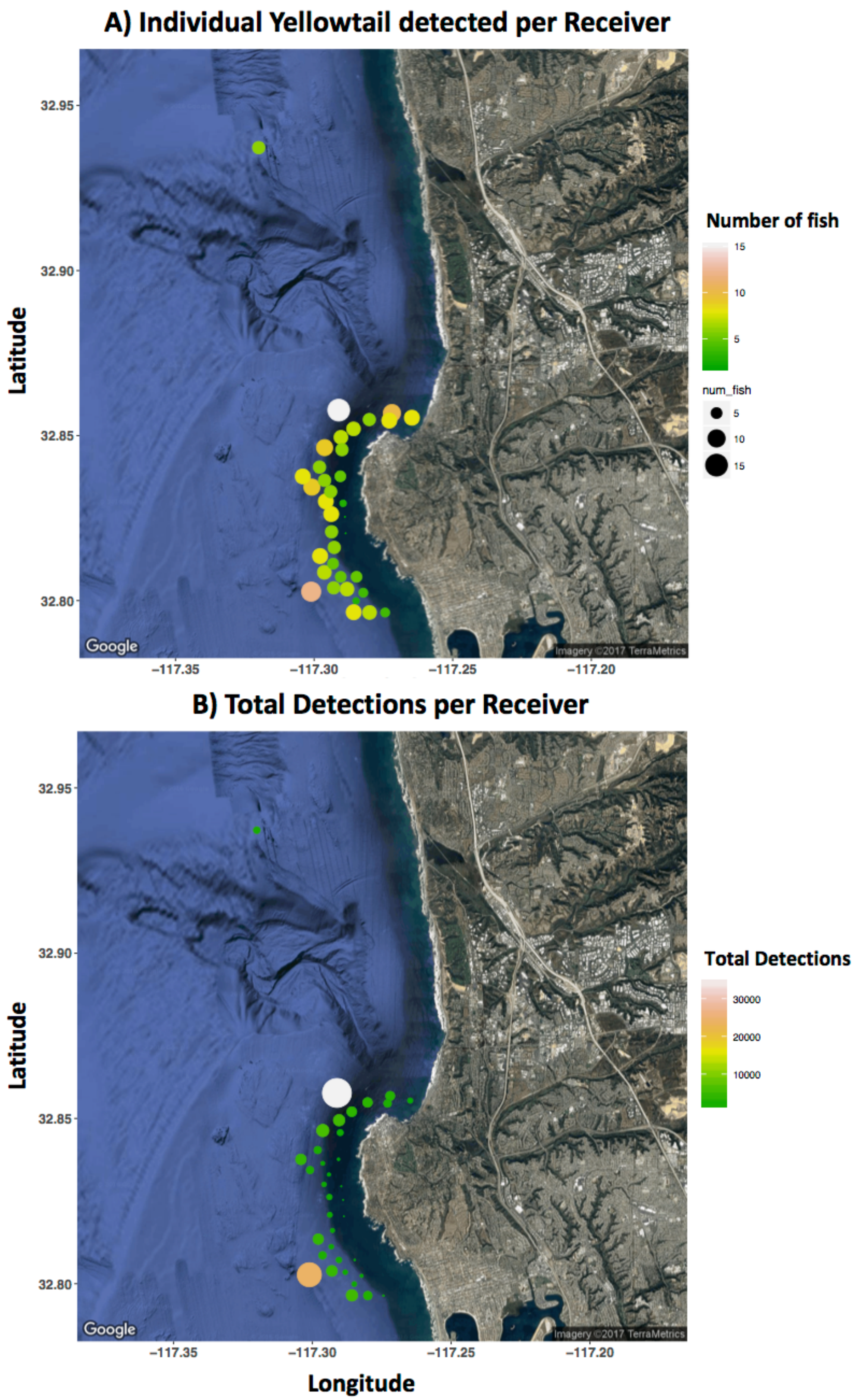

Figure 2-8. A) Number of individual yellowtail detected per receiver in La Jolla. Dot color and size both correspond to number of fish. B) Total number of detections per receiver in La Jolla. Color and size both correspond with number of detections.

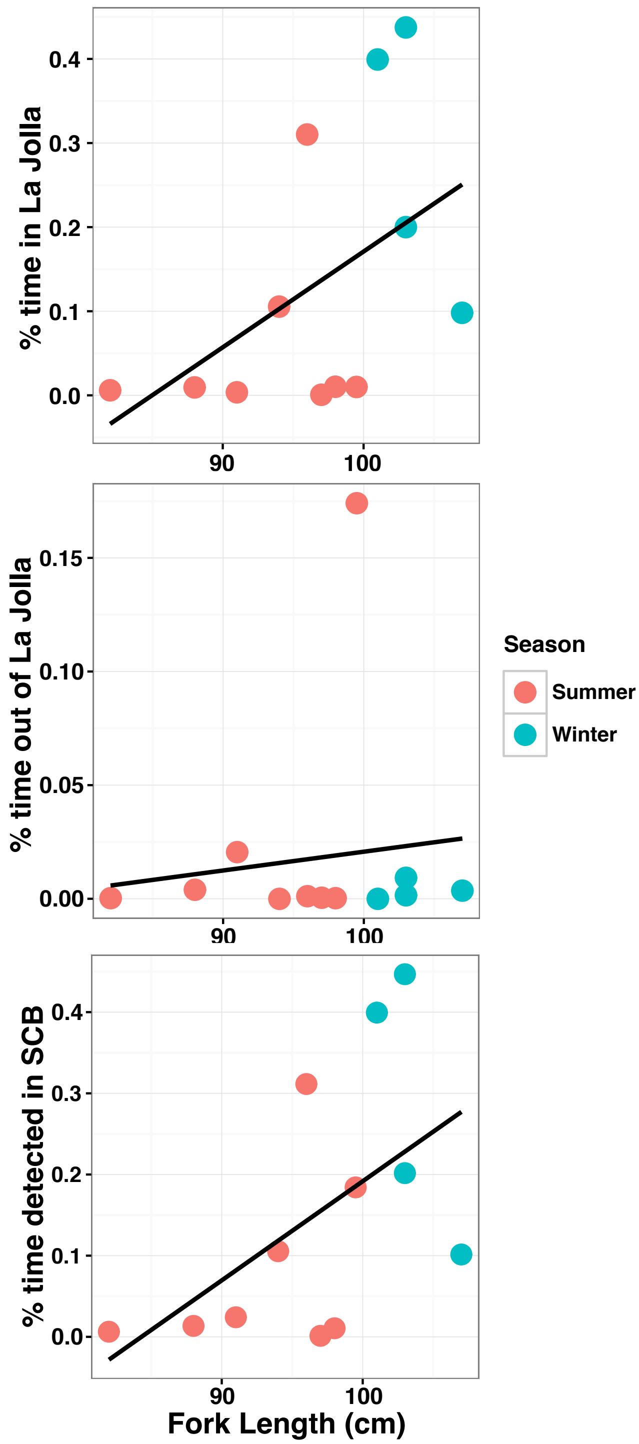

Figure 2-9. Percent time detected in relationship to fork length, red dots are summer-tagged yellowtail, blue dots are winter-tagged. (a) Percent time detected in La Jolla. (b) Percent time detected throughout the Southern California Bight. (c) Percent time detected outside of La Jolla. Significant differences between winter and summer fish in mean percent time detected in La Jolla and throughout the SCB ($p<0.05$), not when La Jolla detections excluded.

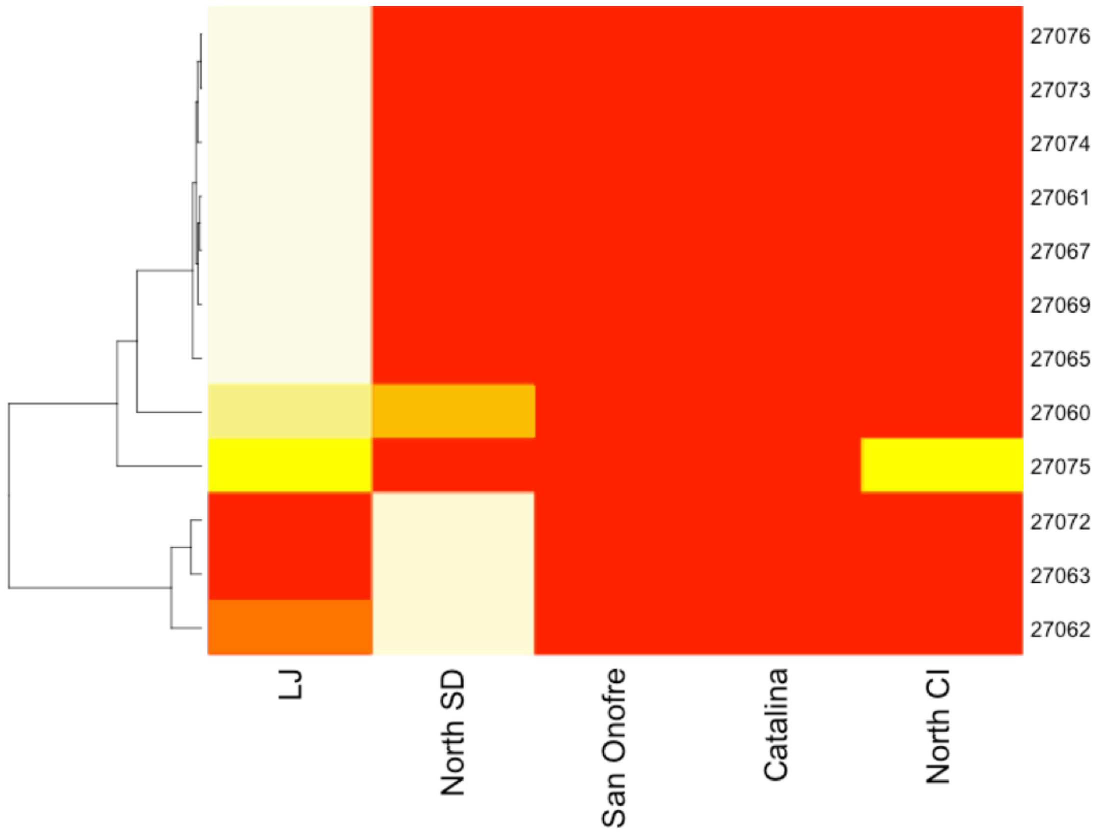

Figure 2-10. Heat map generated through cluster analysis for all fish detected at least once greater than 30 days after first detection. Fish split into 3 groups: La Jolla exclusives, predominantly North County San Diego, and fish splitting time between La Jolla and one other location (either North SD or Northern Channel Islands).

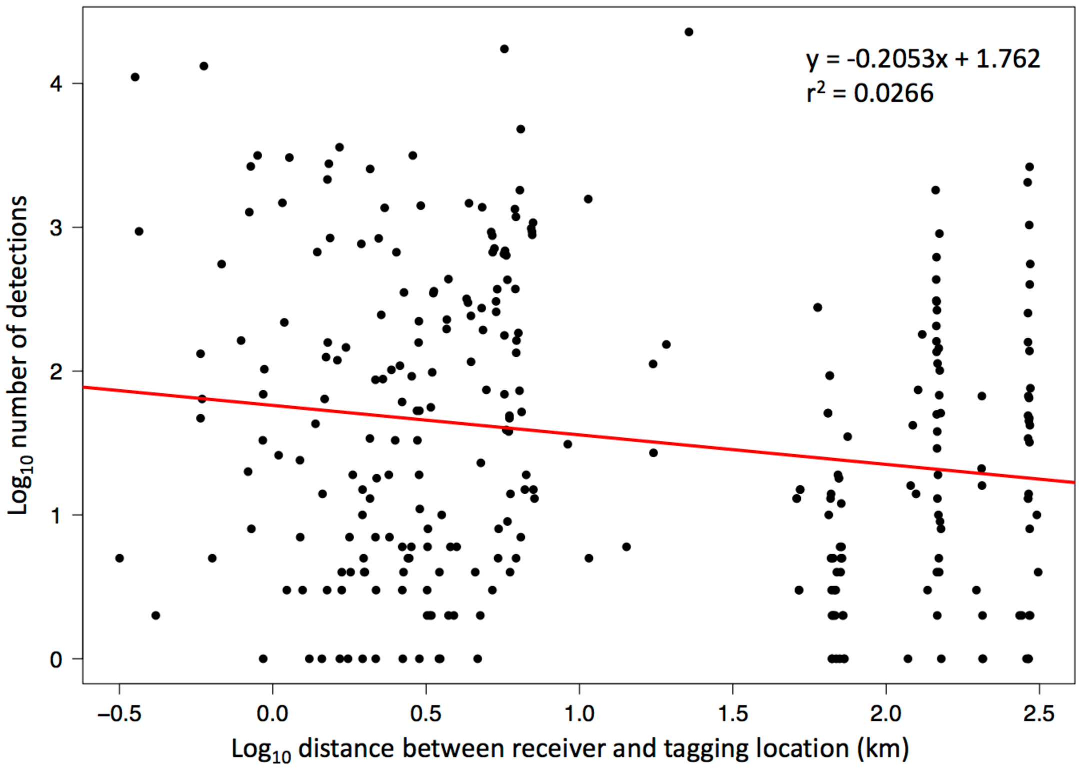

Figure 2-11. Relationship between log-transformed number of detections per given receiver and the log-transformed distance of that receiver from the tagging location ($p < 0.01$).

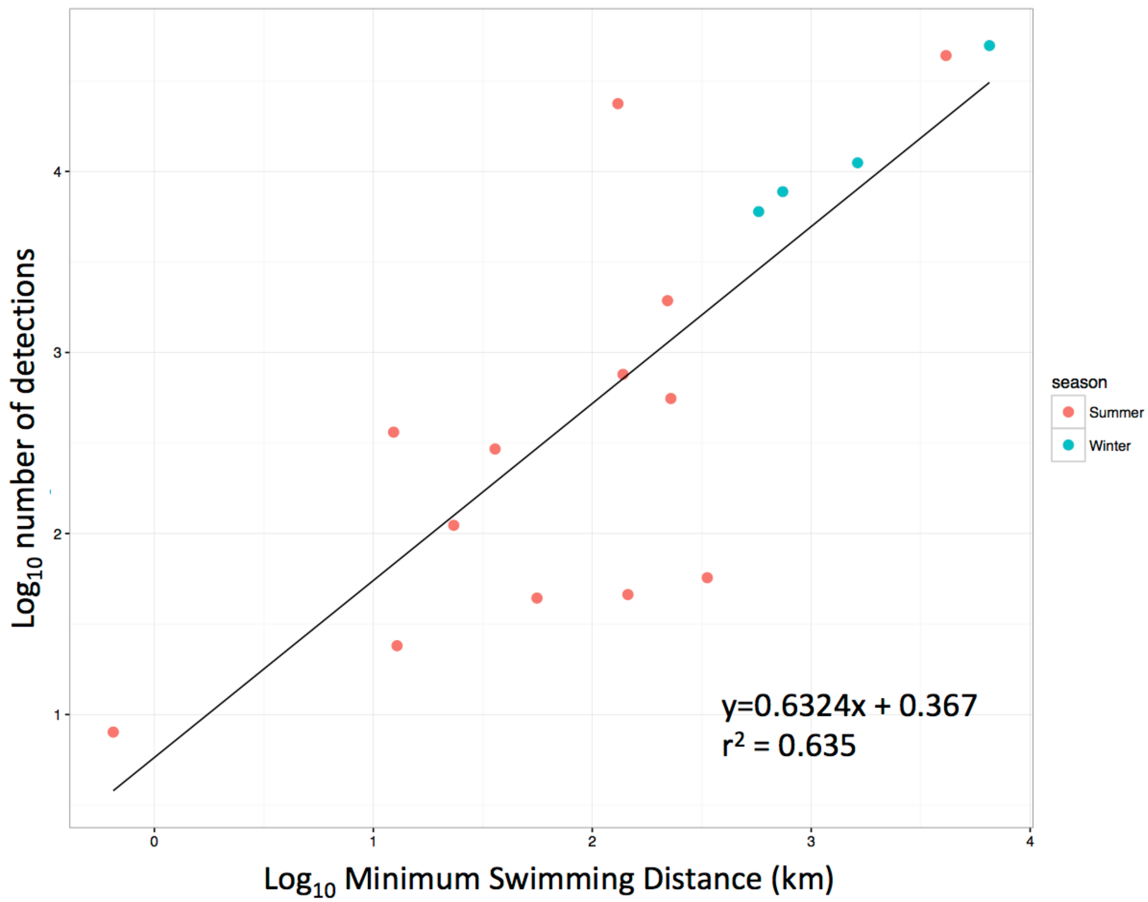

Figure 2-12. Relationship between log transformed minimum recapture distance and log transformed number of times an individual fish was detected ($p < 0.001$).

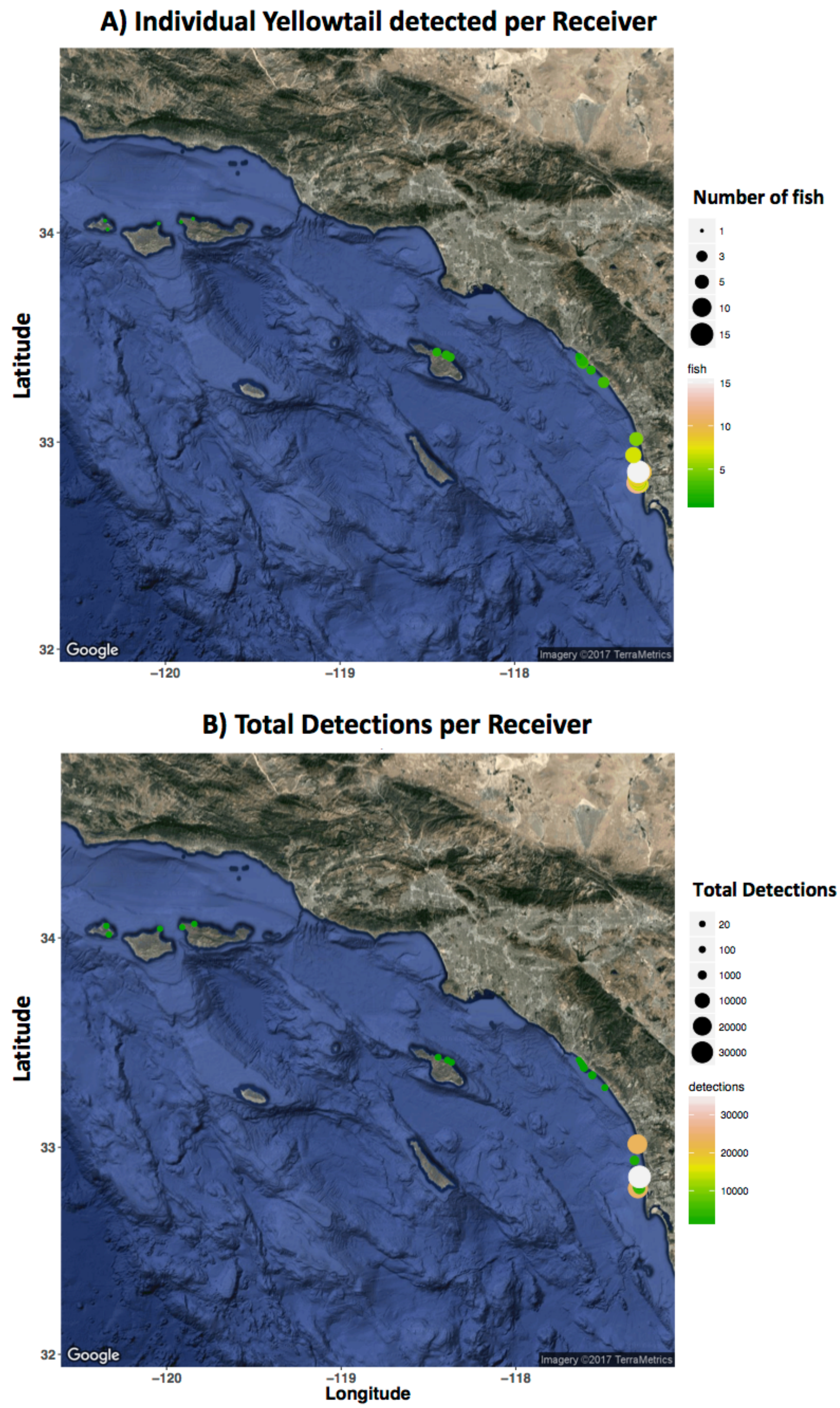

Figure 2-13. A) Number of individual yellowtail detected per receiver in the SCB. Dot color and size both correspond to number of fish. B) Total number of detections per receiver in the SCB. Color and size both correspond with number of detections.

Tables:

Table 2-1. Summary of all tagged and recaptured yellowtail during the study period.

Tag Type	# of Fish Tagged	# of Fish Recaptured	Tag Return %	Max/Min/Mean tagged FL (cm)	Max/Min/Mean recap FL (cm)	Max/Min/Mean recap dist. (km)	Max/Min/Mean TAL (days)
Conventional	182	33	21.4	107/27/59.6	98/31/66.2	420/0/96.8	414/0/103.7
Acoustic	22	6	27.3	107/80.5/93.2	98/83/91.3	310/0.22/83.1	299/9/73.8

Chapter 3:

Investigating Regional Differences in Life-History Characteristics of Southern California Yellowtail (*Seriola lalandi*): Evidence of Ontogenetic Habitat Shifts

Noah Ben-Aderet, Stuart Sandin

Abstract

Yellowtail (*Seriola lalandi*), a highly sought-after gamefish, are targeted across multiple regions throughout the Southern California Bight (SCB) in both U.S. and Mexican territorial waters. Yellowtail differ ontogenetically from many other SCB gamefish species. They exhibit marked shifts in spatial distribution and habitat use while transitioning from their pelagic nursery areas (associated with drifting macro-algal mats) to adult inshore habitats.

This study investigated regional, local and ontogenetic effects on several life-history parameters of yellowtail: size-at-age, diet and trophic position. Transverse sections of sagittal otoliths were used for age estimation. Stomach contents analysis provided a measure of diet, while stable isotope ratios ($\partial^{13}C$, $\partial^{15}N$) were used to investigate tropic position and differences among region. I also developed a novel opercular length to fork length scaling relationship, which allows accurate fork-lengths to be estimated from angler discards, an easy source of biological samples.

The ontogenetic shift from SCB pelagic to neritic habitats effects was evident from life history evidence as no regional differences in size-at-age, diet or trophic position were found. All differences were due to changes in body size. Interestingly, increased body size led to increased diet diversity and in-turn, elevated trophic position (through increased $\partial^{15}N$ levels). While further investigation during non El Niño years (when yellowtail catch, and implied abundance, is depressed) is needed, the existence of ontogenetic shifts in diet, habitat and trophic position are important for life-history and spatially-based management decisions.

Introduction

Yellowtail (*Seriola lalandi*) are one of the most iconic gamefish within the Southern California Bight (SCB) and are widely targeted throughout the region, in both U.S. and Mexican territorial waters. Within the SCB, yellowtail are seasonal migrators, moving northwards as the water warms during the summer (although rarely north of Pt. Conception, CA) and retreating south along the Baja California coastline during the winter and spring (Baxter 1960). This pattern of cross-border migration means these fish encounter a diverse array of anthropogenic pressures, ranging from ocean-warming to agricultural and urban run-off to recreational, artisanal, and commercial fishing as well as the world's largest fleet of Commercial Passenger Fishing Vessels (CPFV's) (Love 2006). This combination of physical, biological and anthropogenic factors significantly influences yellowtail behavior and life-history. This study aims to quantify spatial and temporal changes in a suite of yellowtail life-history parameters – principally size-at-age, diet and trophic position – by collecting samples from recreationally-caught yellowtail at various regions and locations throughout the SCB.

What is currently known about yellowtail life history along the California coast is largely from a California Department of Fish and Game (now Wildlife) fisheries bulletin published by Baxter in 1960. He analyzed diet, age, growth, potential fecundity as well as fishing pressure. While comprehensive, his life-history work lacks defined spatial resolution, with no designation or comparisons between fish caught offshore and fish caught inshore. Furthermore, almost all fish sampled and tagged came from central Baja California as opposed to the SCB. Although central Baja is the center of abundance for California yellowtail, and oceanographically similar to southern California (Bograd &

Lynn 2003, Jackson 1986), the SCB has a much higher human population and is subject to very different anthropogenic pressures, including high levels of recreational fishing pressure and near-shore eutrophication from urban and agricultural run-off (Schiff et al. 2000).

Yellowtail Life-History and Shifting Habitat Use

Yellowtail live and move throughout a highly dynamic coastal ecosystem (Bograd & Lynn 2003) and exhibit marked ontogenetic shifts in distribution and habitat usage (Sakakura & Tsukamoto 1997, Hiyama 1998). Adults live inshore but spawn offshore, their eggs hatch into pelagic larvae and the juveniles recruit to drifting kelp mats (Hobday 2000). While yet to be documented in California, Japanese yellowtail show ontogenetic shifts in their interactions with drifting algal-mats (Safran & Omori 1990). They begin to move further and further away from *Sargassum* rafts (Kasai et al. 2000) but remain offshore until transitioning to inshore, rocky reefs after reaching maturity (Sakakura & Tsukamoto 1997, Sinopoli et al. 2006).

Currently, details about habitat specific yellowtail life history remain unclear, especially regarding their use of offshore and inshore habitats. Among other species, occupying different habitats throughout their life-span impacts growth rates, diet composition as well as trophic position (Hobson 1999). I assume that these effects will be detectable yellowtail as well. As such, previous work analyzing recreational catch data (Ben-Aderet Chapter 1) revealed the existence of size segregation between inshore and offshore catch. Inshore/offshore size segregation is seen in other fish as well as many shark species (Cartamil et al. 2010, Heupel et al. 2007). However, larger individuals are usually found offshore instead of inshore (L'abee-Lund et al. 1993, Cartamil et al. 2010), and opposite of yellowtail where juveniles are offshore and only move inshore after reaching sexual maturity.

Yellowtail appear to transition from a pelagic to inshore habitats much later in life than most other fish (Ben-Aderet *in prep*, (Sinopoli et al. 2006)), but the ecological explanation of this transition remains unclear. Life history (growth rates and movements) and trophic (diet composition) information can provide fundamental insights with which to explore the consequences of such ontogenetic shifts (Werner & Gilliam 1984). Because habitat shifts are often forced by a variety of factors (organism size, predation risk, food availability, etc.) it is necessary to examine multiple parameters from a size-spectrum of individuals sampled across their geographic range (Snover 2008). This chapter aims to complement direct information about movement patterns with spatially explicit information about the life history and trophic position of yellowtail in the SCB. As such, I will attempt to answer the following questions: (1) Are there differences in diet, size- at-age and trophic position between inshore, offshore and island fish? (2) Do these parameters also differ across ontogeny? Answers to these questions are critical for effective management of the species and fishery.

Methods

Sample collection –

I collected 227 yellowtail ranging in fork length (FL) from 22.7 cm to 120.4 cm (mean FL = 75.8 cm) aboard Commercial Passenger Fishing Vessels (CPFV's) and private fishing vessels by hook and line between July, 2014 and September, 2016 (Figure

1). I collected from 10 locations within the Southern Califnornia Bight and along the Baja California, Mexico coastline and grouped those locations into 3 regions, Inshore, Offshore and Island depending on area (Table 1). Samples were primarily discards from recreational anglers. I recorded straight fork length and opercular length (OL) to calculate an OL to FL scaling relationship (n = 107 fish). This relationship enabled me to estimate a fork length for samples taken from yellowtail heads or partial frames after processing aboard CPFV's or donated by anglers after filleting. These samples were often simpler to obtain and reduced the amount of fish sacrificed only for sampling purposes. In addition to measuremnts, I extracted sagital otoliths (for age estimation), a plug of white muscle (stable-isotope analysis) from along the supra-orbital crest of the head of the fish, and excised and immediately froze the stomach for later contents analysis. However, due to varying collection logistics, not all biological samples were successfully extracted from each fish.

Age Estimation

Sagittal otoliths are commonly used to estimate age in fishes (Kimura et al. 1979, Choat & Axe 1996) . Most species deposit a seasonally varying amount of material on the surface of the sagittae, this results in annual growth rings (annula) that can be quantified for an estimate of the fishes age (Hoff & Fuiman 1993, Manooch & Potts 1997). Baxter, 1960, used annual growth rings from scales to age yellowtail sampled along the Baja California coast. However, in 1999, Gillanders performed a comparison of aging methods on Australian yellowtail otoliths, vertebrae and scales and concluded that otoliths provided more accurate age estimations (Gillanders et al. 1999, Shiraishi et al. 2010).

After extracting both sagittal otoliths through careful dissection, otoliths were then rinsed in de-ionized water, air-dried. One sagitta was weighed and measured vertically (dorsal to ventral) and horizontally (rostrum to post-rostrum). The sagitta was then mounted on the edge of a microscope slide to expose the rostrum, but keep the nucleus protected by the edge of the slide. Sagittae were secured using thermoplastic cement (Crystal Bond™). The exposed section of the otolith was ground to the edge of the slide using a decreasing series of wet/dry polishing paper (400 grit [30µm] – 9µm) affixed to a wet grinding- polishing wheel (South Bay Technology INC. Model 900). The ground sagitta was then inverted, centered on the slide, and ground/polished again until reaching the nucleus. The resulting transverse section was covered with a thin layer of Crystal Bond in improve optical clarity (Zgliczynski, Doctoral Thesis). I examined polished otoliths using a dissecting microscope outfitted with a camera and digital imaging software program (ImagePro, Figure 2). Each sample was counted blindly, three times and means calculated for each otolith. When the three counts of an otolith deviated by greater than 2 years, otoliths were re-examined and new estimates made.

Size-at-Age Analysis –

Size-at-age data were fit to the von Bertalanffy growth function (VBGF), defined as:

$$L_t = L_\infty(1 - e^{-K(t-t_0)})$$

Where L_t is the length of a fish at age *t*, L_∞ is the asymptotic length or theoretical maximum length a species would reach if it lived indefinitely, and K is the growth coefficient which is a measure of the rate that maximum size is achieved, t is age in years, and $t0$ is the theoretical age for which length is 0 (Quinn 1999). I generated region-specific growth rates for each collection region and fit size-at-age data using the VBGF. I also compared the growth parameters K and L_{inf} among regions by plotting 95% confidence ellipses around each parameter estimate (Kimura 1980, Choat & Axe 1996).

Diet Analysis

I thawed the stomachs, weighed them, then made a lateral incision from the esophageal opening to the posterior end in order to completely expose the interior. Contents were sorted by size through rinsing with DI water using a series of graduated seives (1cm, 1mm, .1mm) and identified to nearest species. The empty, clean, stomach was then re-weighed. Whole fish and invertebrates were enumerated, identified to species, wieghed and re-frozen for further analysis. Otoliths, vertebrae and cephalopod beaks were identified primarily using Lowry (2011), Clothier (1950) and through comparison to reference samples at the NOAA-Southwest Fisheries Science Center, respectively. Paired structures (otoliths, beaks, crustacean eyes) were counted and divided by two, to estimate individual prey items. I quantified amorphous, unidentifiable contents by subtracting the total prey weight from the difference between the full and empty stomach weights.

I calculated mean percentages for each of the major stomach content groups (fish, crustaceans, cephalopods, amorphous material) for comparison through analysis of variance across sampling location, sampling region, and yellowtail body-size.

Additionally, I compiled a list of prey species from each sampling location and calculated a specific index of diet diversity (Shannon-Weiner) for each individual fish sampled.

Stable-Isotope Analysis

Marine primary production as well as proximity to coastal carbon sources influence an area's baseline isotopic signature and these signatures are reflected and amplified in primary consumers, forage species and subsequently in predators (Hobson et al. 1994, Hobson 1999). The ratio of 15N to 14N increases with each trophic level and is therefore used to estimate an organism's trophic position (Fry 2006) while the ratio of 13C to 14C can be used to estimate dietary sources but does not vary much with changes in trophic level (Post 2002).

To further examine the potential for regional or size-specific differences in the trophic position of yellowtail in the SCB, I analyzed samples of white muscle collected from along the supra-orbital crest for both carbon (∂13C) and nitrogen (∂15N) isotopes. Isotopic turnover rate in yellowtail white muscle is currently unknown, assumed to be about 1 year (D. Madigan, pers comm), their isotopic signature should reflect their aggregate diet over that time period (Peterson & Fry 1987).

Tissue samples were freeze-dried (Labonco® FreeZone 2.5L) for 48 hours to remove all moisture. Samples were then pulverized using a mechanical mill-grinder (Wig-l-Bug®) and a 1mg sub-sample (encapsulated in foil) analyzed for $\delta^{13}C$ and $\delta^{15}N$. Analysis was performed on a Costech 4010 Elemental Combustion Analyzer interfaced with a Thermo Finnigan Delta Plus XP stable isotope mass spectrometer (San Jose, CA) at Scripps Institution of Oceanography. Isotopic values are expressed $\delta^{13}C$ or $\delta^{15}N$, where $\delta = 1000 \times [(R_{sample}/R_{standard})^{-1}]$ and R_{sample} or $R_{standard}$ are the ratio of the heavy to light isotope in parts per thousand (‰). The standards used were Vienna-Pee Dee Belemnite (V-PDB) and atmospheric N_2. The within-run run standard deviation of a glutamic standard was < 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$.

Results:

Opercular Length – Fork Length Relationship

Yellowtail opercular lengths scale isometrically with fork lengths ($FL = 4.1527(OL)^{1.0062}$, $r^2 = 0.942$) creating an essentially linear relationship between the two (Figure 3). I plotted OL versus FL for 103 fish from all sampling locations. Fork lengths ranged 28.0 cm and 117.0 cm FL, and opercular lengths from 5.4 cm to 28.4 cm. This relationship was used to estimate FL for the remaining samples collected from angler discards or otherwise partial yellowtail remains.

Age-Estimation

I estimated ages for 206 yellowtail collected throughout the SCB as well as from 2 locations along the Baja California coast. Fish ranged in estimated FL from 39.2 cm to 120.4 cm and from 1 to 13 years (Figure 4). Neither ages nor growth rate varied significantly between any of the collecting regions (Figure 5). Our mean fork lengths for years 1 through 4 were shorter than those reported by Baxter. In general, variation of within-year lengths were greater than those reported by Baxter (Table 2).

Stable Isotope Analysis

White muscle samples from 227 yellowtail were analized $\partial^{13}C$ and $\partial^{15}N$. There were no spatial trends for $\partial^{13}C$ nor $\partial^{15}N$ values at either the region or location level (Figure 6). However, $\partial^{15}N$ increased significantly with increasing body size (Figure 7, $p > 0.001$, $r^2 = 0.626$), indicating that as yellowtail grow, they become more enriched with ^{15}N.

Stomach Content Analysis

Stomach contents from 148 fish were sorted into functional groups (fish, squid, krill, pelagic red crab, and amorphous material) and identified to species when possible (Table 3). In general, most stomachs were at least partially full, with over half the contents comprised of amorohous, or mostly digested material (mean proportion = 65.4% by weight). The proportion of functional groups varied geographically across collecting region and sampling location (Figure 7), although sample size discrepancies hampered statistical investigation. However, prey diversity (Shannon-Weiner index) increased with yellowtail size (Figure 8), meaning that larger fish consume a wider array of species than smaller fish. Increasing diet diveristy also correlates with increasing ∂15N (Figure 9). Thus, as yellowtail grow, they increase in trophic level and consume a broader diet.

Discussion:

The findings of this study indicate that while spatial variation between different regions of the SCB is much less significant than originally assumed, temporal and ontogenetic influences drive many of the patterns seen in diet, trophic postion and growth-rate.

Opercular Length – Fork Length Relationship

Several fork length to total length conversion factors already exist for yellowtail from California as well as from Austrailia/New Zealand (Baxter 1960, McKenzie et al. 2014, Holdsworth et al. 2013), however, the OL-FL conversion factor I developed is novel. The creation of a robust conversion factor between opercular and fork length means that accurate estimates of fork length can be computed from discarded yellowtail heads, which most CPFV captains and crew are happy to donate to researchers. This greatly enhances our ability to sample efficiently across a large area of the SCB and Mexican coastline since CPFV's large size and range allows them to access areas less commonly targeted by private recreational fishing skiffs (Love 2006) as well as that yellowtail are a favorite target of most SCB and Baja California CPFV anglers (Dotson & Charter 2003).

Evidence for effects of Elevated SST on Age-Classes?

There were no spatial differences in yellowtail length-at-age between inshore, offshore and island sampling regions and, unfortunately, an insufficient number of fish were sampled during winter months within the SCB to be able to conduct a seasonal comparison. However, climate-mediated recuitment pulses are possibly reflected in age/length frequency within the 227 fish sampled for this study. In the SCB, warmer-than-average conditions are coincident with El Nino (ENSO 3.4 positive anomaly > 0.5) summers (Chavez et al. 2002), and are thought to support yellowtail spawning in the outer-SCB as well as correlate with increased yellowtail recruitment success (Tian et al. 2012).

Mean and median ages across the entire data-set were 6 and 6.2 years respectively, these ages coorespond with spawning during summer 2009. 2009 was a mild El Niño year (ENSO 3.4 anomaly + 0.9, NOAA - Climate Prediction Center), with elevated ocean temperatures in the SCB. Additionally, fish in the 90th percentile of our size-distribution were larger than 96 cm FL and according to our age-estimations, greater than 10 years old. These fish were most likely spawned between 2003 and 2006, again, a period of elevated summer SST's in the SCB (NOAA-CPC). The prevalence of fish who resulted from spawning during anomalously warm-water conditions in the SCB, coupled with cyclical increases and decreases in yearly catch, further supports the idea that both spawning and recruitment are increased in the SCB during episodes of elevated SST's.

Early Growth Presents Issues for Accurate Aging

Baxter (1960) reported a mean FL of 50.6 cm (size range = 37.1 – 63.3 cm FL) for age 1 fish, and a mean FL of 63.4 cm for age 2 fish. This is much larger than our year 1 and 2 fish (mean FL = 26.3 cm, 44.1 cm respectively). Our estimated length-at-age consistently under performs Baxter's findings until year 12, the maximum age he reported. This discrepancy is likely due to 2 reasons, (1) the different structures used for age-estimation and (2) our significantly lower sample size of fish smaller than 65 cm FL and younger than 4 years.

Baxter estimating age from growth-rings on scales as opposed to transverse sections of otoliths. Gillanders, in 1999, compared 3 separate methods of aging *Seriola*, scales, otoliths and vertebrae, and concluded that length-at-age for scale-derived lengths is generally lower than estimates from either otoliths or vertebrae, and that scale and otolith readings diverged below age 4 (Gillanders et al. 1999). This divergence might help explain the discrepancies between our young age-estimates and those by Baxter.

Additionally, Gillanders found that no scale-aged fish were classified as year-class one, a very different finding than that of Baxter. This issue of difficulty in classifying early year-classes (1 and 2) in *Seriola spp.* occurs multiple times in the literature, both from greater amberjack (*Seriola dumerili*) from the Gulf of Mexico (Manooch & Potts 1997) and from yellowtail kingfish (*Seriola lalandi*) from New Zealand (McKenzie et al. 2014). In both instances, the authors recommend further work to validate the position of first annual growth zone on *Seriola* otoliths.

Our study made no attempt to determine the annual otolith deposition zones. Gillanders et al. (1999) conducted marginal increment analyses on whole otoliths of fish aged 2–4 years and suggested that one zone is laid down per year in the southern hemisphere winter (August – September), although their data only spanned eight months of the year. Stewart et al. (2004) believed that identification of the first annual zone is still problematic, our findings support this as well and validation of the formation and position of the first growth zone is necessary for any future age-estimations of yellowtail in the SCB. In summary, our findings report a similar overall population age-structure as those from Australia, New Zealand and Baja California. However, there are some differences in length-at-age for young fish (ages 0-3) that still need to be resolved.

Body size effects ∂15N

No consistent spatial or temporal trend explained the variation seen in yellowtail white muscle ∂15N and ∂13C values. Trends in variation were inconsistent even between fish sampled from areas with very different baseline signatures, this result is most likely because of 2 confounding biological factors. (1) Yellowtail are rapid swimmers with the potential for large daily and seasonal movements, as demonstrated by acoustic telemetry in chapter 2 (*Ben-Aderet unpublished data*). (2) The rate at which ∂15N is replaced in yellowtail white muscle tissue, while unquantified, is most likely significantly longer than their residence time in any one location (Madigan et al. 2012; MacNeil et al. 2006).

While I found no significant spatial or temporal differences in white-muscle ∂15N or ∂13C levels, ∂15N does track closely with body-size, meaning that as yellowtail grow they ascend trophically as well. The most ∂15N enriched fish differed by more than 3‰ than their least enriched conspecifics (13‰ vs. 18.34‰ ∂15N), which means they are between one and two empirical trophic levels higher (Post 2002). Interestingly, the upper bound of ∂15N levels seen in SCB yellowtail are consistent with values found in *Seriola lalandi* and *Seriola riviolana* from the East Cape region of the southern Gulf of California by Richert in 2015. Both *Seriola spp.* were the most enriched of any migratory predatory fish sampled in that study (Richert et al. 2015).

The consistent trend of increasing ∂15N with body size potentially indicates an ontogenetic shift in habitat as well as diet. Offshore, pelagic, habitats are generally lower in ∂15N than inshore habitats influenced by seasonal upwelling and other sources of nitrogen (Lajtha & Michener 1994). The lower levels of ∂15N in smaller yellowtail, even those caught inshore, could be a remnant from their time as juveniles in the pelagic environment, especially considering potetially lengthy isotopic turnover rates in muscle tissue.

Size-Mediated Opportunistic Predators

As with the stable isotope results, I did not notice any stong spatial trends in yellowtail diet. Yellowtail are known to feed on a wide variety of species and are best thought of as generalist, opportunistic predators (Baxter 1960). Our analysis confirms this, although several prey species made up the majority of all contents. Pelagic red crabs (*Pleuroncodes planipes*) in particular was widely represented across all areas within the SCB. This is particulary indicative of the time-frame in which I sampled, as summer 2014 through spring 2016 were anomalously warm in the SCB due to strong El Niño conditions. The prescence of *P. planipes* in the SCB is a classic biological indicator of El Niño, as they usually occur significantly further south in more tropical waters, but are advected northwards during El Niño episodes (Lluch-Belda et al. 2005).

Sampling stomach contents from CPFV caught yellowtail presents obstacles to determining spatial trends in diet, in that these fishing operations predominantly use live-bait and live-chum in the form of sardines, anchovies or juvenile mackerel. In an effort to control for the amount of CPFV chum in yellowtail stomachs, I noted the number of fresh, undigested chum species for each sample processed. Another obstacle to CPFV sampling is that schooling yellowtail tend to feed on the same prey, and most CPFV catches come in concentrated events when the vessel encounters actively feeding fish. I rarely sampled more than 10 fish from any one CPFV trip in order to control for the over-representation of some prey items.

Spatial differences provided little explanatory power as to yellowtail diet within different regions of the SCB. However, as with $\partial 15N$ levels, size had a much greater effect. I calculated diet diversity, H, for each fish sampled based on the amount of unique species were present in the stomach. Bigger fish had consistently higher values of H, indicating a more diverse diet as compared with smaller fish. Diet diversity also increased with ∂15N, indicating that as diet diversity increased, so did trophic level.

As the diet of yellowtail broadens, their trophic level increases; this is particulary interesting in the context of ontogenetic habitat shifts. Juvenile yellowtail live and feed primarily in the pelagic environment in close proximity to drifting kelp mats (Uehara et al. 2006). As they age, they begin to move greater distances until transitioning to inshore habitats after reaching maturity (Kasai et al. 2000; Sakakura & Tsukamoto 1998). This transition means the prey assemblage shifts as well, from a low-diversity, low ∂15N, pelagic environment to a high-diversity, inshore, reef or kelp-forest habitat. This increase in prey diversity, as well as trophic level, in the habitat yellowtail occupy as adults is the likely explanation for size-mediated increased in both diet diversity and ∂15N.

Conclusions

Yellowtail diet, trophic position, and growth-rates within the SCB do not spatially vary as much as hypothesized. This is most likely due to their large daily movements as well as their seasonal migratory patterns. The anomalously warm "blob" and El Niño conditions within the SCB during our sampling time-frame also confounded potential regional differences due to changes in prey assemblage as well as the larger volume of yellowtail (potentially southern migrants moving with suitable SST) present in the SCB, indicated by elevated recreational catches during the same time period (Ben-Aderet – chapter 1). While yellowtail throughout the SCB are probably one, homogenous, population, they show consistent ontogenetic variation in diet, trophic position and growth-rate. These factors are not yet fully understood and need further investigation particulary during “average” or non El Niño years, before being taken into account for potential management decisions.

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Chapter 3, in full, is currently being prepared for submission for publication of the material. Ben-Aderet, Noah J.; Johnston, Erin; Cravey, Richard; Sandin, Stuart A. The dissertation author was the primary investigator and author of this material.

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Figures:

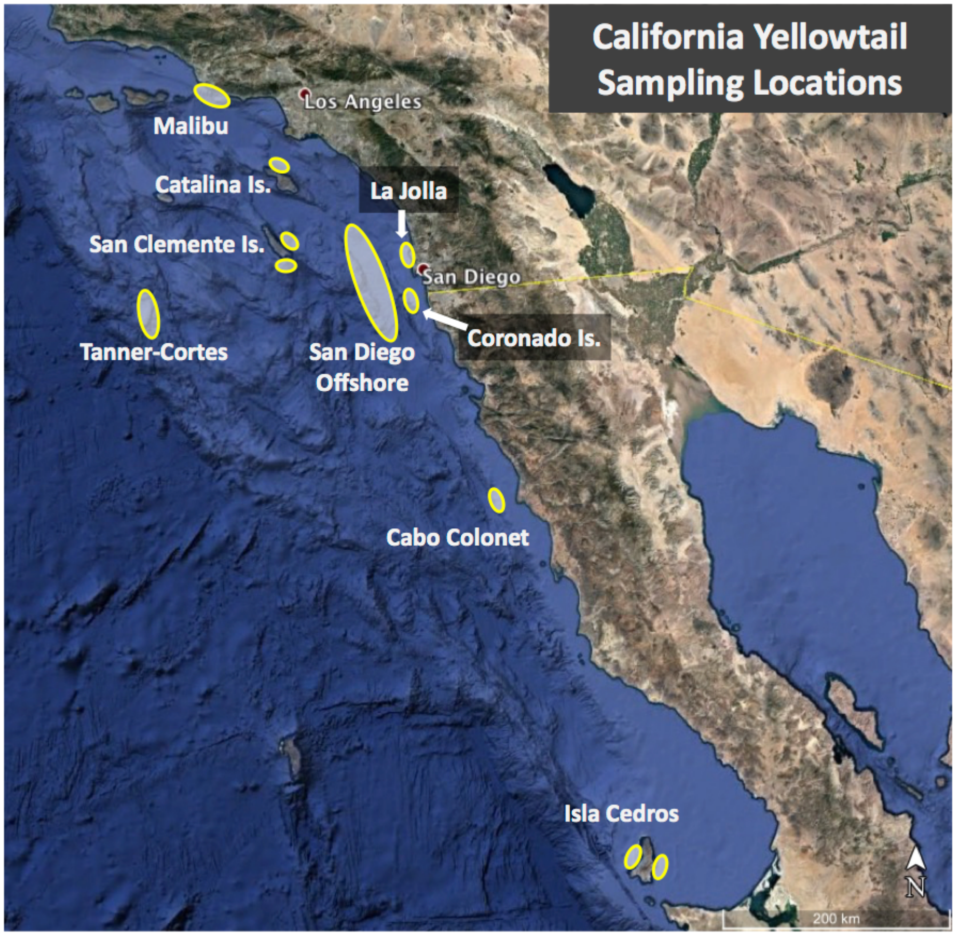

Figure 3-1. Map of the Southern California Bight and northern Baja California coastline with sampling collections outlined in yellow.

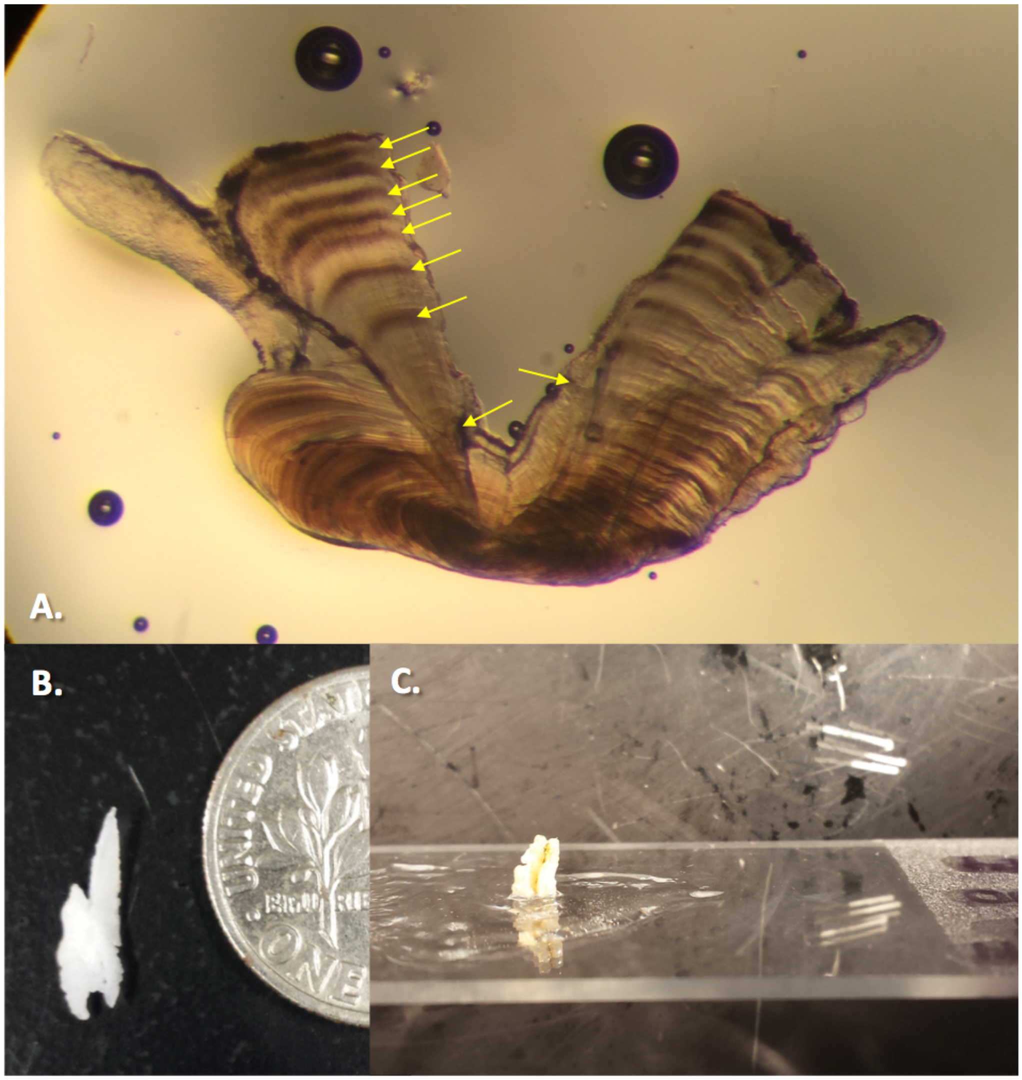

Figure 3-2. (A) Photograph of transverse section of a yellowtail sagittal otolith with annual growth zones marked by yellow arrows. (B) Intact yellowtail sagittal otolith next to a dime for scale. (C) Semi-ground sagittal otolith mounted to a microscope slide (nucleus facing slide) prior to grinding.

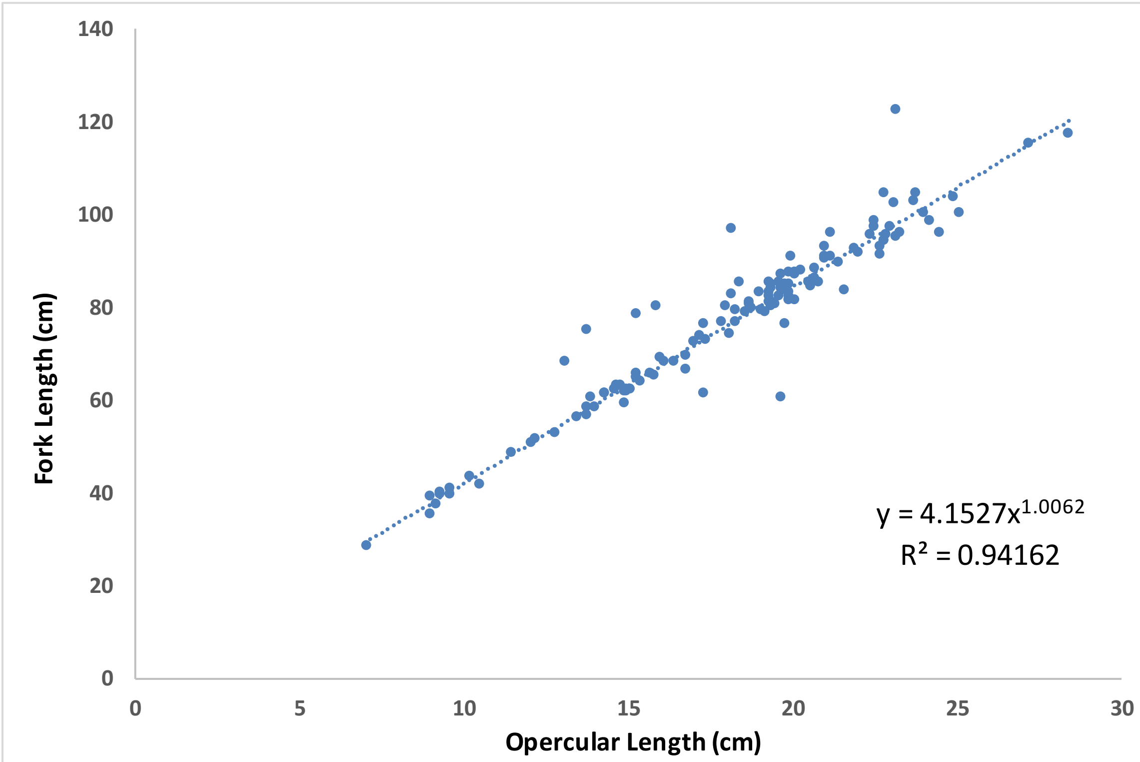

Figure 3-3. Relationship between yellowtail opercular length (OL) and fork length (FL). Conversion equation is listed, x = OL, y = FL. Outliners with highest deviance are presumed OL measurement errors.

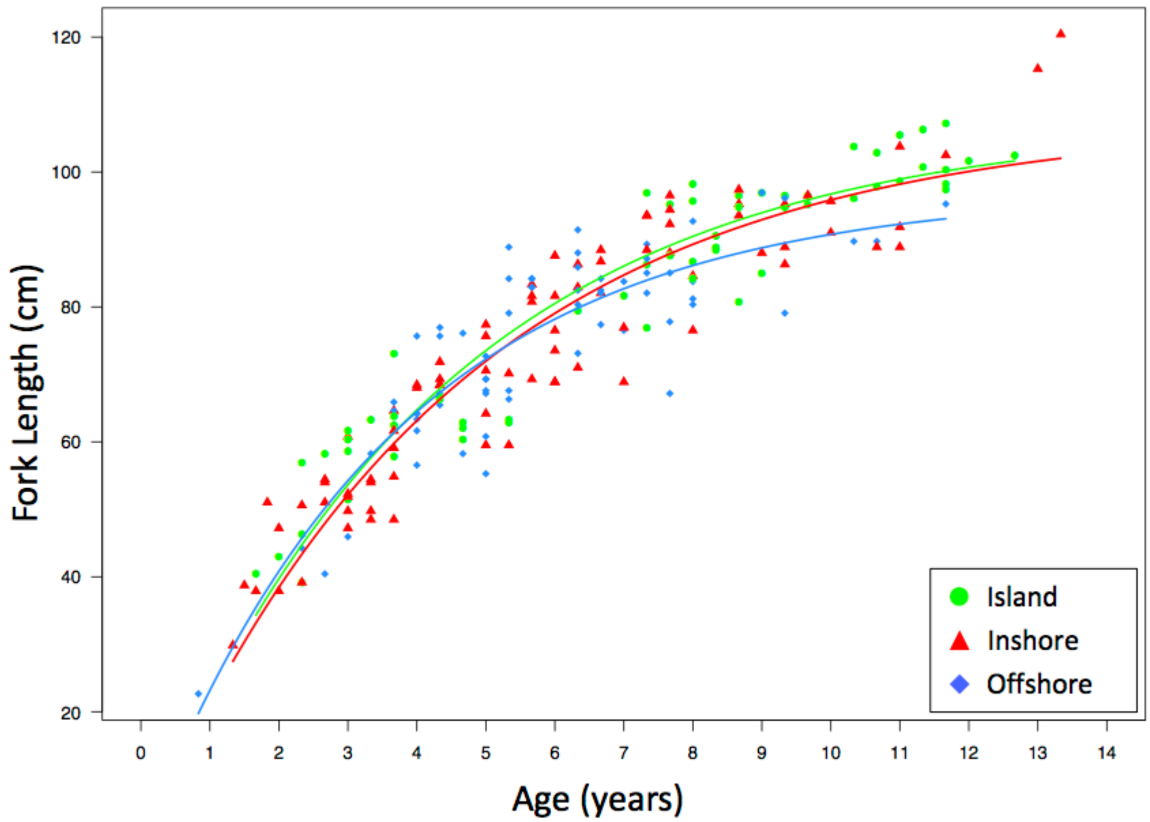

Figure 3-4. Relationship between yellowtail fork length and age. Region-specific growth curves calculated using the von Bertalanffy growth function. Colors denote sampling region.

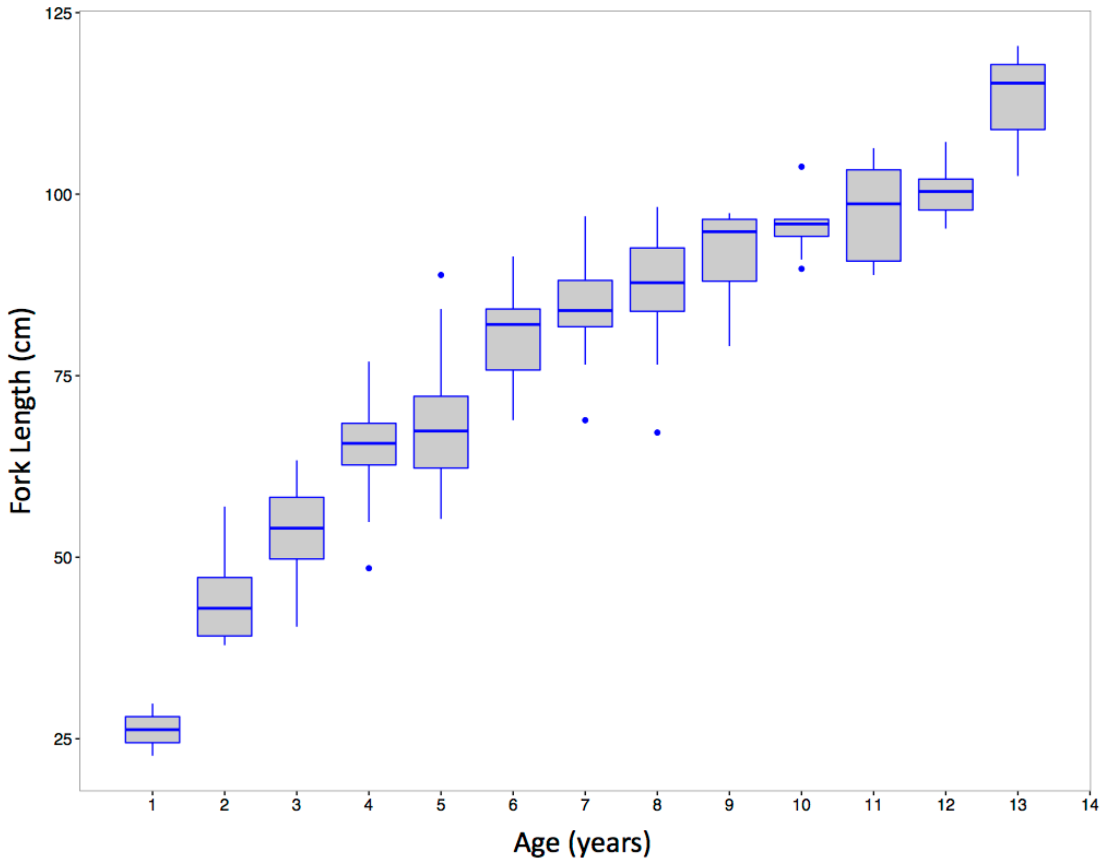

Figure 3-5. Relationship between yellowtail fork length and age for all fish sampled. Blue bars are mean size, boxes denote 95% confidence intervals.

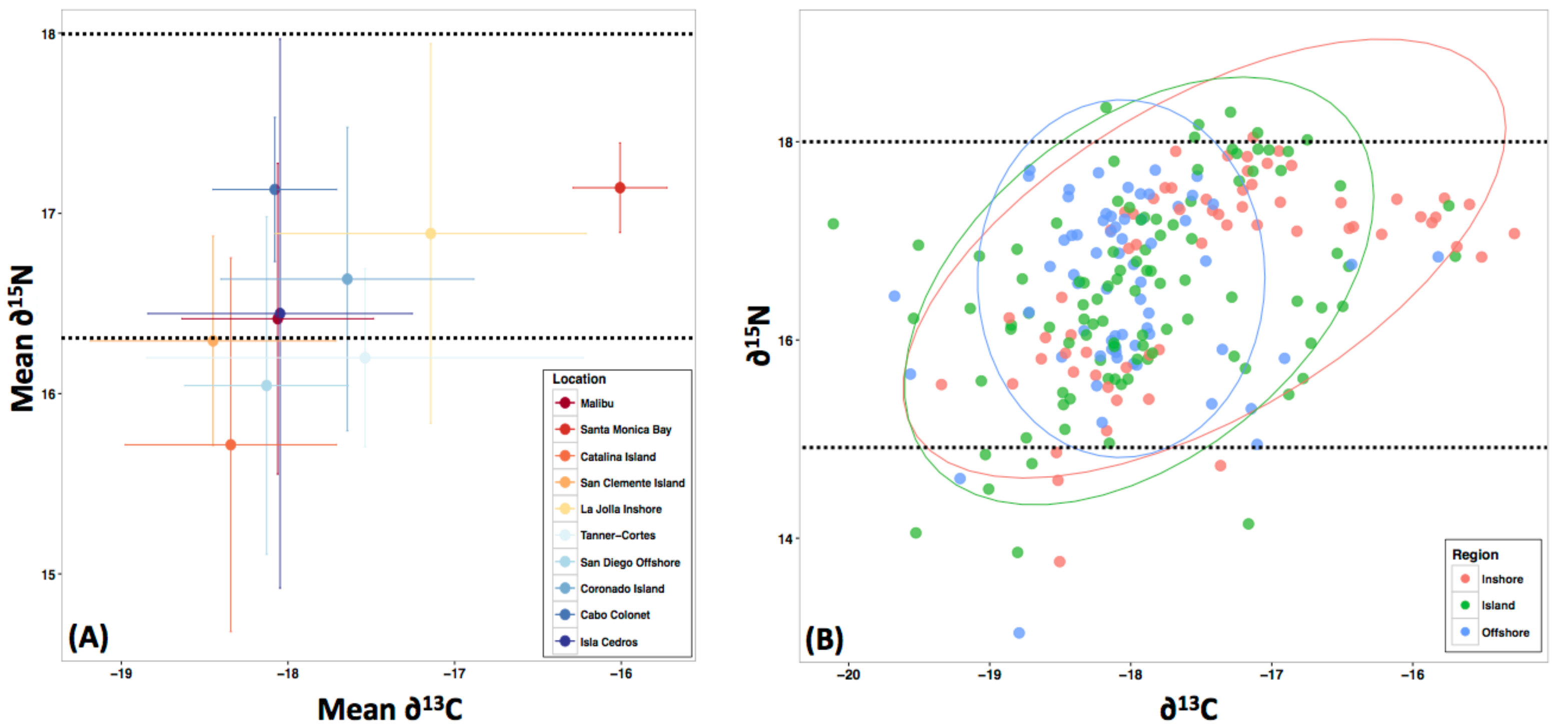

Figure 3-6. (A) Location-specific mean $\partial^{13}C$ and $\partial^{15}N$ values, horizontal and vertical error bars denote carbon and nitrogen isotope standard deviations respectively. (B) All samples plotted by $\partial^{13}C$ and $\partial^{15}N$ values. Ellipses are 95% confidence, color denotes sampling regions, dashed lines signify approximately one trophic step.

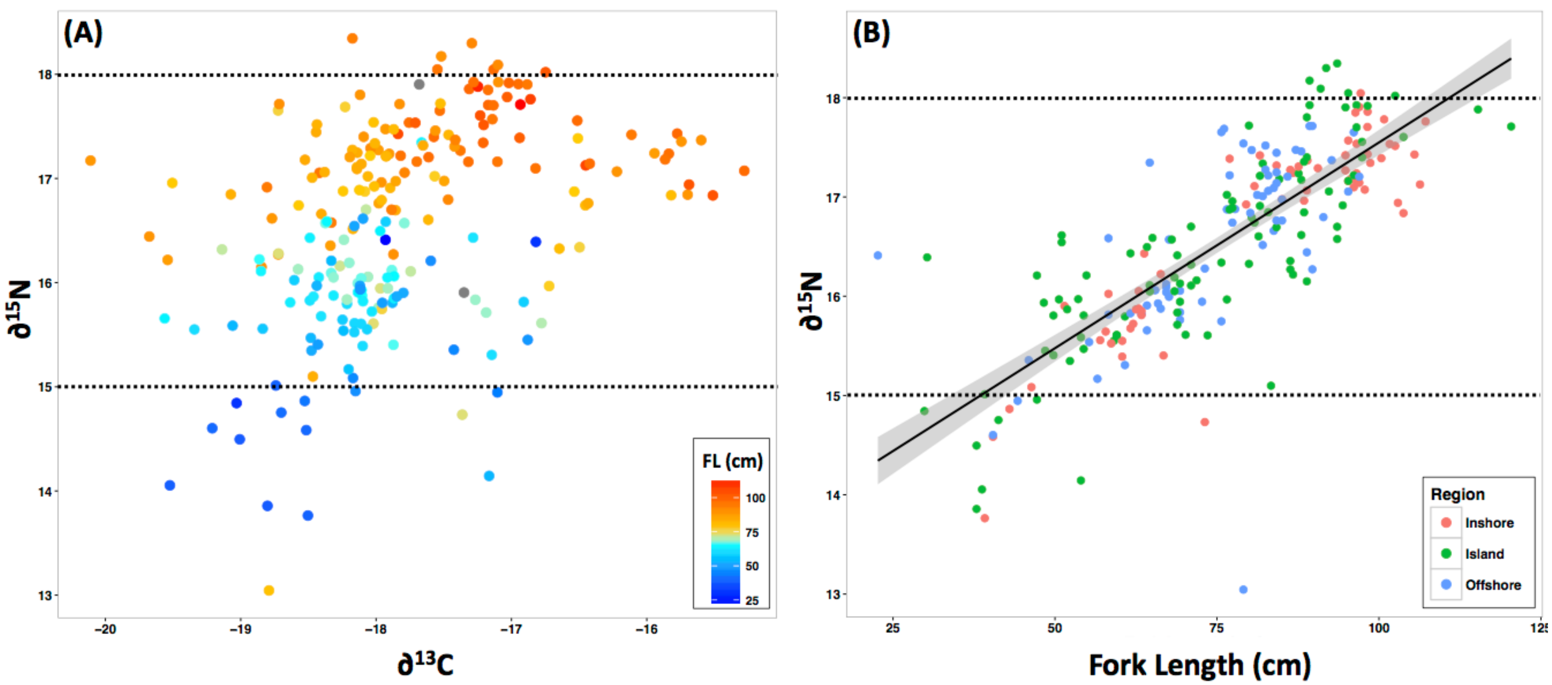

Figure 3-7. (A) $\partial^{13}C$ and $\partial^{15}N$ values for all samples, color-coded by fork-length, dashed lines signify approximately one trophic step. (B) $\partial^{15}N$ values plotted by fork length. Shaded region surrounding regression line is 95% confidence, color denotes sampling regions, dashed lines signify approximately one trophic step.

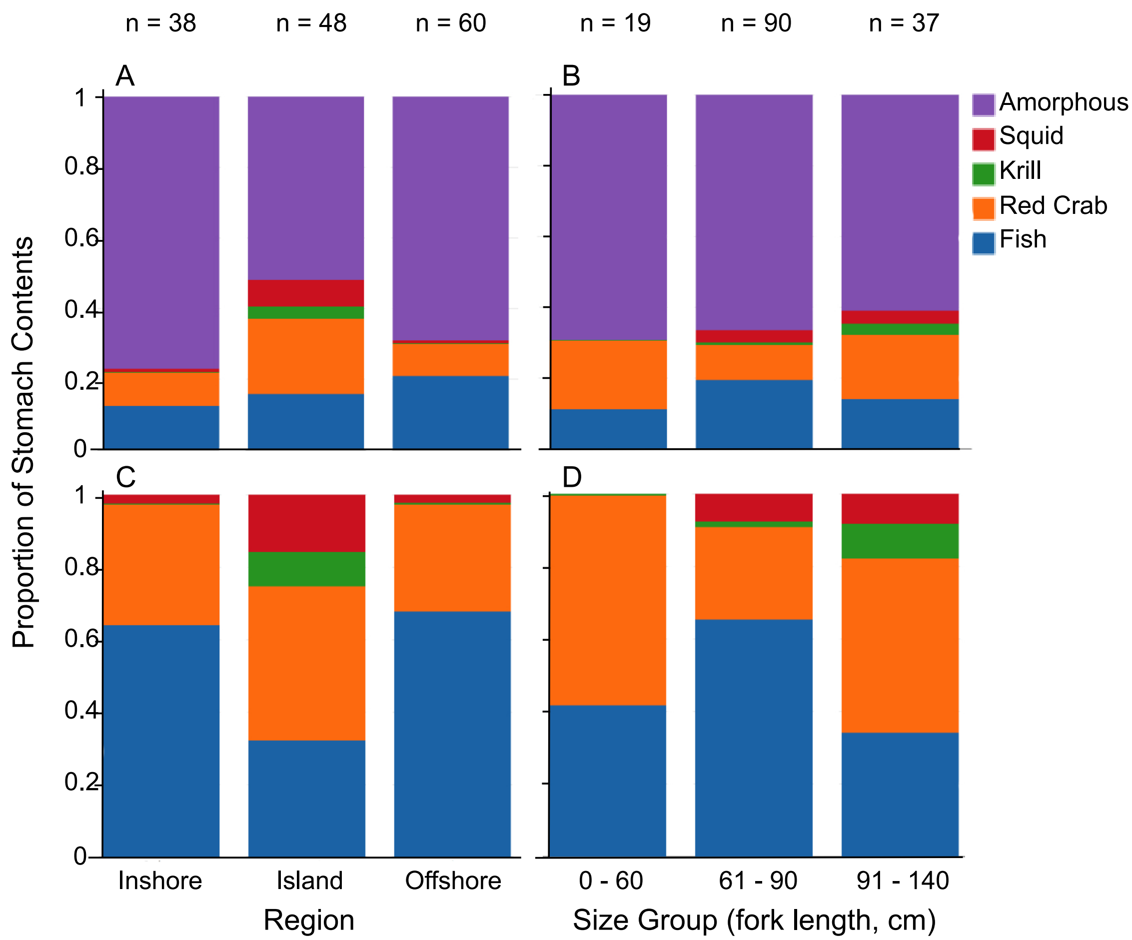

Figure 3-8. Yellowtail stomach contents: proportional (by weight) representation of prey groups. Plots A/B include unidentifiable amorphous digested material, plots C/D are total identifiable stomach contents. Plots A and C are divided by sampling region, B and D are divided by fork length.

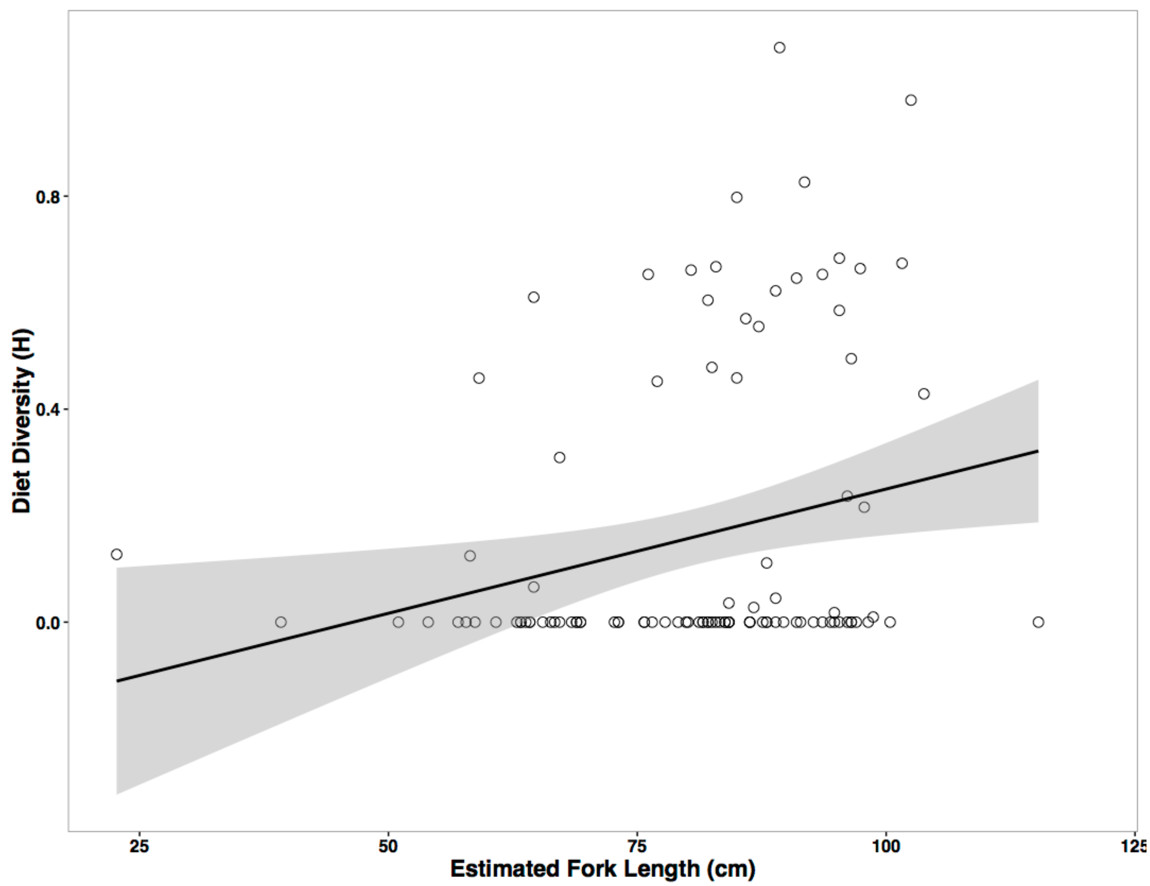

Figure 3-9. Relationship between yellowtail diet diversity (H) and fork length (estimated from opercular length). Shaded area surrounding regression line represents 95% confidence.

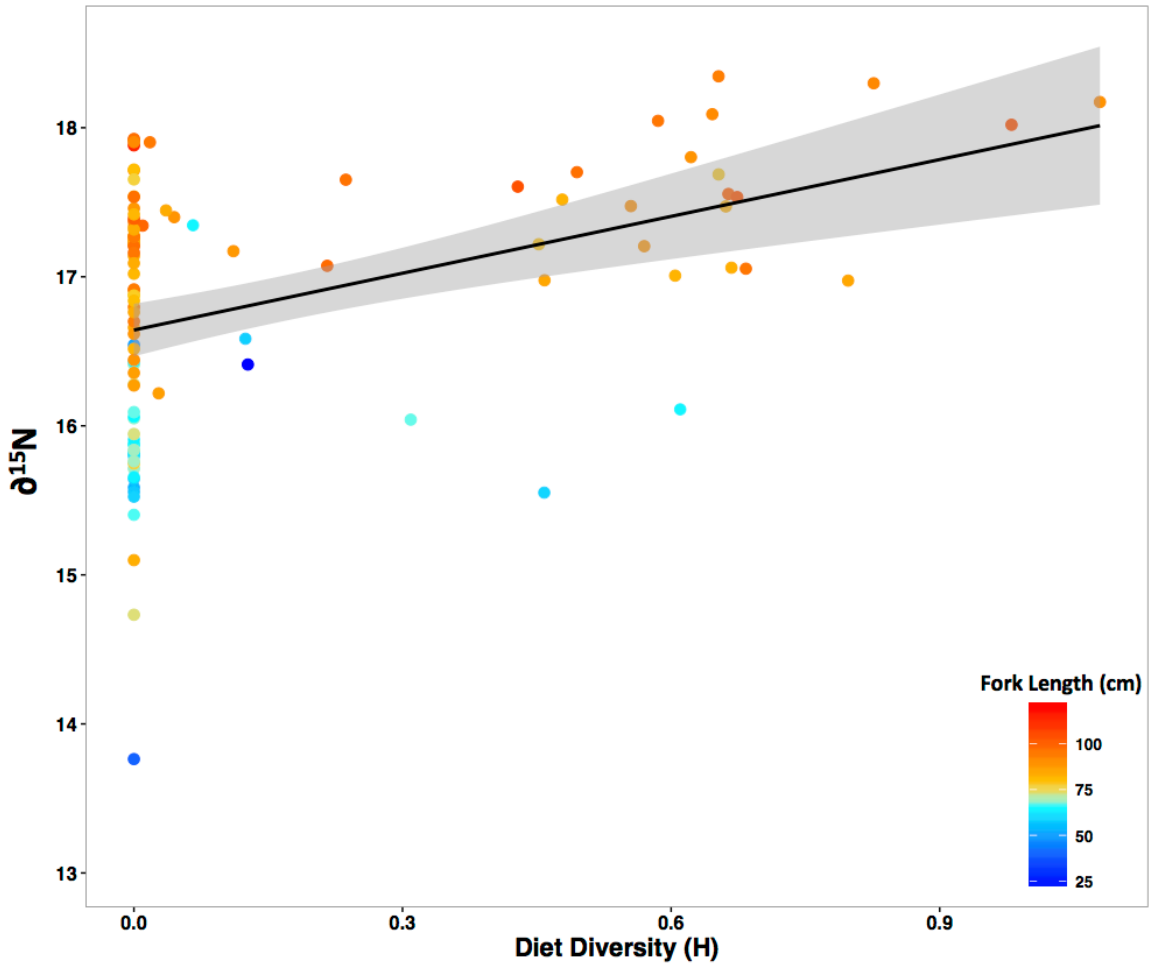

Figure 3-10. Relationship between diet diversity (H) and $\partial^{15}N$. Shaded area surrounding regression line represents 95% confidence.

Tables:

Table 3-1. Number and size distribution of yellowtail collected per location, divided into inshore, offshore and island regions.

Total Sampling Effort and Fish Size Range (estimated FL (cm))					
Sampling Location	Region	N	Min FL (cm)	Max FL (cm)	Mean FL ± SD (cm)
Malibu	Inshore	24	57.8	100.4	71.3 ± 13.9
Santa Monica Bay	Inshore	3	88.9	102.9	95.5 ± 7.1
Catalina Island	Island	6	54.0	84.6	69.5 ± 13.5
San Clemente Island	Island	18	48.5	95.3	78.0 ± 15.7
La Jolla Inshore	Inshore	36	39.2	107.2	87.0 ± 20.0
Tanner-Cortes	Offshore	7	55.3	88.9	72.3 ± 14.1
San Diego Offshore	Offshore	31	22.7	83.8	65.9 ± 13.1
Coronado Island	Island	57	30.3	102.5	71.9 ± 16.5
Cabo Colonet	Offshore	28	58.2	97.0	84.6 ± 7.7
Isla Cedros	Island	17	29.8	120.4	76.0 ± 31.0

Table 3-2. Ages of yellowtail as determined through sagittal otolith annula and associated fork lengths.

Year Class	Sample Size	**Size Range (cm)**		Mean FL (cm)	Std. Error (cm)
		Min. FL	Max. FL		
1	2	22.66	29.84	26.25	± 3.59
2	13	37.89	56.97	44.05	± 1.68
3	21	40.43	63.35	53.64	± 1.27
4	30	48.48	76.95	65.47	± 1.14
5	26	55.28	88.87	68.12	± 1.62
6	24	68.87	91.42	80.30	± 1.31
7	22	68.87	96.96	84.11	± 1.39
8	22	67.17	98.24	87.09	± 1.6
9	17	79.08	97.39	91.90	± 1.45
10	8	89.72	103.78	95.58	± 1.49
11	11	88.87	106.34	97.74	± 2.05
12	7	95.26	107.19	100.37	± 1.48
13	3	102.50	120.41	112.73	± 5.33

Table 3-3. Percent stomach contents made up of the largest 4 prey groups by proportion to overall contents (Fish, Squid, Pelagic Red Crab and Krill). A.) Sampling Location. B.) Sampling Region. C.) Size Grouping

A.

Catch Location	N	Fork Length (min - max (cm))	Median FL (cm)	Std. Deviation (cm)	Mean % Fish	Mean % Squid	Mean % Red Crab	Mean % Krill	Mean % Amorphous Mat.
Malibu	23	57.8 - 100.4	63.8	14.38	13.1	0.0	0.0	0.0	86.9
Catalina Is.	2	54 - 83.3	68.65	20.72	68.5	0.0	0.0	0.0	31.5
San Clemente Is.	17	54.4 - 95.3	86.3	14.31	1.8	21.2	10.9	0.0	66.0
La Jolla Inshore	15	39.2 - 101.6	86.7	23.30	11.5	2.4	24.0	0.3	61.9
Tanner-Cortes	5	67.2 - 93.1	84.2	9.95	48.2	0.0	0.0	0.0	51.8
San Diego Offshore	28	22.7 - 83.8	67.6	12.43	15.1	1.8	8.2	0.0	74.9
Coronado Is.	19	51 - 102.5	91	13.81	22.7	0.0	20.5	8.7	48.1
Cabo Colonet	27	58.2 - 97	84.2	7.80	21.9	0.0	11.8	0.5	65.8
Cedros Is.	10	81.6 - 120.4	96.3	13.10	16.4	0.0	44.8	0.0	38.8

B.

Sampling Region	N	Fork Length (cm) (min - max)	Median FL (cm)	Std. Deviation (cm)	Mean % Fish	Mean % Squid	Mean % Red Crab	Mean % Krill
Inshore	38	39.2 - 101.6	76.3	18.5	64.1%	2.3%	33.3%	0.3%
Island	48	51 - 120.4	88.45	15.4	32.2%	15.7%	42.6%	9.4%
Offshore	60	22.7 - 97	79.1	13.2	67.8%	2.1%	29.5%	0.6%

C.

Size Grouping (cm FL)	N	Fork Length (cm) (min - max)	Median FL (cm)	Std. Deviation (cm)	Mean % Fish	Mean % Squid	Mean % Red Crab	Mean % Krill
1: (≤ 60)	19	22.7 - 60.8	57	10.3	41.7%	0.0%	58.0%	0.3%
2: (61-90)	90	61.6 - 89.7	79.9	9.0	65.4%	7.5%	25.5%	1.5%
3: (> 90)	37	91 - 120.4	96.1	5.9	34.3%	8.2%	48.0%	9.6%

Conclusion

This study aimed to understand and quantify how yellowtail use the Southern California Bight (SCB), how that usage affects their biology and what patterns exist in the recreational fishery that targets them. Three separate chapters dealt with individual aspects of the overarching goal: analysis of long-term recreational catch records, conventional tagging and passive acoustic telemetry as well as spatially-explicit analysis of age, growth, diet and trophic position.

From the perspective of the entire region, the main conclusion is that there is most likely one contiguous population of yellowtail in the SCB, that may be reliant on seasonal influxes of fish from the south to sustain current fishing levels. This is supported by data presented in this thesis as well as by Baxter's (1960) tagging results. Baxter recorded multiple tag returns within the SCB from fish tagged as far south as Punta Eugenia, Baja California. In fact, the majority of his returns occurred north of his central Baja California tagging locations. There was less of a clear directionality to current tag returns from fish tagged within the SCB (Chapter 2), however this could be because the SCB is the northern extent of yellowtail's range. When these fish are in the SCB, they display less of a consistent movement direction and more of a pattern of following prey, searching for productive foraging areas or inshore/offshore transitions due to potential spawning behavior.

The conclusion of one, panmictic, SCB yellowtail population is further supported by results from life-history analysis. There were no significant differences in age/growth, diet, or trophic position between yellowtail from different sampling locations or sampling regions, even when sampling occurred at opposite ends of the SCB (Chapter 3).

Ontogenetic shifts in habitat and diet within one, contiguous, population is most parsimonious explanation for results from each chapter presented in this thesis.

The primary differences across all investigated parameters were all size-mediated. Inshore and offshore catch sizes were different across various sampling waves. Size, rather than tagging season best explained detection rates of acoustically tagged fish, supporting, although not confirming, claims by recreational anglers that large fish caught inshore are year-round residents in the area in which they were captured. Additionally, diet composition as well as trophic position (as inferred from ∂15N) varied across yellowtail body size as opposed to collection region or location. Larger fish consumed a greater number of unique species regardless of spatial distribution. This was further reflected in ∂15N values, as the largest fish sampled were significantly more enriched (and more than one trophic step above) than the smallest fish, even when collected from the same region. The entire suite of size-mediated differences all point towards SCB yellowtail as one homogenous population ranging throughout a variable environment and seasonally targeted across much of their range, albeit with catch concentrated within a small number of areas consistently targeted by recreational anglers.

Implications for Management

The California Department of Fish and Wildlife's 2016-2017 yellowtail regulations read as follows:

"28.37. YELLOWTAIL.

(a) Limit: Ten

(b) Minimum size: Twenty-four inches fork length except that: Five fish less than twenty-four inches fork length may be taken or possessed."

Viewed in the context of the above regulations, the findings of this thesis have clear management implications for SCB yellowtail. The high tag-return rate (21%), the existence of specific catch "hotspots" and ontogenetic trophic and habitat shifts mean that certain size-classes of yellowtail are more vulnerable to concentrated recreational fishing pressure than others.

The elevated tag return rate, particularly that 15% of all returns occur within 100 days of tagging, indicates that seasonal fishing pressure in the SCB is extremely high. While Baxter made a similar claim in his 1960 fisheries bulletin, I think it bears repeating that due to still unknown spawning locations and unquantified recruitment levels, the SCB is probably a net population sink for yellowtail along the west-coast of North America (MacCall 1996, Dotson 2003). Thus, to maintain consistent catches, the population needs to be constantly replenished, most-likely with fish moving north from Mexico (Baxter 1960) where recreational fishing has long been significantly lower than in the U.S. portion of the SCB (although small-scale commercial fishing pressure is on the rise (Young 2001).

The historical pattern of seasonal yellowtail movements and a lack of recreational yellowtail fishing in Baja California has allowed catch-rates to remain relatively stable since Baxter's work. However, if shifting patterns seen during the 2015 El Niño, as well as previous ENSO events are any guide to the future, warming seas could force yellowtail to move further north. This will put yellowtail in year-round range of SCB anglers and negates the "seasonal refuge" provided by wintering off central Baja. To further complicate things, this scenario does not account for ongoing population growth and associated rises in fishing pressure in Baja California (Young 2001). However, forecasting future effects on SCB yellowtail movements and populations is next to impossible without designated tagging programs and more comprehensive research. Due to their trans-national migrations, however, any large-scale tagging requires cooperation as well as support from Mexican fisheries officials and researchers.

With the past several years markedly warmer than average (NOAA – NCEI) and mean sea-surface temperatures in the SCB projected to increase due to global climate change (Sydeman et al. 2014), yellowtail spawning in the outer SCB will likely increase (see chapter 1, length-frequency bubble-plot). While potentially good for overall recruitment, spawning aggregations are notoriously easy to over-exploit (Erisman et al. 2011) and thus should be either monitored or preemptively managed.

Based on these results, size and season-based management strategies will prove much more effective than spatial strategies at maintaining the sustainability of the recreational fishery for yellowtail. It is clear from the extent of their daily movements (as recorded through passive acoustic telemetry), that all existing marine reserves within the SCB are significantly too small to be effective yellowtail management tools. However, adjustments to existing regulations could greatly benefit yellowtail during periods of highest vulnerability. For example, simply adapting regulations seasonally to relieve pressure on large, drift-kelp associated fish could improve spawning success within the SCB. Additionally, instituting a slot-limit or increasing minimum size limits could prevent CPFV's and private vessels from over-exploiting sub-reproductive juveniles, which are particularly vulnerable due to their associations with drifting kelp-mats.

While yellowtail catch has been relatively consistent, albeit cyclically varying throughout most of the last century (Dotson & Charter 2003), it is important to account for estimated historical abundance levels (Dayton & MacCall 1992) in addition to current catches and future environmental variability when considering management strategies. Yellowtail have long been southern California's most iconic and sought-after inshore gamefish, a status that carries certain advantages. The southern California recreational angling community is currently undergoing a shift in attitude from simply fishing for food to one more amenable to catch-and-release and fishing for sport (through organizations such as the Coastal Angler Tagging Cooperative). Angler enthusiasm is a powerful force for bottom-up management and one that could easily be leveraged to maintain sustainable levels of yellowtail exploitation throughout the SCB.

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