COP Format for Project Final Report

I. Post-settlement Life History of Key Coral Reef Fishes in a Hawaiian Marine Protected Area Network; Phase II (Yr 7)

By: Dr. James D. Parrish (P.I.) & Jeremy T. Claisse (co-P.I.)
Hawaii Cooperative Fishery Research Unit/ UH Dept. of Zoology.
Grant Number: NA03 NOS4260044 HCRI 6
31 January 2006

II. Abstract

This project initiated investigations of the life history and species biology of fishes important in the commercially valuable and growing ornamental fish industry in Hawaii. Recent regulation of aquarium fishing by establishing protected reef areas and legislative oversight of the fishery have made it imperative to obtain such information, beginning with young fish at early stages after settling into the demersal reef habitat. The research includes studying the extent of movements over the bottom, description of the bottom habitat, and study of its effects on size and location of aquarium fish populations. Appropriate methods have been applied for the first time to estimate age of fish and relate age to size and growth rate in the habitat. The ageing work relates to studies of size and age when young fish become reproductive, and to studying reproductive seasonality. Substantial progress has been made in all these areas. This knowledge of the biology and ecology of the key species, as related to their habitat associations, is leading toward assessment of the effects of habitat management and thereby to the selection of the appropriate type and level of habitat management to maintain aquarium fish populations.

III. Executive Summary

Much concern has been expressed about actual or potential overfishing of ornamental reef fish species (primarily small acanthurids) in Hawaii. This valuable fishery is heavily concentrated on the west coast of Hawaii Island. In 1999, the Hawaii legislature approved a series of Fishery Replenishment Areas (FRAs) along this Kona Coast, from which aquarium fish may not be collected. These FRAs, a specific form of Marine Protected Area (MPA), are currently being evaluated for their effectiveness in protecting and enhancing stocks of aquarium species. An important aspect of such an evaluation is the life history and species biology of the particular species harvested. In the case of the West Hawaii acanthurids, very little is known in these subject areas. This project initiated the first serious studies of this biology relevant to management of this fishery.

Studies were done at several sites among the FRAs and other protected areas of West Hawaii, with emphasis on Ke'ei, Kealakekua, Keauhou, Wawaloli and Wawaloli Beach (Map 1). Species studied were the yellow tang (*Zebrasoma flavescens*), which provides ~80% of the aquarium catch in West Hawaii; the kole (*Ctenochaetus strigosus*), which is a less important target species; and the brown surgeonfish (*Acanthurus nigrofuscus*), which is not targeted (used as a "control" species in this study).

Collections at all the sites gave some first indications of size range and frequencies of the species and provided specimens to establish plausible length versus weight relationships and relationships between standard length (SL) and total length (TL). Size at first reproduction (SFR) was estimated for yellow tang (140 mm TL for females, 160 mm TL for males). Specimens were collected to make estimates for the other two species and rough estimates were made, however further collections would be necessary to provide an accurate estimate of SFR for these species.

First estimates of ages over a range of sizes have been made for yellow tang and kole, and are yet to be validated based on live specimens with otoliths chemically marked. These initial readings of otoliths suggest considerable longevity (up to ~35 years for yellow tang). The results may also suggest that a major target species has greater longevity in areas protected from collection: further sampling and otolith processing will be necessary to confirm this.

Intensive underwater observations, over much of a year, of newly settled focal species, supplemented by tagging older juveniles and adults for individual identification, gave evidence of seasonality in settling from the plankton (more in summer, especially June and July), with peak settlement activity observed on two successive full moons. Locations of settlement were monitored using transects at several depths on the reef profile. Small and medium size yellow tang occurred mostly on the reef slope (~13 - 20 m deep), and the largest individuals occurred in shallower depths (~8 m). Yellow tang females appear to make the transition to shallower daytime habitat usage at ~140 mm TL, and males at ~165 mm TL. For females, this appears to happen at the onset of sexual maturity. For males, sexual maturity may be reached slightly before the transition, but data are inconclusive at this time. Yellow tang and brown surgeonfish seem to have an inverse relationship of numerical distribution on the reef profile. Individual yellow tang settlers and small-medium juveniles could be identified and observed for weeks or months in the same very small bottom habitat areas (often within a very few meters), implying high fidelity to specific, small home ranges at those life stages. Repeated observations of individually tagged juvenile yellow tang at three sites indicated that ~30% of individuals disappeared from the specific site over a period of 5 months. This result provides the first estimate of mortality/loss for this species over a given size range. A great deal of information on the particular bottom habitat that these species use was collected by making measurements of substrate rugosity and analyzing photoquadrats to assess the type of substrate and other habitat characteristics.

The results of these studies are providing information essential for any assessment of these exploited aquarium stocks, and will contribute much to understanding how FRAs and other reserves function, assessing their value, and improving the selection/design of such reserves.

IV. Purpose

A. Problems or impediments: None.

B. Objectives:

The long-term goal of this project is to gain a more complete understanding of post-settlement processes for important demersal fish species that are key to the reef ecosystem in the coastal waters of West Hawaii. What is learned about life history and species biology there, will be broadly applicable throughout Hawaiian reefs. This greatly increases the ability of resource managers to effectively manage the coral reef resources in their custody in these waters by contributing to the knowledge of life history and population structure of key species and their post-recruitment processes in ways that can be expected to lead to understanding how MPAs function and to enhance the design of ecologically effective MPAs.

We are investigating the following primary research questions:

1) How much immigration/emigration is occurring with fish that have been assumed to be site specific? How does this level of movement change with age and habitat?

For yellow tang it has long been suggested that newly settled juveniles maintain specific home sites and then begin to move progressively farther away from these sites as they grow. However, no study had been performed in which individuals were identified and tracked to test these observations rigorously. One of our objectives was to quantify levels of immigration to and emigration from specific initial home sites, so that meaningful estimates of mortality can be established. For groups in a cohort of a species that remain sufficiently aggregated, natural mortality estimates may be feasible based on identifiable individuals of known age, and may be useful for comparison with mortality estimates for fisheries in the subsequent exploited life stage.

2) What specific habitats are used by the juveniles and sub-adults of these species? How does the presence/absence of this habitat affect population abundance and/or recruitment level?

As part of the post-settlement movement work, we map the distribution of surviving individuals and details of the habitats where they occur. Results may permit making quantitative statistical associations with habitat characteristics (as done by the P.I. in previous research elsewhere) that would lead to predicting distribution of post-settlement juveniles based on habitat characteristics This should provide an understanding of habitat usage on these reefs at a finer scale.

3) What is the relationship between body size and age? How does growth rate change with age? What is the age structure of the populations of these species? How do exploitation and protection affect population age structure?

We are developing an understanding of the relationship of size with age (thus determining growth rates), and estimating the lifespan and the age structure for selected focal species along the Kona Coast. A previous study used counts of daily rings on otoliths to estimate time spent in the plankton before settlement and for some time thereafter. We are finding what we believe to be annual rings in specimens of all three focal species. This permits estimates of distinctive growth rates for these species. This information is vital to the mortality/survivorship study, so that sizes of fish seen in the field can be translated to estimated ages, and age estimates of a representative collection can be used to estimate the age frequency structure of the population as a whole.

4) What is the normal reproductive lifespan and seasonality of spawning? At what size in each sex is sexual maturity achieved?

Using existing sources of field results and review of literature from previous reproductive work done on these species in Hawaii, and our own collections and analysis of gonads for maturity and frequency of reproduction, we are defining the reproductive season(s) and determining the size/age when reproduction begins for each sex of each focal species.

V. Approach

A. Methods

RESEARCH SITES

Research in the project was concentrated at 5 sites along the Kona coast (Map 1). The sites were chosen to represent a range of protection histories to provide for possible assessment of effects of protective status on the species biology. These sites are currently being monitored regularly by the Hawaii Division of Aquatic Resources (HDAR) following up the West Hawaii Aquarium Project (WHAP), so data on fish abundance collected by HDAR and WHAP over the last 7 years – and possibly in the future – can be used with our data. We also used the WHAP numbering system for our sites.
The sites, WHAP numbers, and histories of protection are:

(9) Wawaloli Beach
    – No protection (open), experiences heavy collection
(10) Wawaloli FMA
    - FMA since 1991
(15) Keauhou FRA
    - FRA since 2000, but heavily collected before this designation

(19) Kealakekua MLCD
- No take since 1969

(20) Ke'ei FRA
- FRA since 2000, but heavily collected before this designation

FISH COLLECTIONS

Fish were collected using spears to obtain anatomical data at intervals over much of the life of the study, i.e. in Nov 03, Feb 04, Apr 04, Jun 04, and Aug 04, Feb 05 and Apr 05. This schedule provided a range of seasons to examine seasonal effects such as reproductive timing, and a period of time long enough to contribute to validating otolith readings for age. In 2004 a range of sizes was collected in a haphazard manner to represent the overall range of sizes within the population. In Feb 04 collections were made to examine the perceived/assumed ontogenic shift in habitat use by yellow tang. Previous work by Dr. William J. Walsh (HDAR) and our own observations and tagging work in 2004 led us to believe that, as yellow tang grow, they make a shift in daytime habitat use from stable, fixed, small home sites in deeper (8 – 40 m) reef areas to roving schools of larger individuals that spend the day feeding in shallow (1 – 8 m) reef flat areas. Therefore, we did a set of collections at Ke’ei (Site # 20) (referred to hereafter as “split collections”) in which we collected 30 individuals from the deeper reef areas and 30 individuals from the shallow reef flat schools. In Apr 04, collections were made from shallow reef flat schools at 3 sites (#9 Wawaloli beach, #10 Wawaloli, #19 Kealakekua).

Collected fish were placed on ice and transported back to the lab, where they were measured and weighed. In 2004 some were dissected then, others were frozen and then thawed ~2 weeks later. In 2005 all fish gonads were dissected out, weighed to the nearest 0.001g, and preserved in a solution of:
600 ml distilled water
300 ml 95% ethanol
100 ml 37% formaldehyde
20 ml glacial acetic acid,
before the rest of the body was frozen. Later, fish were thawed, and otoliths (for estimating age and growth), were removed, rinsed with fresh water, stored dry, and later weighed to the nearest 0.1 mg. If they had not already been removed, gonads (for reproductive studies) were then dissected out, preserved in the solution described above, and later weighed to the nearest 0.001 g. Results were calculated using weights of fresh gonads if available; otherwise sets of preserved gonads were used. For each gonad collected, the gonadosomatic index (GSI) was calculated. This is the gonad weight as a percentage of the somatic body weight [i.e. 100 x Gonad wt/(body wt-gonad wt)]. Guts and tissue samples for DNA analysis were also provided to collaborative projects.

To date, combined specimens collected for HCRI Year 6 and Year 7 include 412 yellow tang, 205 kole, and 186 brown surgeonfish.

AGE ESTIMATION – OTOLITH PROCESSING & READING

A large subsample of fish collected was selected to be processed initially because of the time demands associated with otolith processing. All otolith samples collected will be processed and read when time allows. One sagitta (the largest of the three paired otoliths) from each fish was randomly chosen to be processed and read. The otolith was mounted on a clear glass slide using thermoplastic cement Crystalbond^{TM} on the slide edge, and then ground down to the nucleus using No. 1000 grit abrasive paper on a modified rock polisher grinding wheel. The otolith was then mounted at the center of a new slide with the polished side toward the glass, and the opposite side was ground down to the nucleus, leaving a thin section of the otolith through the nucleus. This side was then covered with Crystalbond^{TM} cement to improve the optical quality of the section.

Otolith sections were then read under a dissecting microscope using transmitted light. Each section was read 3 times, never on the same day, for bands that we believe to be annuli, but still remain to be validated. If two of the three readings were the same, that number was kept as the age. If all three readings were different, they were read a fourth time. If no consistent age could be determined, the otolith was excluded from age analysis. The validation process, when complete, could cause a change in interpretation such that the age of all bands could shift as a group by ~1 year (older or younger). It is therefore highly likely that all otoliths will be re-read after validation is complete.

FIXED TRANSECTS

Fixed transect surveys were intended primarily to provide an overall idea of population densities and size ranges of the 3 focal aquarium fish species, associated species and predators, on the vertical reef profile from reef flat down to the sand or rubble interface at ~25 m depth. An important objective was to identify where on the reef profile these fish settle and what aspects of the reef structure, in terms of vertical profile and reef surface habitat, are used by these fish at all sizes. This study includes potential partitioning of habitat by size classes and among competitors.

To reveal whether settlers of the focal species prefer to settle to specific microhabitats along the profile of the reef, and how microhabitat and interactions among species may affect the subsequent distribution of both settlers and adults, a set of semi-permanent transects was installed at Wawaloli FMA and along the reef at Ke'ei in Jun 04. Each set of transects consists of a number of 15-m long x 2-m wide belt transects running ~parallel to the shore, with ends of all transects aligned, and transects spaced 10 m apart along the vertical profile of the reef from the reef flat to the sandy interface at a depth of ~25 m (Fig. 1). The total number of transects is dependent upon the total length of the reef profile; hence the Wawaloli FMA currently has 10 such transects, while Ke'ei, with a greater length of reef profile, has 12 transects. This layout of the transects was designed using preliminary data and observations compiled over the previous 6 months, and was based on the feasibility of performing accurate surveys of the composition of the benthic flora and fauna as well as the census of the focal species in the area (with 2 divers on a single dive).

Our previous reconnaissance, as well as work by Walsh (1984) and HDAR (unpublished data) led to distinguishing six classes for the focal species. Yellow tang settlers were divided into three categories based on both size and morphology:

1. Small: morphologically different from older stages, translucent pale yellow color and vertically extended body and fins, total length ~30 mm TL
2. Medium: looks like miniature adult, total length 30-40 mm TL
3. Large: looks like miniature adult, total length 40-50 mm TL.

Settlers of the other focal species were divided into three categories based on size only: Small 20-30 mm TL, medium 30-40 mm TL, and large 40-50 mm TL.
Juveniles and adults of other species were divided into three size classes: 50-100 mm TL, 100-150 mm TL and >150 mm TL. Observers did extensive underwater training before the surveys began to learn to place fish visually into these classes.

In addition to the three focal species, piscivorous fishes and other herbivorous species that were seen commonly interacting with the focal species were censused on each of the transects. Examples of additional fish species censused include *Cephalopholis argus, Caranx melampygus,* and *Stegastes fasciolatus*. These species were not placed in specific size classes. Because *Chaetodon multicinctus* settlers were observed interacting with the settlers of the focal species, we counted the number of settlers for this species separately. Each transect at Wawaloli was surveyed weekly from 11 Jun 04 to 20 Aug 04, twice in Oct 04, once in Dec 04, and weekly from 19 May 05 to 9 Aug 05. Each transect at Ke'ei was surveyed weekly from 17 Jun 04 to 19 Aug 04, then twice in Oct 04, once in Dec 04 and weekly from 22 May 05 to 19 Jul 05. Sampling was done on a more intensive weekly schedule during the summer period when most settlement occurs.

In an effort to minimize disturbance to the fish during the survey period, semi-permanent floats with markers were placed at the ends of each transect before the survey period began in Jun 04 and will remain until the study is over. This eliminated the need to lay out a new transect line each time the survey was performed, a process that could alter the counts. Both markers were easily visible to the divers, allowing for a consistent orientation to the direction of the reef tract and a fixed depth on the reef profile. Since the settlers tend to spend most of the time in close proximity to the substrate, two passes are made on each of the transects. During the first pass, the diver stays approximately 3 m above the substrate and surveys for all species and size classes except settlers. A second pass at ~1 m above the substrate is then immediately completed by the same diver to identify and count the settlers of the focal species. If needed, extra time is taken on the second pass so that the diver is confident of the counts. Practice counts were made before the actual surveys began, and no effect was seen of the first pass on the number of settlers counted in the second pass.

To determine the percent cover and species composition of the coral and algae present in each of the transects, digital photoquadrats (with the camera 75 cm off the bottom and an image area of ~60 cm x 40 cm) were taken at 1-m intervals along the transect using a digital Olympus C-5050. A transparent plexiglass support rod was attached to the camera housing and allowed the photographers to maintain a consistent distance between the substrate and camera. To facilitate analysis of the photos, the camera was set to the highest resolution possible and white balanced at the beginning of each transect to account for variations in levels of irradiance. It should be noted that the time of day photos are taken should be considered, as it will affect the amount of shadows in the pictures and therefore the quality of identifications.

Once in the lab, all photos were downloaded onto a computer and analyzed for benthic composition using *Coral Point Count with Excel extensions* (CPCe). CPCe software allows for random generation of any desired number of points within a picture. The program scrolls though the points allowing the user to assign the substrate under each point to a specified taxonomic or physical category. This particular study adopted the "taxonomic" categories (referred to as coral code in CPCe) used by West Hawaii’s HDAR office. The coral code is written in a text document, and then loaded into the CPCe program prior to starting the photo analysis. The portion of each picture to be analyzed is adjustable, as well as the distribution of the points throughout the picture. Methods employed in these quadrats corresponded to techniques implemented by the HDAR office: a simple random distribution of 20 points was overlaid on the entire picture. A circle with a crosshair was used for the data point shape, and the category for each point was determined by identifying the substrate or taxon that occupied the majority of the circle. In the absence of a distinguishable coral, algal, or invertebrate species, the substrate was defined as turf/bare, which could then be further specified as turf/bare on rubble, or skeletons of various coral species. Octocorals and coralline algae were also classified according to the substrate where they grew, whether pavement, rubble, or a specific coral skeleton. Algae were identified to genus when possible, but most often were grouped into divisions, e.g. rhodophyta, chlorophyta.

TAGGING YELLOW TANG

In order to monitor the settlement, growth, movement and survival of yellow tang settlers, juveniles, and adults, individuals were collected, measured, and tagged for identification. This permitted divers to identify individual fish under water over long periods of time and have confidence that successive observations were indeed made on the same individuals.

All fish were collected, measured and tagged under water with the aid of scuba equipment. To collect fish in the least stressful and most efficient way, we interviewed aquarium fishermen from the Kona Coast and adapted their techniques to meet the needs of this project. Details of technique for tagging and maintaining the selected individuals benefited from experience in tagging small fish with elastomer in previous Unit research. Yellow tang ranging from 31 mm to 157 mm TL were captured using a 3-m x 20-m barrier net with 0.5-in. mesh. Two divers using 1-m “tickle sticks” gradually herded groups of yellow tang into the barrier net. Once blocked by the barrier net, fish were taken with small, 0.5-in. mesh hand nets, and then transferred to a submerged holding pen. The holding pen was constructed by fastening the open ends of two plastic laundry baskets together. A hole was cut in the bottom of one of the baskets and a spring-loaded door was attached. Floats were attached to the baskets to make the holding pen buoyant, while a 1-m line with a 3-lb. weight was connected to the bottom basket to hold the pen in place.

Once all the fish were transferred to the holding pen, the divers stowed the barrier net and began the tagging process. Fish were removed from the holding pen individually, total and standard length were measured, they were injected with a unique combination of elastomer colors and body locations, and released. The elastomer is a proprietary product of Northwest Marine Technology, Inc. It was mixed and injected according to instructions provided by the manufacturer. We have currently used three colors of elastomer that are commercially available to successfully tag yellow tang at 12 different locations on the body. Each fish has at least two tags, to allow for identification in the event that one of the tags fades or is rejected by the fish's tissue (which so far seems to occur very infrequently). Tag size has ranged from 5 mm to 20 mm, depending upon the size of the fish.

Tagging began in early Jul 04, and has continued as recently as Jul 05. Thus far, ~100 yellow tang individuals have been tagged at the Ke'ei site, ~65 at the Wawaloli FMA, and ~80 at the Keauhou site. For juvenile tagged fish, surveys have been performed weekly for the first month after tagging and then once every 2 months. Most of the tagged fish used habitat in and around the semi-permanent transects at each site. A code was therefore created which allowed the divers to document where, within the grid created by the transect markers, a particular fish was located during the survey. This subsequently became an efficient way of measuring home site fidelity and estimating home range over long periods of time (>1yr), however these data have not yet been analyzed.

During early August 2004, we began recapturing tagged fish at both Ke'ei and Wawaloli and have continued at all three tagging sites since then. Fish were recaptured using the barrier net and techniques described above. They were then remeasured to determine growth, and when necessary, the tags were augmented with fresh elastomer to prevent fading. To date, a total of 16 juveniles and 8 settlers have been remeasured.

HOME RANGE ESTIMATION

Estimates of home ranges for yellow tang were made by concentrating on a particular fish and observing its behavior quietly over a period of time. For juvenile/adult fish, only individuals that had previously been tagged with an individually identifiable elastomer code were selected. New settlers, too small to tag, could be identified readily as such by size and appearance because all individuals selected were relatively solitary and were found at each search event in exactly the same location, apart from other fish.

Some settlers had distinguishable fin clips as well, which ensured continual tracking of the same fish throughout the entire allotted observation period.

Juveniles:

When a tagged individual was found, its size was visually estimated and recorded and a colored marker (a nail tied with survey tape) was placed at the initial location. As the fish was observed subsequently, additional colored markers were placed at new peripheral positions where the fish was observed. At the end of the observation period, the two longest perpendicular distances across the area used were measured.

In order to establish the amount of observation time necessary to accurately determine the size of a settler's habitat, 9 fish were observed over a period of two dives for 30-45 minutes total. These fish were observed for 5-minute intervals (with more than 5 minutes between observation periods) over the course of two dives. At the end of each 5-minute observation period, the home sites were measured. The size of the home range did not increase after 25 minutes of total observation time for any of the 9 individuals, and for most individuals, the size had stopped increasing after 15 minutes of total observation time. Thereafter, all fish were observed for 25 minutes total over the course of 2 dives. The same protocol was also used for settlers.

Settlers:

When a solitary new settler was found, its size was visually estimated and recorded and a colored marker (a nail tied with survey tape) was placed at the initial location. As the fish was observed subsequently, additional colored markers were placed at new peripheral positions where the fish was observed. At the end of each observation period, the two longest perpendicular distances across the area used were measured, with care taken to avoid underestimates of home range.

Untagged juvenile/adult fish

The presence of two yellow tang with natural, distinctive marks that made them identifiable provided the opportunity to check on whether the tagging process had an effect on home range size. We followed these two individuals, which were not tagged with elastomer, using much the same protocol as above. Each fish was followed for two observation periods a week apart.

B. Project Management

The organization responsible for performance of the work, and in fact performing almost all aspects, is the Hawaii Cooperative Fishery Research Unit (HCFRU), located at the University of Hawaii at Manoa.

The key individuals are: P.I.: Dr. James D. Parrish, Unit Leader
Co-P.I.: Mr. Jeremy T. Claisse, PhD candidate, U. Hawaii
Zoology, Graduate Research Assistant
Graduate Research Assistant: Ms. Sarah A. McTee
MS candidate, U. Hawaii Zoology
Graduate Research Assistant: Ms. Megan E. Bushnell
MS candidate, U. Hawaii Zoology

We obtained much of the needed background, history, local knowledge of sites, habitats, species and their general distribution and biology from local sources in West Hawaii, especially the local staff of the Hawaii Division of Aquatic Resources (HDAR) and other participants in the West Hawaii Aquarium Project (WHAP) (substantially funded by HCRI over a period of several years). We collaborated closely with HDAR and WHAP throughout the project, and received logistic support from HDAR and the Kaloko Honokohau National Park.

We gained familiarity with the sites, habitats and species, and developed the scope, planning and methodology for the research based on field reconnaissance trips using Unit boats and scuba surveys of the area before the start of Year 6 HCRI funding. The project research involved extensive field work (collection, manipulation, census, survey, habitat description, and standardized observations), largely under water on coastal coral reef tracts, using scuba with support from Unit boats, vehicles and marine equipment. Some live specimens were held at the Hawaii Institute of Marine Biology facility of Univ. Hawaii. Extensive laboratory work included measurements on specimens, dissections for gonad examination and measurement, and extraction of otoliths for age determination. This work was done using the Unit's temporary field quarters and HDAR facilities in West Hawaii, and the Unit's laboratory facilities at Univ. Hawaii Manoa campus. Otolith reading was done both in the specialized ageing laboratory at James Cook University, Queensland, Australia, and in Unit ageing facilities at the Univ. Hawaii Manoa campus.

VI. Findings

A. Accomplishments and findings:

SIZE DISTRIBUTION OF SPECIMENS

The size distribution of specimens collected is shown for yellow tang, kole, and brown surgeonfish (Fig. 2), and maximum and minimum lengths and weights appear in Table 1. For yellow tang, the largest specimens were males. Some large females occurred, but a considerable majority of yellow tang >155 mm TL were males. For kole, the same general pattern occurred for all size classes of large fish where the number of specimens was more than trivial. The dominance in numbers of males was established by about 130 mm TL, and a large majority of all kole >150 mm TL were males. The total number of brown surgeonfish collected was somewhat smaller, and the full range of sizes represented was somewhat less. However, where the sample size was more than trivial, large males were also more numerous than large females (a size range of ~135-150 mm TL), and the sample of fish larger than 150 mm TL was inadequate.

For yellow tang taken during the split collection in Feb 05, for each sex there were clear size breaks between those living in the deeper reef areas and those in schools on the shallow reef flat. Females made this habitat usage transition at ~140 mm TL; males made the transition at ~165 mm TL. See Fig. 3.

Sex ratios (Table 1) for the 3 focal species were calculated using the same sample as used for size distribution (Fig. 2), including all sizes/ages in the count of each sex. The results for collections of all 3 species suggest that the sex ratios of the populations may be skewed toward males, but the sample sizes are too small for kole and brown surgeonfish to interpret with confidence. At present, the best interpretation is probably simply that large numbers of both sexes are present in the local populations, and it seems unlikely that the sex ratios for the actual populations are radically skewed. At best, Fig. 2 and Table 1 describe the collection well. For yellow tang, after analyzing the split collection, it became clear that this ratio would be skewed because of the difference in size at which males and females make the shift to shallow reef habitat. Because of this difference, the largest individuals (140 - 165 mm TL) found on the deep reef are almost exclusively males. Therefore, haphazard collections that are made to represent the sizes present in this area would naturally be skewed towards males. Therefore we also calculated the sex ratio for fish ≤ 135 mm TL: (M:F) 52:50 = 1.04. So for settlers and smaller juvenile yellow tang, the sex ratio is effectively 1:1. This may also be the case for kole and brown surgeonfish, but further research on the basic biology of these species would be necessary to determine this.

LENGTH-WEIGHT RELATIONSHIPS

Based on the lengths and weights of all specimens collected for each species in 2003-2004, a relationship between length and weight was described by fitting the data to a simple power function:

$$W = a(SL)^b$$

where: W is the whole wet body weight of the fish in grams
SL is standard length in millimeters
a and b are fitting parameters

The results of the regressions for the 3 focal species (using data from all specimens collected), together with the regression equations and r^2 values are shown in Fig. 4, 5, and 6. SL is used for this purpose because it most closely corresponds with the mass of the fish body and is less variable among individuals, and therefore can be expected to give the least variable relationship with body weight. A good deal of data in this project is collected by visual estimation of the length of live fish under water. Total length (TL) seems to be the length that divers estimate most accurately in these situations, and it is the length that has become accepted in the WHAP, a recent, large-scale, long-term project, and in subsequent HDAR research with these species, with which we expect to continue to exchange data throughout our study. For these reasons, linear regressions were run with SL measurements against TL measurements to permit conversion of data between those lengths whenever it is useful. Data from sexes were pooled, and measurements from all available specimens of the focal species were used. The model fitted by regression was of the form:

$$TL = c + d(SL)$$

where c and d are fitting parameters, and all measurements are in millimeters. The results of the regressions for the 3 focal species, together with the regression equations and r^2 values are shown in Fig. 7.

REPRODUCTIVE DEVELOPMENT

Yellow tang

Gonadosomatic index (GSI) values were examined for each sex separately and sorted by season when collected and by TL. Initial plotting for each sex of GSI vs. date of collection (Fig. 8) provided a general idea of reproductive season. Collections from 2005 (Feb and Apr) were consistent with our current estimate of a peak in spawning period from roughly February through July. Occasional sightings of what appeared to be very recently settled individuals at all times when observations were made suggest that some low level of reproduction occurs at all seasons.

Fresh gonad weights of fish taken during the collections in 2005 were used to calculate sizes at first reproduction (SFR) for females and males (Fig. 9). GSIs were plotted versus TL to provide the estimate. To arrive at a single working size criterion for maturity for each sex, SFR was selected as the TL at which half the specimens in the size range of transition (GSIs above background level and below the fully developed level) were shorter, and half were longer. For yellow tang females, this SFR was estimated at 140 mm TL; for yellow tang males it was estimated at 160 mm TL.

Split collection

Almost all females collected from schools on the shallow reef flat had higher GSIs than those individuals from the deeper reef collection, which would indicate that females in the reef flat schools are reproductively active adults (Fig. 10). Males on the reef flat tend to have higher GSIs than those from the deeper collection, but the trend is not as clear as in the females (Fig. 10). There is much more spread in GSI values of shallow males, which could mean that only a fraction of the males in that group would have spawned on the day they were collected. In the deeper reef group, there were a few individuals that had higher GSI values, so they could be transitional males (males that may soon move into the reef flat group), or there could be a small fraction of this group that is reproductively active as well.

Kole

Gonadosomatic index (GSI) values were examined for each sex separately and sorted by season when collected and by TL. Initial plotting for each sex of GSI vs. TL with the points labeled by date collected (for females, but not males) (Fig. 11) provided a general idea of reproductive season (highest GSIs seen in Feb and Jun). However, the sample size is limited for much of the year, so further collections would be necessary to define the spawning season closely. For kole females, the SFR was estimated at 100 mm TL; for males it was estimated at 140 mm TL. Both are rough estimates, and a larger sample size during the reproductive season would be necessary to clearly define these SFRs.

Brown surgeonfish

Gonadosomatic index (GSI) values were examined for each sex separately and sorted by season when collected and by TL. Initial plotting for each sex of GSI vs. date collected provided no clear evidence of a defined reproductive peak season. Further collections would be necessary to define the spawning season closely. However, sightings of what appeared to be very recently settled individuals at all times when observations were made suggest that some level of reproduction occurs at all seasons. For brown surgeonfish females, SFR was estimated at 120 mm TL; for males it was estimated at 130 mm TL (Fig. 12). Both are rough estimates, and a larger sample size during the reproductive season (if there is one) would be necessary to clearly define these SFRs.

AGE ESTIMATION FROM OTOLITHS

Yellow tang

To date, we have processed and read otoliths from 114 yellow tang ranging in size from 69 mm to 192 mm TL. Our interpretations of otolith bands provide estimates for an age range of 0.5 to 35.5 years, assuming that the conspicuous bands seen are deposited annually. Fig. 13 provides a plot of TL vs. number of bands, organized by sex. A von Bertalanffy growth function (VBGF) was fitted to data of each sex. From this plot it is apparent that yellow tang individuals exhibit rapid growth for the first few years, followed by much slower growth for the rest of the lifespan. Furthermore, it appears that most males initially grow faster and reach larger size than most females. Age estimates from this first reading will require confirmation once validation of frequency of bands is complete. What is learned from our validation process could cause a change in interpretation such that the ages of all bands shift as a group by ~1 year (older or younger). Validation trials are underway and should contribute to improved interpretation in all subsequent ageing.

Yellow tang taken in the split collections were also aged (Fig. 14). Females collected from the reef flat school (n=30) ranged in estimated age from 4.5 to 35.5 years, and males ranged from 8.5 to 31.5 years. Females collected from the deeper reef area were all 2.5 years old, except for one older individual that was similar in size to the other deeper specimens. Most males on the deeper reef ranged from 1.5 to 10.5 yrs old. Two of the older individuals (9.5 and 10.5 yrs) had higher GSIs, which could mean that they were reproducing, and they could be in a transitional phase between the 2 habitats. Two males in this deeper group were much older (22.5 and 25.5 years). Both had low GSIs, so their reproductive status is unclear.

There is evidence of some trends in the initial review of ages at the various sites. Kealakekua (the site with the longest history of protection) appears to have the highest proportion of fish over 10 years old (mean age ~11 years at Kealakekua), in comparison with the other three sites with less history of protection (mean ages all ~5yrs). However, the site with the second highest proportion of fish over 10 years old is the area open to aquarium collecting at Wawaloli Beach. Interpretation of these results is not clear at this point, but may become so as the sample size of processed otoliths is increased for all sites. The range of sizes collected at all sites appears to be similar, so our results are not simply an artifact such as might be produced by a biased collection with stronger effort collecting larger fish at Kealakekua.

Kole

To date, we have processed and read otoliths from 136 kole ranging in size from 74 mm to 188 mm TL. Our interpretations of otolith bands provide estimates for an age range of 0.5 to 18 years, assuming bands are annual. Fig. 15 provides a plot of TL vs. number of bands, organized by sex. A von Bertalanffy growth function (VBGF) was fitted to data of each sex. From this plot it is apparent that kole individuals exhibit rapid growth for first few years, followed by much slower growth for the rest of the lifespan. Furthermore, it appears that most males initially grow faster and reach larger size than most females. As with yellow tang, it is likely that the time relationship within the group of bands is reasonably well estimated now, but with both species it should be noted that the annual formation of bands still has not been validated.

Brown surgeonfish

To date, we have processed and read otoliths from 112 brown surgeonfish ranging in size from 87 mm to 170 mm TL. Our interpretations of otolith bands provide estimates for an age range of < 1 to 10 years, assuming bands are annual. Fig. 16 provides a plot of TL vs. number of bands, organized by sex. A von Bertalanffy growth function (VBGF) was fitted to data of each sex. From this plot it is apparent that brown surgeonfish individuals exhibit rapid growth for the first few years, followed by much slower growth for the rest of the lifespan. Furthermore, it appears that males reach slightly larger size on average than most females. As with yellow tang, it is likely that the time relationship within the group of bands is reasonably well estimated now, but with both species it should be noted that the annual formation of bands still has not been validated.

FIXED TRANSECTS

Results for timing of settlement of yellow tang

2004 – Fig. 17

Two peaks in settlement of yellow tang on the fixed transects at Wawaloli (Site #10) came about a month apart and corresponded with the full moon (2 Jul 04 and 31 Jul 04). A peak in settlement on the fixed transects at Ke’ei (Site # 20) occurred during the first full moon during our survey period (2 Jul 04), however overall settlement was much lower at this site. A very small peak may have occurred during the second (31 Jul 04) full moon, but the overall low absolute level of settlement during the rest of the month makes it hard to interpret.

2005 – Fig. 18

Two peaks in settlement of yellow tang on the fixed transects at Wawaloli (Site # 10) and Ke’ei (Site # 20) came about a month apart and corresponded with the full moon (23 May 05 and 22 Jun 05). The overall level of settlement was much higher in 2005 than in 2004.

Results for general location of settlement on the reef

For settlers on transects at Wawaloli:

Settlers of all 3 focal species and *C. multicinctus* found on fixed transects were mainly on transects # 2, 3 and 4 (Fig. 1) along the edge of the reef slope as it drops off (~15-20 m depth), with high coral cover (to be quantified from our benthic photoquadrat data). No settlers were ever found shallower than transect # 7 (~8 m). Free swimming surveys made early at multiple sites along the Kona Coast during summer 2004 found yellow tang settlers on the reef between ~6 m and 25 m deep. Solitary kole settlers were found as shallow as 2 m on the reef flat, and solitary brown surgeonfish as shallow as 3 m. However, such shallow sightings were very rare. Apparently these ornamental species can settle over a range of depths from at least ~3 m to ~25 m, but most settlement is focused in a much narrower band near neither extreme. Data from 2005 confirm the results from 2004.

Benthic habitat characteristics

To examine associations and possible habitat preferences of yellow tang settlers with benthic habitat characteristics along each transect, for a month of the summer settlement period for 2004 and for 2005 at each site, we calculated Pearson correlations between mean settler density per transect and each of the following characteristics of the benthic transects separately: transect number (distance to shore/location), rugosity, average depth, and percentage of total substrate of the following variables: sand, turf/bare, substrate, crustose coralline algae, macroalgae, total coral cover, *Pocillopora meandrina*, *Porites compressa*, *Porites lobata*. See Table 2 for the results. At Wawaloli there was a significant positive correlation with % coral cover, *Porites compressa*, and *Porites lobata* and a significant negative correlation with % substrate (which is essentially the inverse of % coral cover) and turf/bare. For Ke'ei the only significant correlation found was with *Porites compressa*. One or more of these characteristics could be important in settler habitat preference, although there is no strong pattern across the two sites. Further (probably multivariate) analysis will be required to resolve any such associations.

Overall populations/size and depth distributions of focal species

Continued counts of numbers of various size classes on fixed transects are being plotted to determine the usual distribution of fish size/age for each focal species along the reef profile. Early emerging trends include:

Small and medium size yellow tang peak in deeper areas (~13 - 20 m); the largest size yellow tang peak in shallow depths (~8 m). (See split collection results for more details.)

Yellow tang and brown surgeonfish appear to be partitioning the habitat between them. When all size classes within each species are totaled, peaks of the two species do not overlap along the series of transects.

TAGGED FISH SURVEYS

First survival/retention estimates for yellow tang

Estimates of the fraction of yellow tangs surviving and retained within initial areas of ~1500 m^2 were made with the fixed transect grids at Ke'ei (Site # 20), Wawaloli (Site # 10), and Keauhou (Site # 15). All areas are protected from aquarium fishing, so apparent mortality is assumed to not include fishing mortality. At each of these sites, a group of yellow tang of known sizes ranging from 31 mm to 157 mm TL were tagged to be individually identifiable and released initially in Jul 04. The release area was visually censused to locate all the individuals just after release. Similar standard censuses were made weekly for the first month and then once every 2 months thereafter.

Beginning with the 54 individuals initially released at Ke'ei, the 28 individuals initially released at Wawaloli, and the 82 individuals initially released at Keauhou, the number observed on each survey was converted to a percentage of the total number tagged initially, and the results appear in Fig. 19 as "%Observed" values. The progressive reductions in numbers (percent) of tagged fish resighted reflect all types of loss, including possible (but unlikely) removal by illegal fishing, natural mortality (death by all other causes), and emigration from the study area (at least temporarily, at the times of census). At all three sites, a distance of ~30 m or more beyond the normal boundaries of the main census area was also searched (less intensively), and considerable additional surrounding bottom area was observed incidental to other work in the general area. None of the tagged individuals were seen outside the normal census area. This suggests that yellow tang of this (substantial) size range have high fidelity to a small home area over periods of at least 12 months, and makes it unlikely that absence of individuals from later censuses was strongly influenced by emigration. The only likely exception to this would be if a juvenile reached the size necessary to join the shallow reef flat schools and made this habitat transition. In future analysis, we may be able to see whether such loss occurs, and could thus correct our estimates of survivorship for fish of this size. At present we cannot separate loss by emigration from loss by mortality. However, since the evidence to date suggests that emigration losses may be minimal for the period of study thus far, it seems reasonable to use % observed as a good estimate of survivorship. At worst it could be viewed as a minimum estimate of survivorship. All 3 sites ended with a similar % survivorship. Keauhou and Ke'ei (76% and 74% respectively) were almost identical (habitat very similar), and Wawaloli was lower (64%).

The loss of 1 individual during the first week at Ke'ei, 2 individuals during the first week at Wawaloli, and 2 individuals at Keauhou could possibly be attributed to trauma associated with tagging. Correcting for such an assumed artifact by reducing the initial number of tagged fish for the calculation would only slightly affect the outcome. However, our experience with this tagging material and procedure (here and elsewhere), with the fish always submerged and given minimum handling, indicates that tagging mortality is very low. It seems highly unlikely that tagging mortality, if present at all, persisted beyond the first week after tagging.

Growth estimates from recovery data

Juveniles

Measurements (TL and SL) were made of a total of 14 yellow tang tagged for identification of individuals at Ke'ei and Wawaloli, released in Jul 04, and recovered and remeasured over periods of 1 to 5 months (see Table 3). Linear growth rate estimates across the whole range of fish sizes and both sites ranged from ~2 to 6 mm/mo based on data from 1 month at large, and from ~1 to 4.2 mm/mo based on data from 5 months at large.

Settlers

Settlers are much harder to tag because they tend to remain in crevices in the coral. Over the course of the project, we tagged only 17 individual yellow tang settlers but made 8 recaptures. The average growth rate was 7.8 mm/mo based on data from recaptured fish at large between 3 and 6 weeks.

It is too early to interpret these data meaningfully, but there may be indications that large juvenile individuals are growing more slowly (as expected), and it is clear that settlers are growing much faster then juveniles. Measurements of lengths of tagged fish will continue with specimens currently at large, and most will be collected at some point in 2006. The goal is to develop an adequate sample size for analysis, to examine trends in growth with size/age, to compare growth rates at different sites, and to evaluate the utility of sequentially measured lengths at known time intervals (age) in this species to construct growth models useful for managing this fishery.

HOME RANGE ESTIMATION

Summary results for 47 yellow tang settlers (30 - 50 mm TL) were:
The range of all observations for areas of individual home ranges was 0.3 to 8.9 m^2. The overall mean area for all observations of all settlers was 2.9 m^2.

Summary results for 34 juvenile yellow tang were:
The range of areas of home ranges was 3.0 to 174 m^2. The overall mean area for all juvenile fish was 31.5 m^2.

At Ke'ei during 2004, when peripheral markers from the first week of estimating home ranges were left in place for a second week and the fish movements were again observed, only one fish (a juvenile) exceeded (by 1 m) the borders marked the first week. This latter result gives some indication of stability of the home range over this time frame.

An increase in size of the home range with size of the individual might have been expected. However, no significant relationship was seen between size of home range and size of individual settlers or juveniles. This is probably due to the variation of the habitat within each individual home range. However, there is a large difference in size of home range between settlers and juveniles (Fig. 20). This difference, combined with behavioral differences observed, strongly suggests that these are distinctly different life stages rather than just labels of particular size ranges.

Untagged juvenile/adult fish

The presence of two yellow tang individuals with natural, distinctive marks that made them identifiable provided the opportunity to check on whether the tagging process produced an artifact in estimating home range size. We followed these two individuals, which were not tagged, using much the same protocol as above. Each fish was followed for two observation periods a week apart. The resulting estimates of their home ranges fell into the range of the elastomer tagged fish, and did not change over the week between observations.

B. No significant problems developed which resulted in less than satisfactory results.

C. Immediate prospects for additional work. Certain aspects of this project will continue with funding from University of Hawaii Sea Grant and HDAR. These aspects primarily include movement of adult individuals, collecting all tagged individuals for direct growth measurements, and further work on yellow tang reproduction.

VII. Evaluation

A. Attainment of project goals and objectives

1. Project goals and objectives have been largely attained, by methods basically described in the project proposal, to the extent feasible with the timing of Year 7 funding (see below).

2. No significant modification was made to the goals and objectives. Work proceeded as time and funding allowed and as behavior of the animal subjects permitted. (Timing of settlement is varies from year to year, and timing of some aspects of the project had to be adjusted accordingly.)

B. Dissemination of Findings:

Findings from this project have been and will continue to be communicated promptly through HCRI channels and directly to HDAR staff, WHAP investigators, NPS staff and other interested parties. Project staff has been working closely with NPS and HDAR staff as well as WHAP personnel. We intend to maintain this close collaboration into the future as work on yellow tang biology continues, so that interested natural resource personnel of the agencies can be involved in the scientific objectives, data collection, analysis and interpretation, as well as in developing appropriate management plans/recommendations. Such collaborations should help to develop capacity within the agencies and enhance resource managers' capabilities for reaching their goals. Results have been and will continue to be disseminated to the audiences mentioned above and to the broader scientific community through the normal scientific channels (see below for more specifics).

1. Staff presented progress and results of the project at HCRI periodic meetings. These meeting are attended by Hawaii resource managers, legislative staff, and staff from other HCRI projects.
2. Staff made a presentation and answered questions about the research project to the West Hawaii Fisheries Council in Apr 04. Staff have also participated in Council meetings in Feb, May, Jun, Jul and Dec 2004, and Aug and Oct 2005, providing scientific expertise to the Council as appropriate, and were available to the

Council as resource people. We are also planning to present the findings of this project to them in Mar 2006.

3. In Dec 04, project staff conducted a workshop at Kona for staff of HDAR on live capture of aquarium fish and tagging *in situ* to identify individuals, using color-coded elastomer material.
4. The project provided research data and preliminary results to HDAR during 2004 for use in preparing the 5-year review, mandated by the Hawaii legislature, of effects of the protected area program on West Hawaii aquarium fish stocks.
5. The project staff contributed results from the project to HCRI administrative staff for use in preparing the brochure “Hawaii Coral Reef Initiative Research Program: West Hawaii Projects” and provided scientific editing assistance at some stages of preparation of the brochure.
6. A presentation was made at the University of Hawaii Tester Memorial Symposium, sponsored by the Zoology Department 16-17 Mar 05.
7. A presentation was made at the 7th international Indo-Pacific Fish Conference in Taipei, Taiwan in May 05.

VIII. Signature of Principal Investigator

A. Principal Investigator must sign and date Project Final Report

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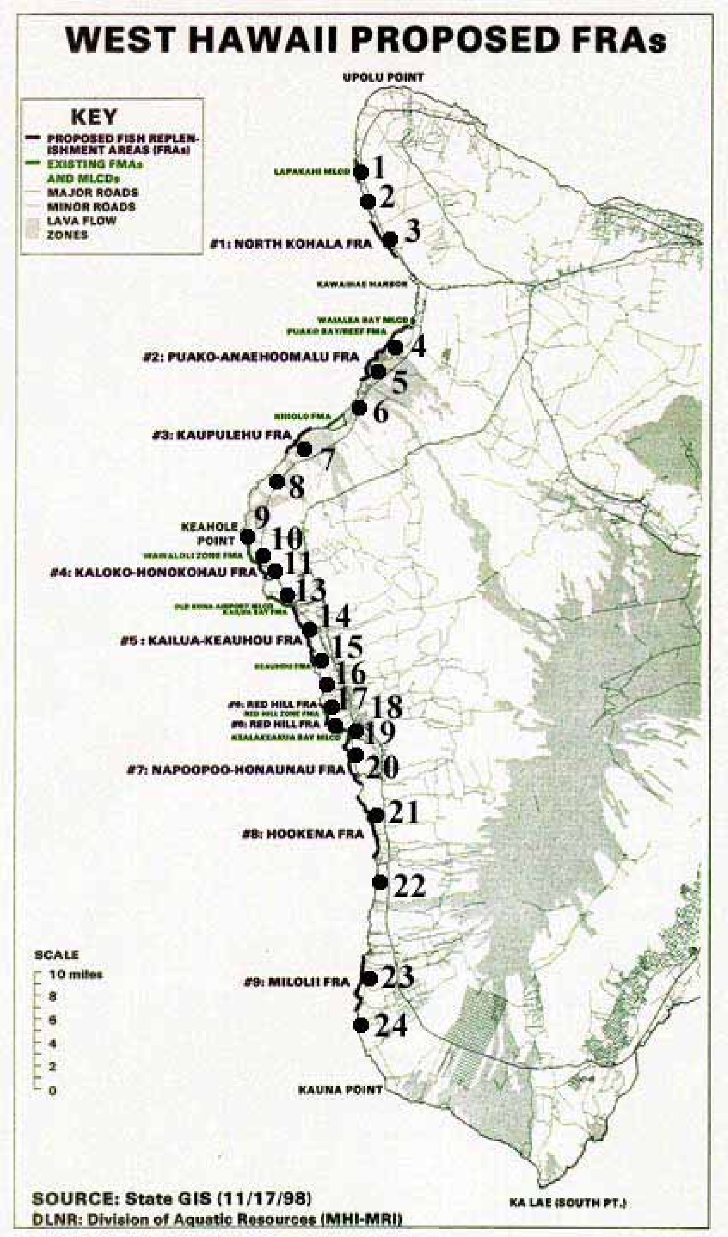
Dr. James D. Parrish (P.I.)

Map 1. Main study sites (WHAP numbering) and histories of protection are:

- (9) Wawaloli Beach (open)
- (10) Wawaloli FMA (FMA since 1991)
- (15) Keauhou FRA (FRA since 2000)
- (19) Kealakekua MLCD (No take since 1969)
- (20) Ke'ei FRA (FRA since 2000)



SOURCE: State GIS (11/17/98)
DLNR: Division of Aquatic Resources (MHI-MRI)

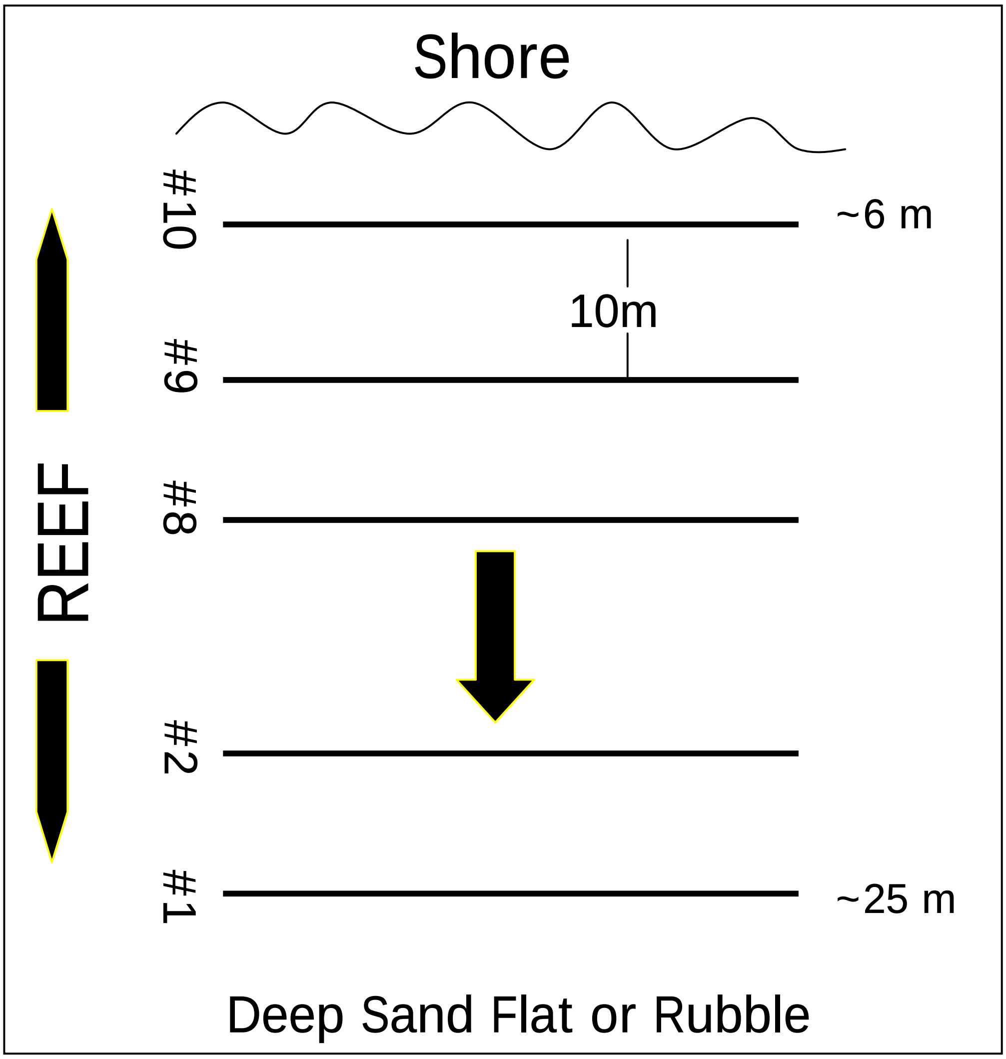


Figure 1. Layout of fixed transects across reef profile.

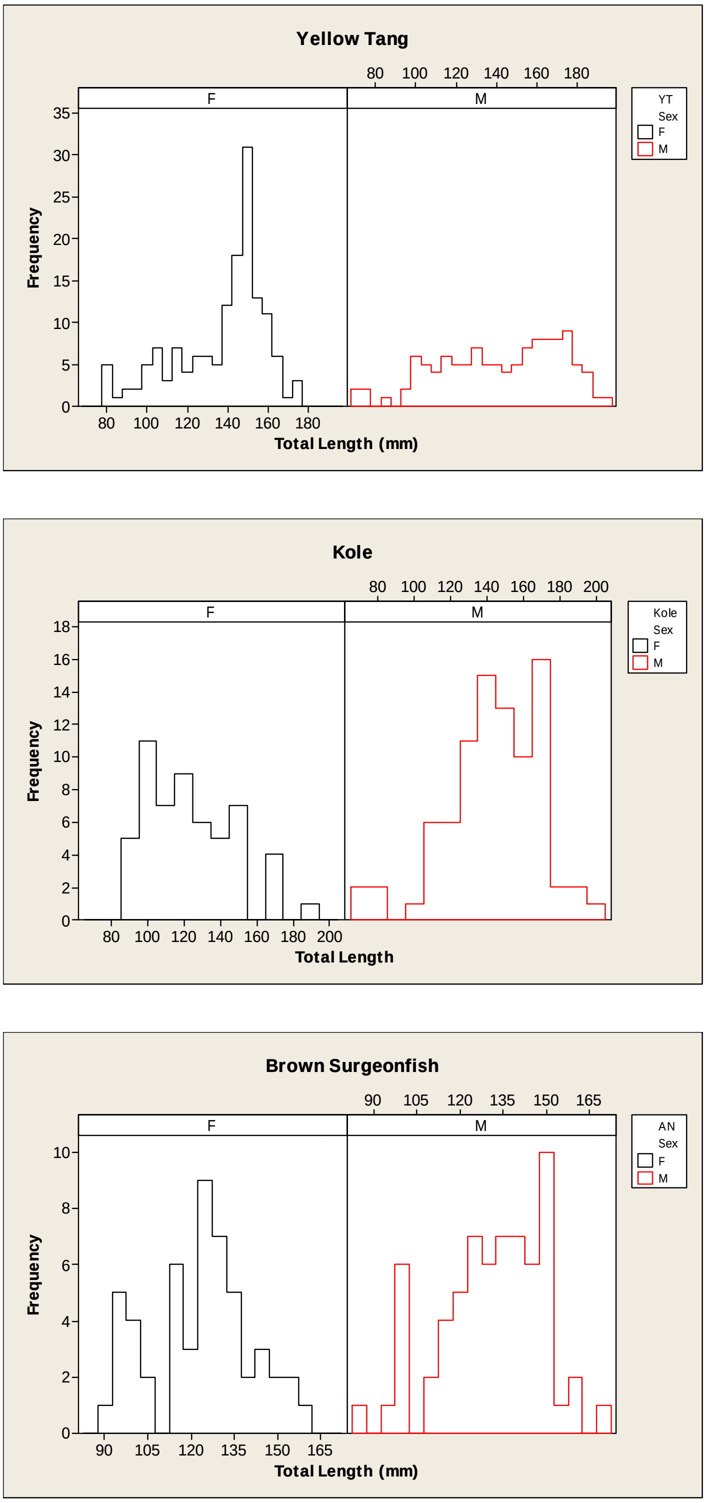


Figure 2. Frequency distributions of total lengths (TL) of male and female yellow tang, kole and brown surgeonfish collected.

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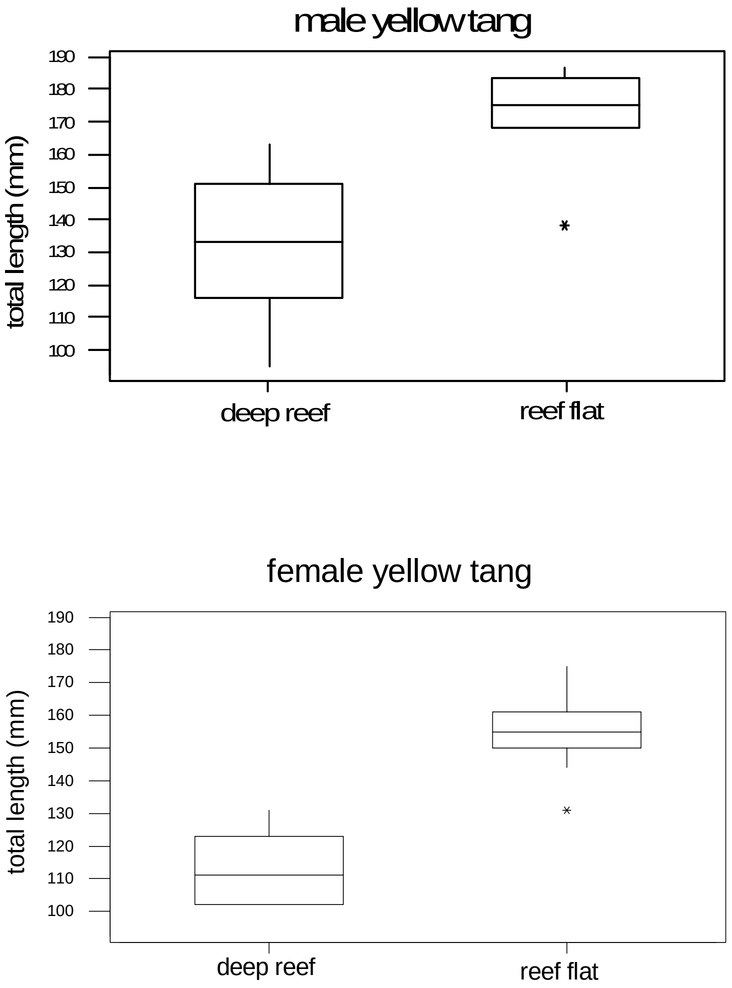


Figure 3. Size distribution of yellow tang taken during the split collection of yellow tang males and females from the deeper reef area and shallow reef flat area occupied by schools of larger individuals.

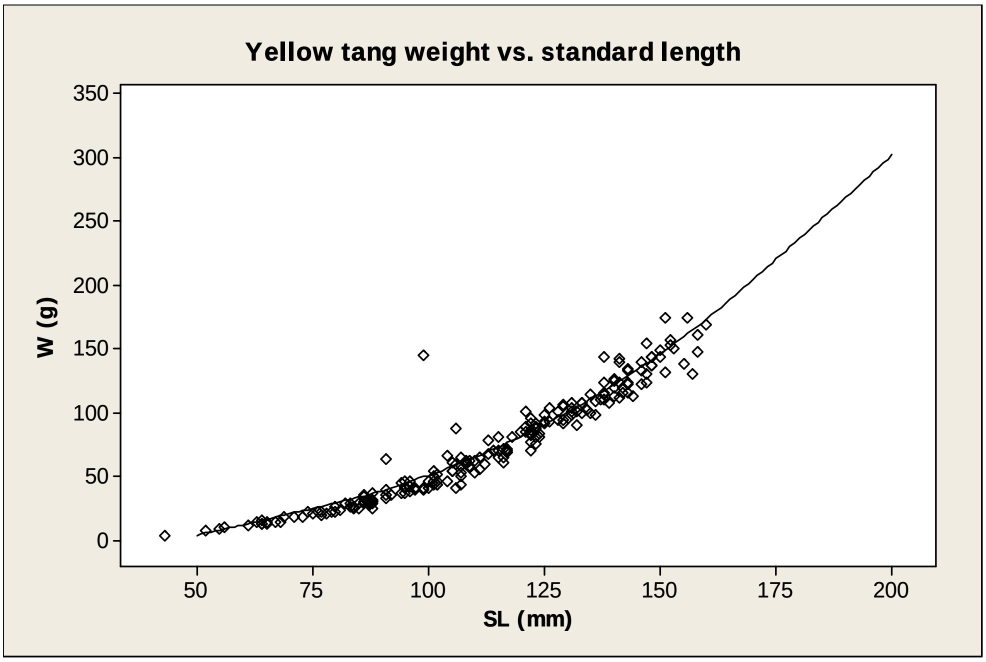


Figure 4. Relationship of whole wet weight (W) in grams of yellow tang to standard length (SL) in millimeters.
The best fit equation is W = (.00021)$(SL)^{2.68}$
Estimated $r^2 = 0.940$ n = 208

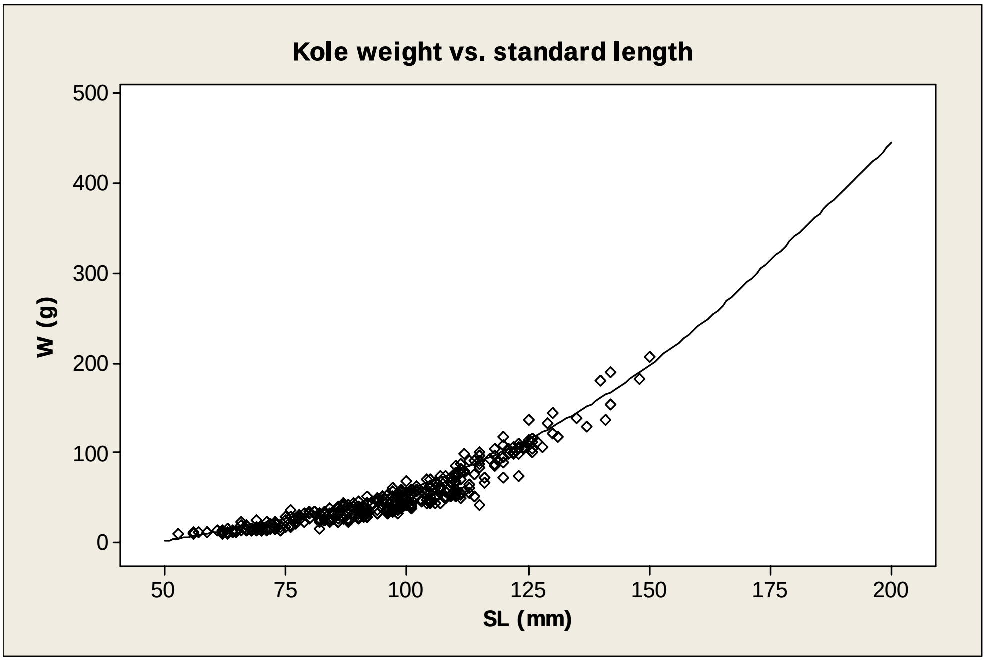


Figure 5. Relationship of whole wet weight (W) in grams of kole to standard length (SL) in millimeters.
The best fit equation is W = (.000045)$(SL)^{3.05}$
Estimated $r^2 = 0.961$ n = 202

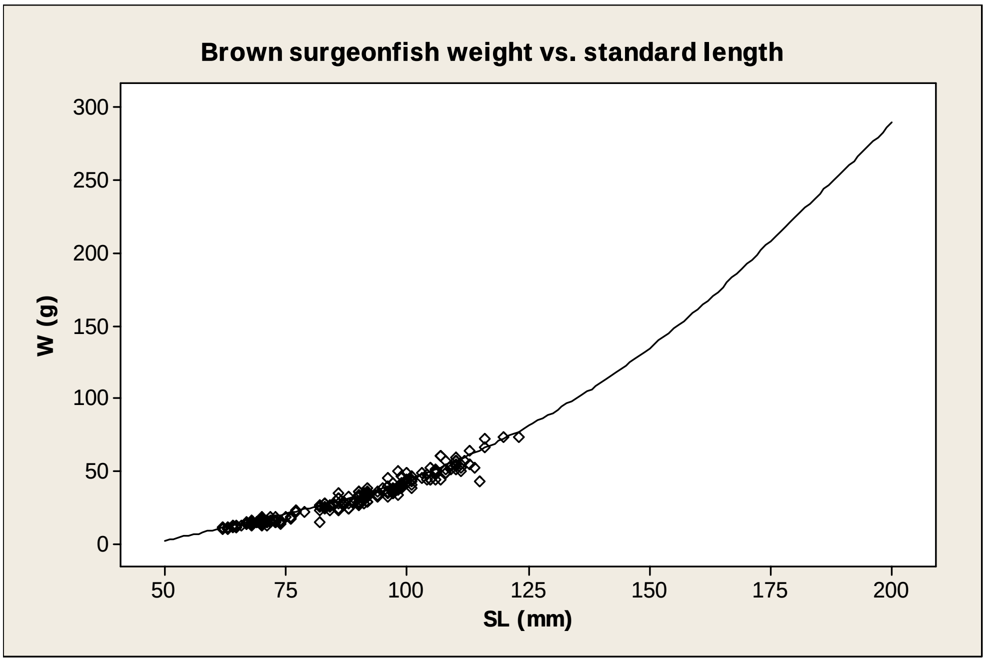


Figure 6. Relationship of whole wet weight (W) in grams of brown surgeonfish to standard length (SL) in millimeters.
The best fit equation is $W = (.000080)(SL)^{2.86}$
Estimated $r^2 = 0.945$ $n = 184$

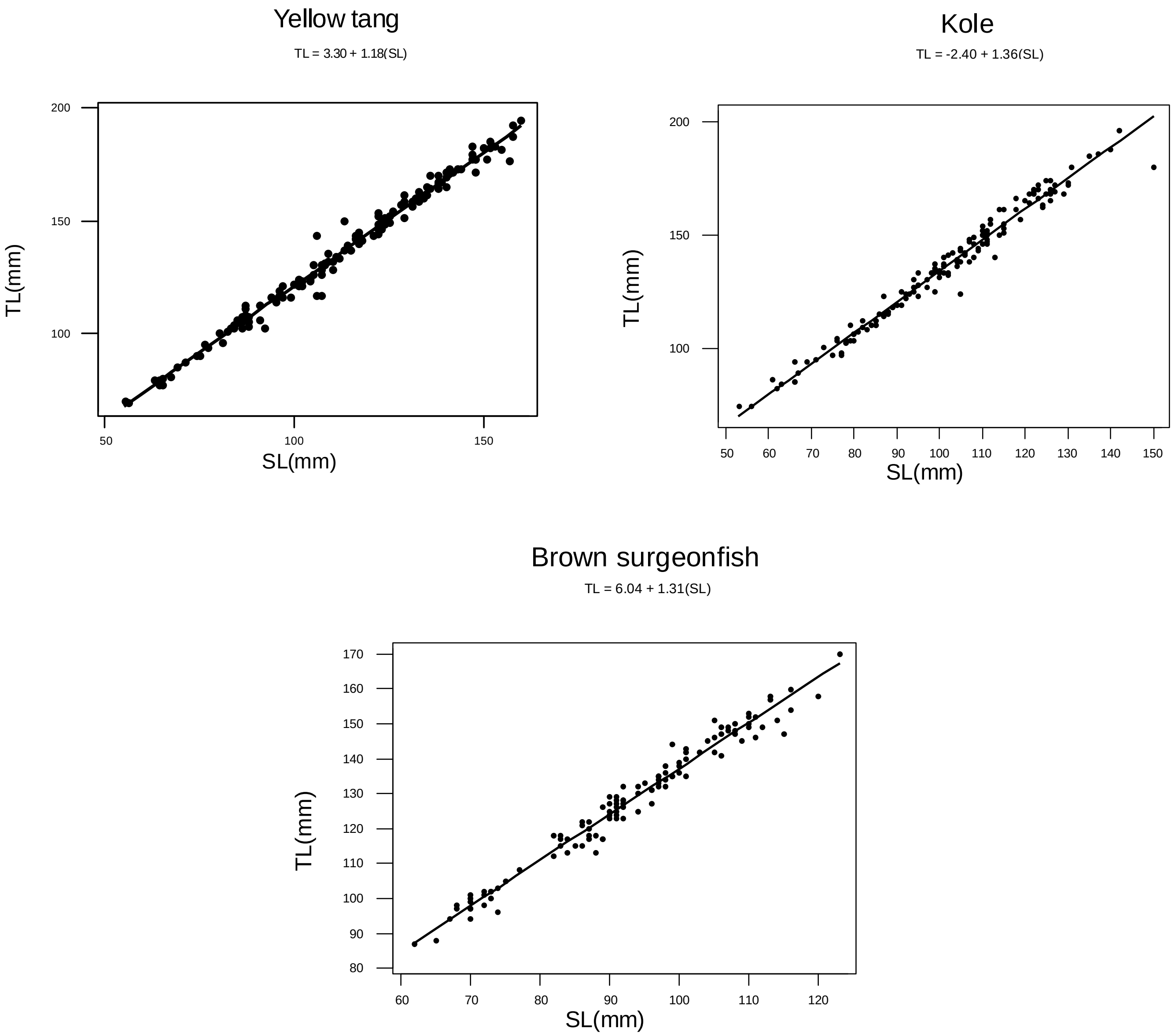


Figure 7. Relationship of total length (TL) vs. standard length (SL) for collections of yellow tang ($r^2 = .987$, n = 208), kole ($r^2 = .976$, n = 202) and brown surgeonfish ($r^2 = .961$, n = 184).

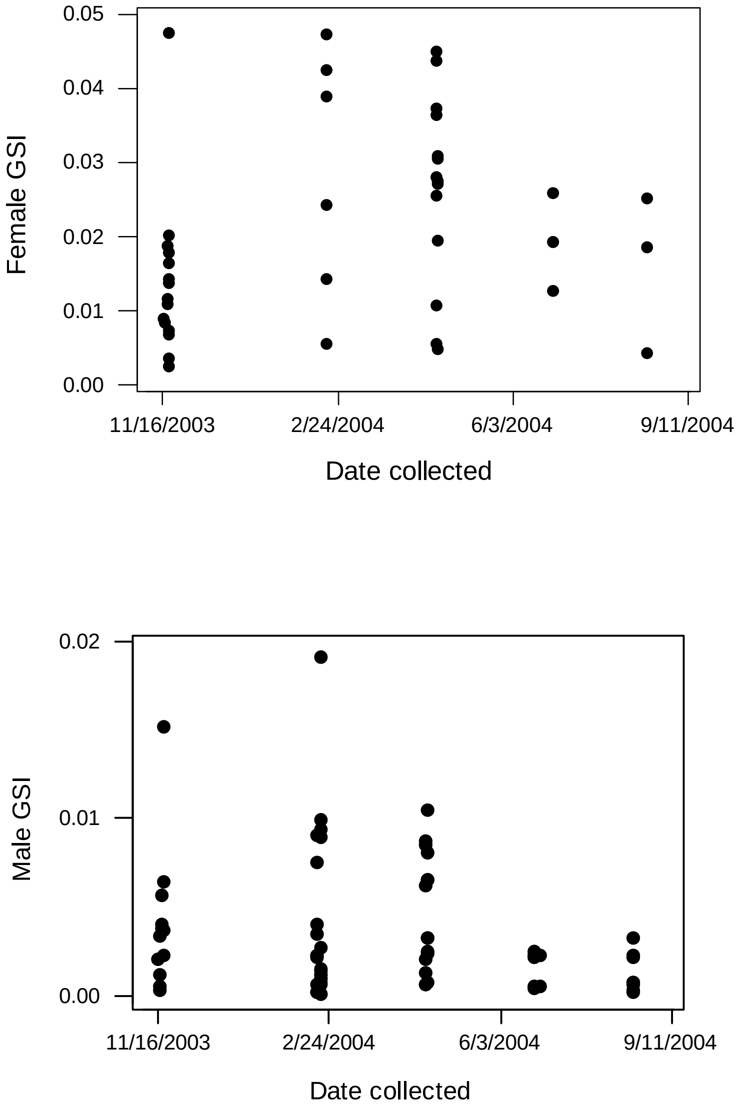
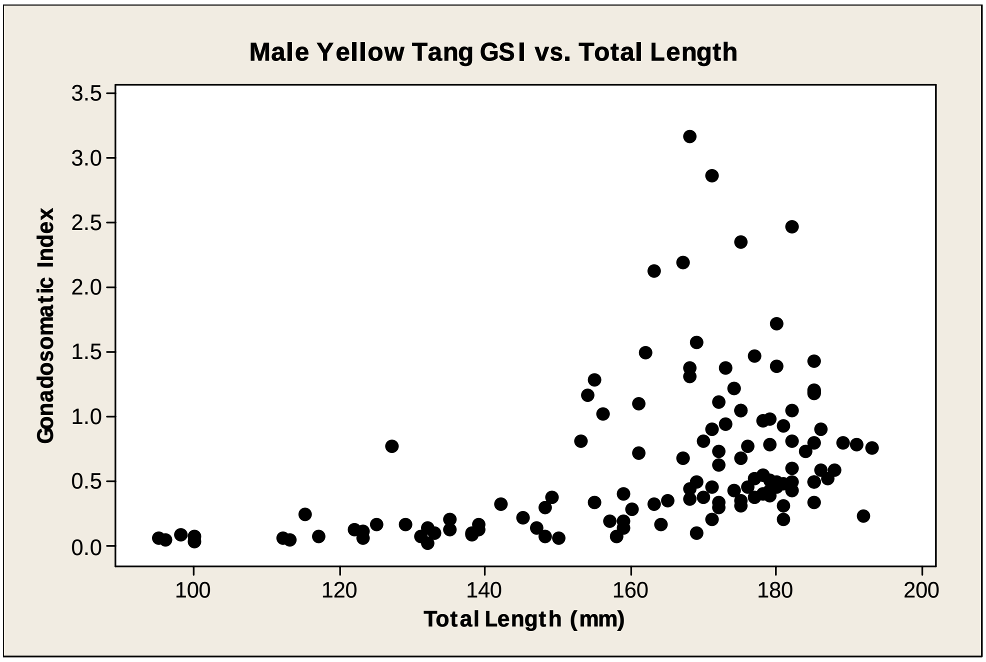


Figure 8. Seasonal variation in gonadosomatic index (GSI) of yellow tang females and males.



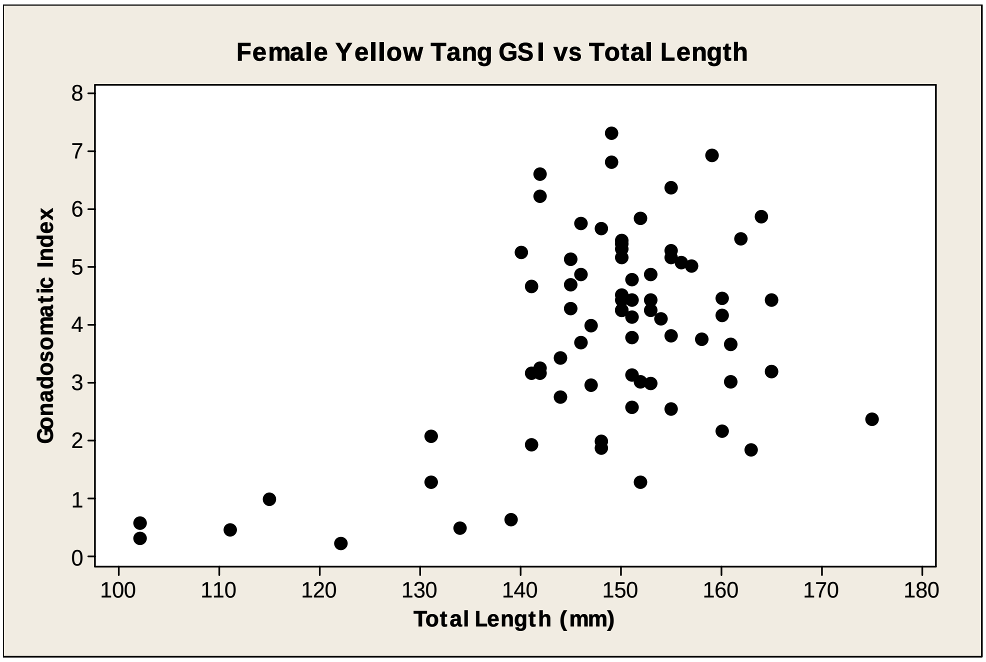


Figure 9. Gonadosomatic index (GSI) vs. total length (TL) for yellow tang males and females.

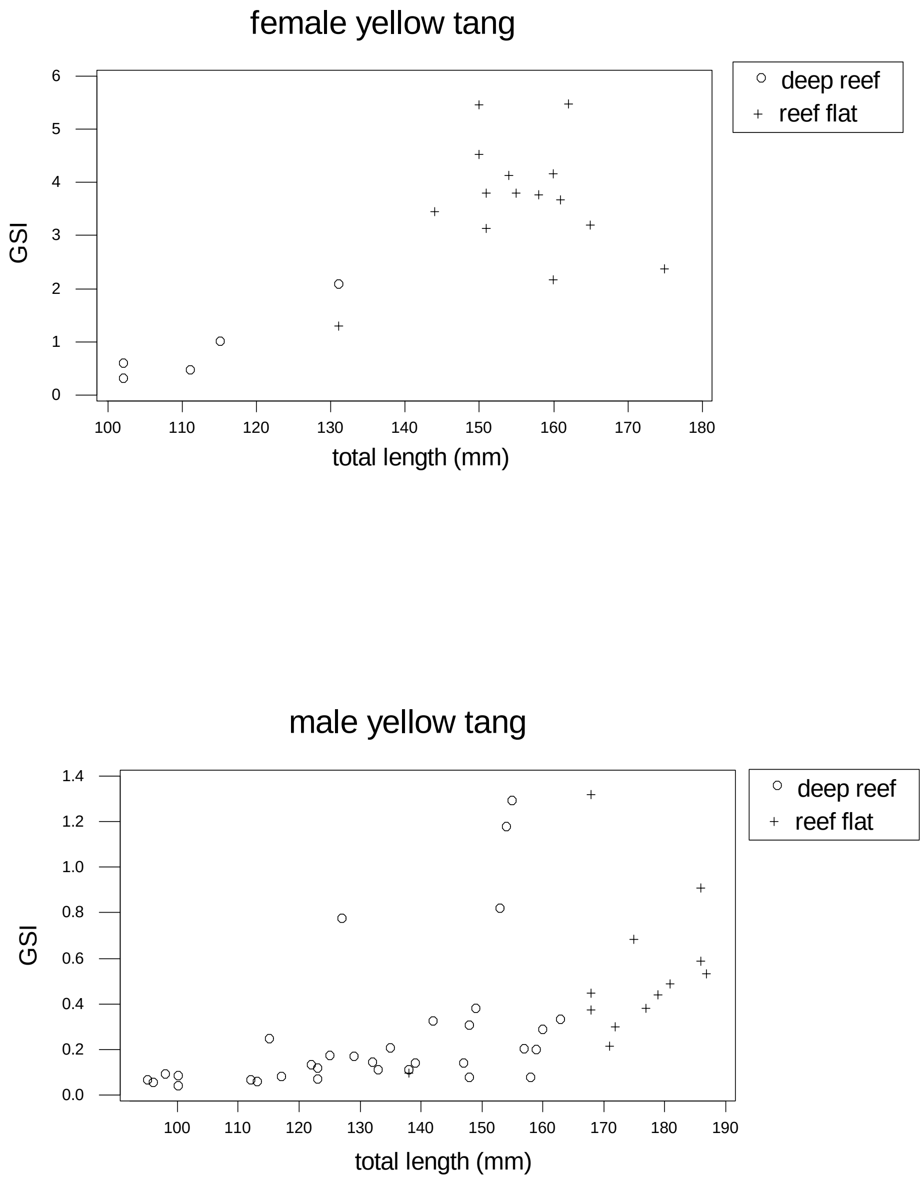
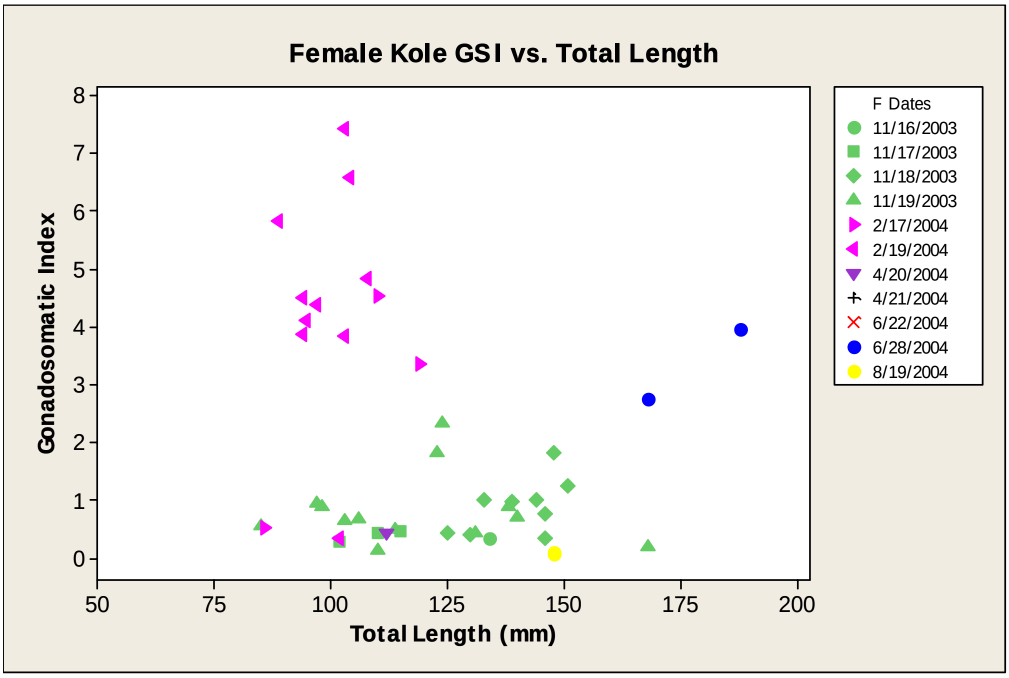


Figure 10: Gonadosomatic index (GSI) vs. total length (TL) during the split collection of yellow tang males and females from the deeper reef area and shallow reef flat area occupied by schools of larger individuals.



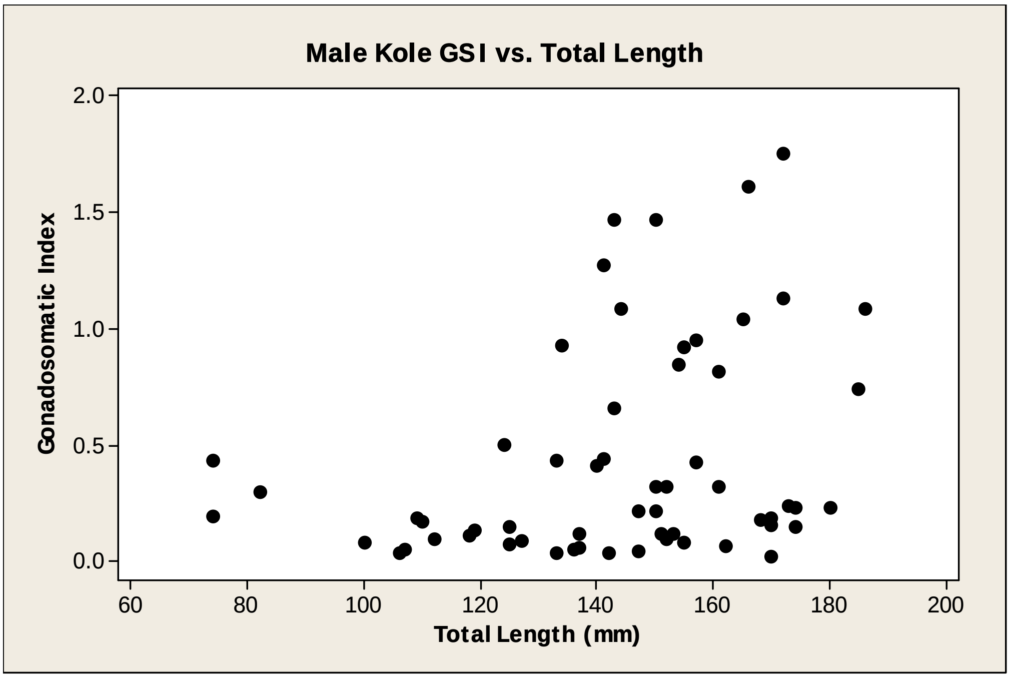
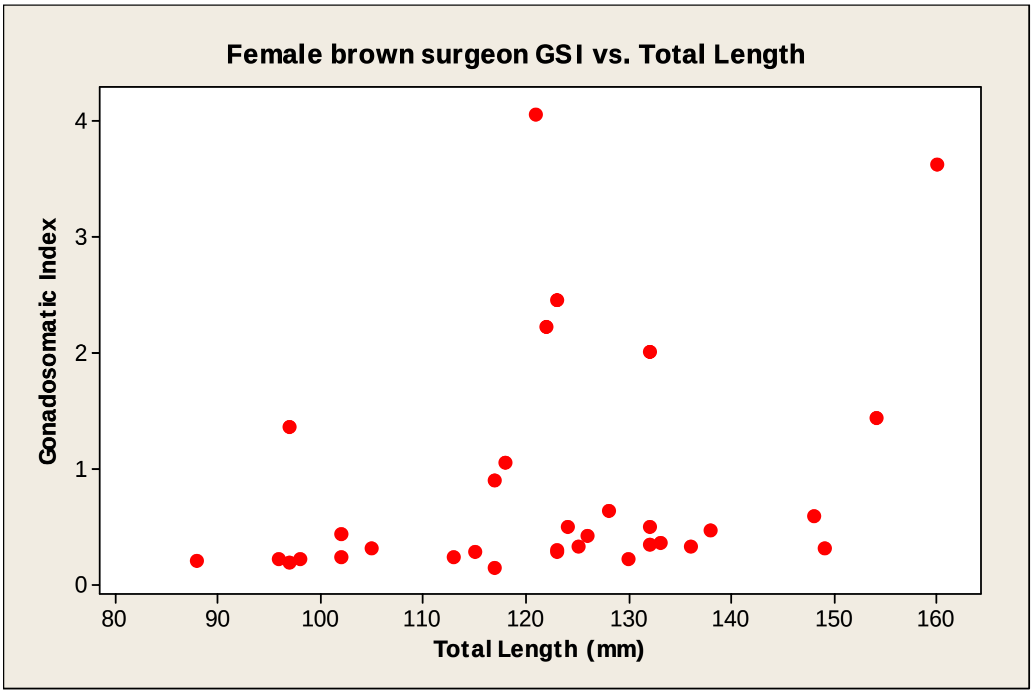


Figure 11. Gonadosomatic index (GSI) vs. total length (TL) for female and male kole.



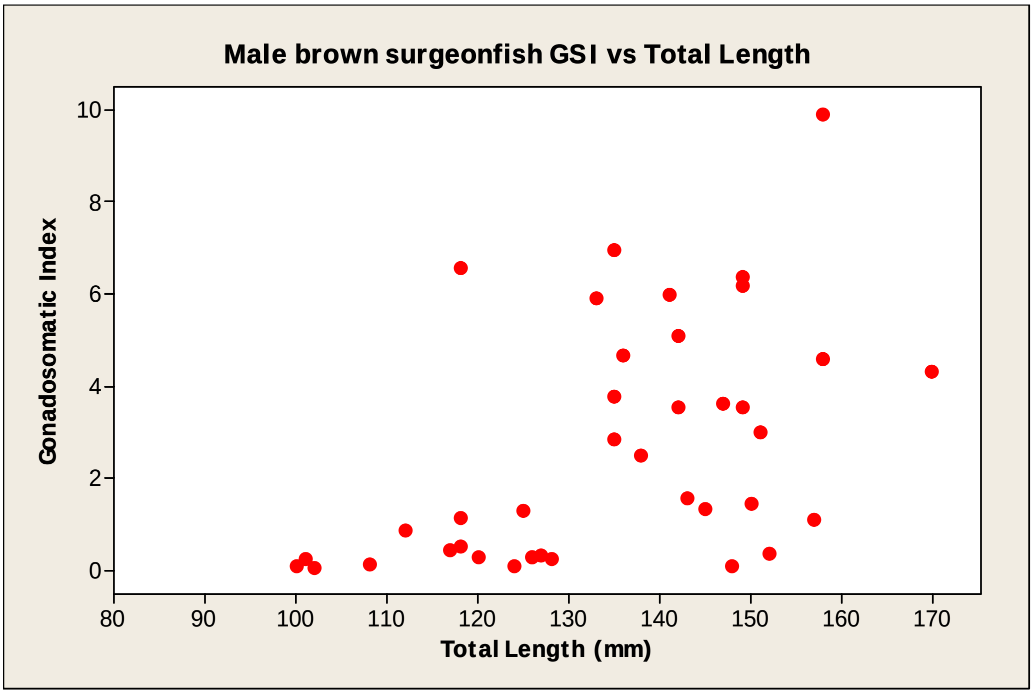


Figure 12. Gonadosomatic index (GSI) vs. total length (TL) for female and male brown surgeonfish.

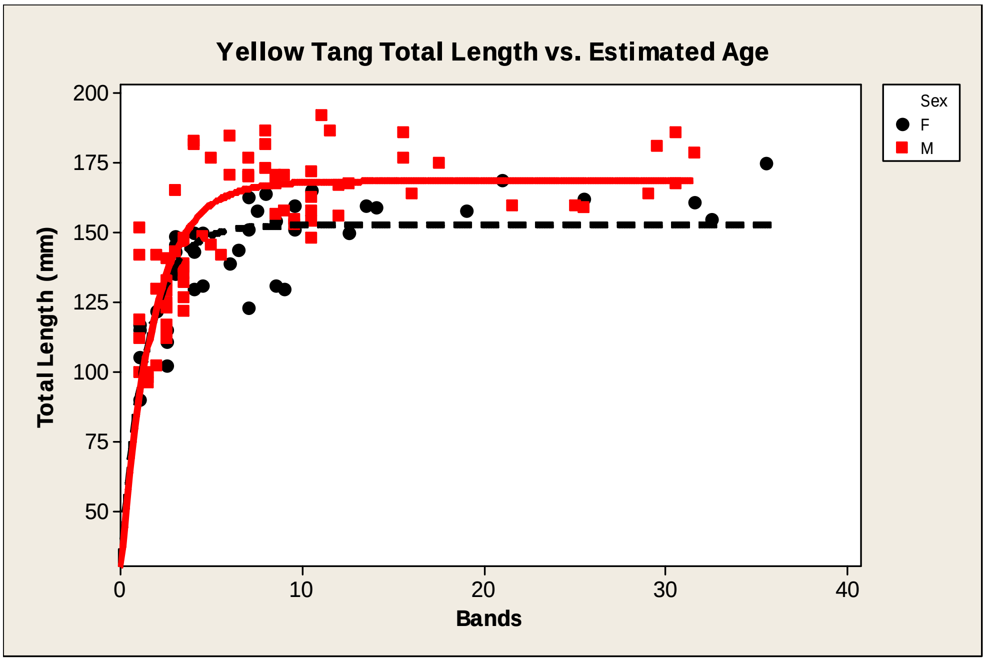


Figure 13. Total length (TL) vs. number of bands counted (assumed annual) in yellow tang otoliths. Von Bertalanffy growth curves fitted to data for males and females (dotted line).

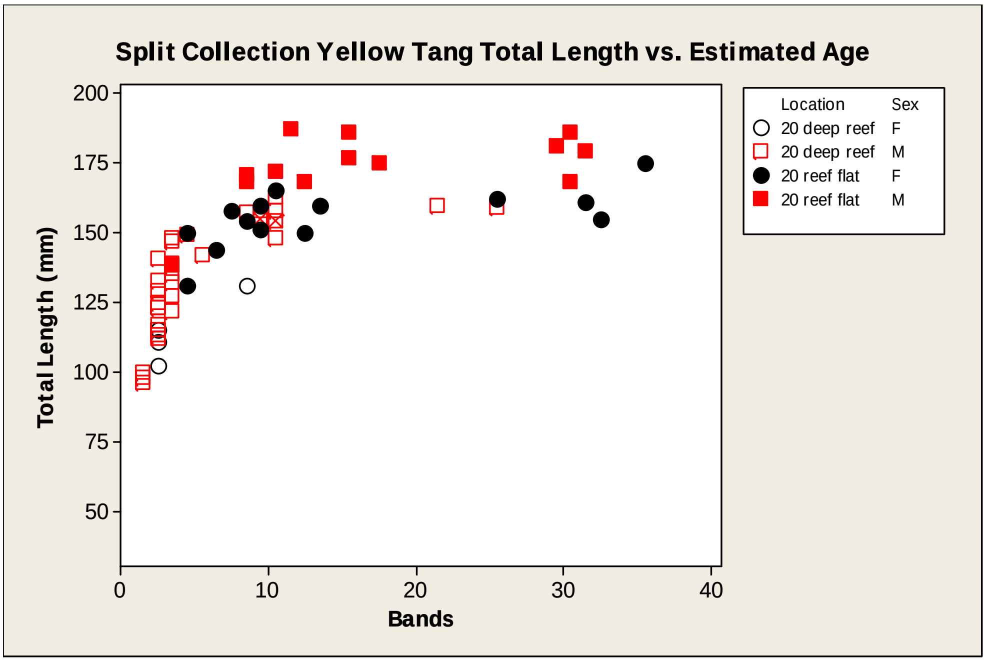


Figure 14. Total length (TL) vs. number of bands counted (assumed annual) in yellow tang otoliths in collections split by depth/habitat, male and female.

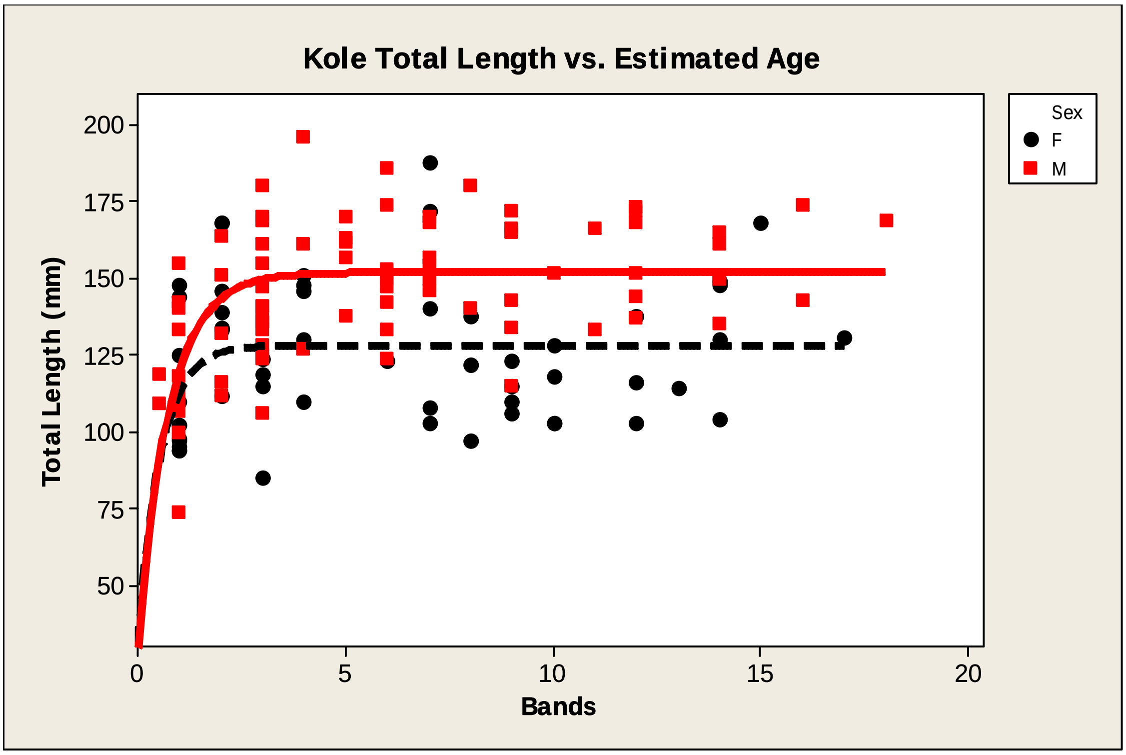


Figure 15. Total length (TL) vs. number of bands counted (assumed annual) in kole otoliths. Von Bertalanffy growth curves fitted to data for males and females (dotted line).

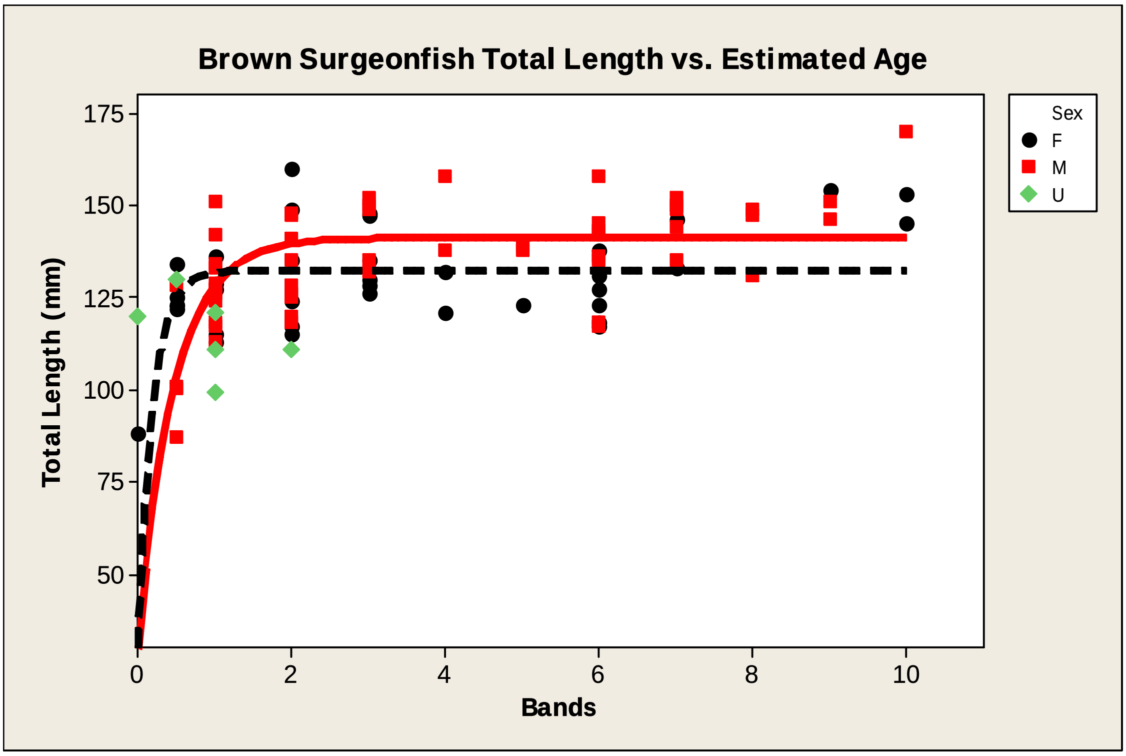


Figure 16. Total length (TL) vs. number of bands counted (assumed annual) in brown surgeonfish otoliths. Von Bertalanffy growth curves fitted to data for males and females (dotted line). “U” indicates unidentified sex.

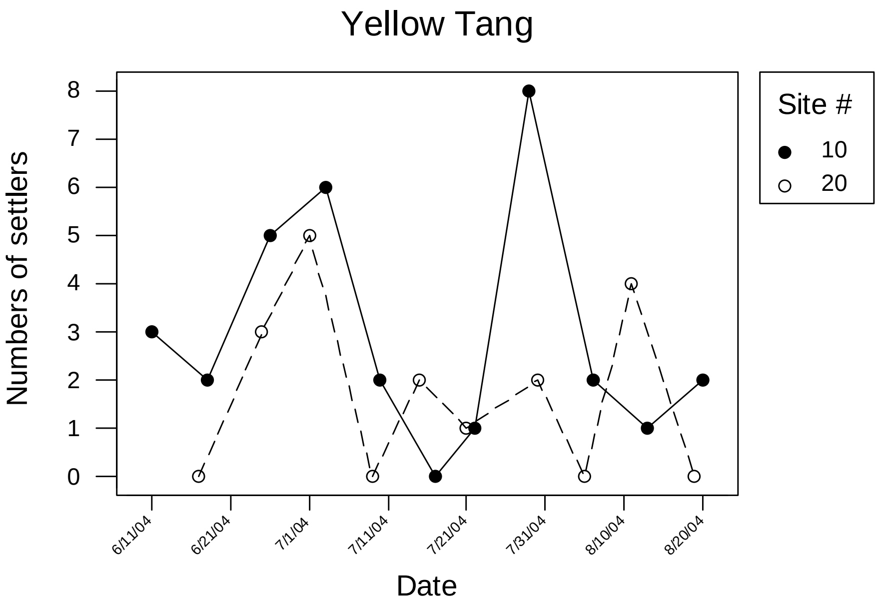


Figure 17. Numbers of recent yellow tang settlers at two sites during summer period in 2004 totaled across all fixed transects at each site for each count. Dominant settlement peaks correspond with full moons during the period.

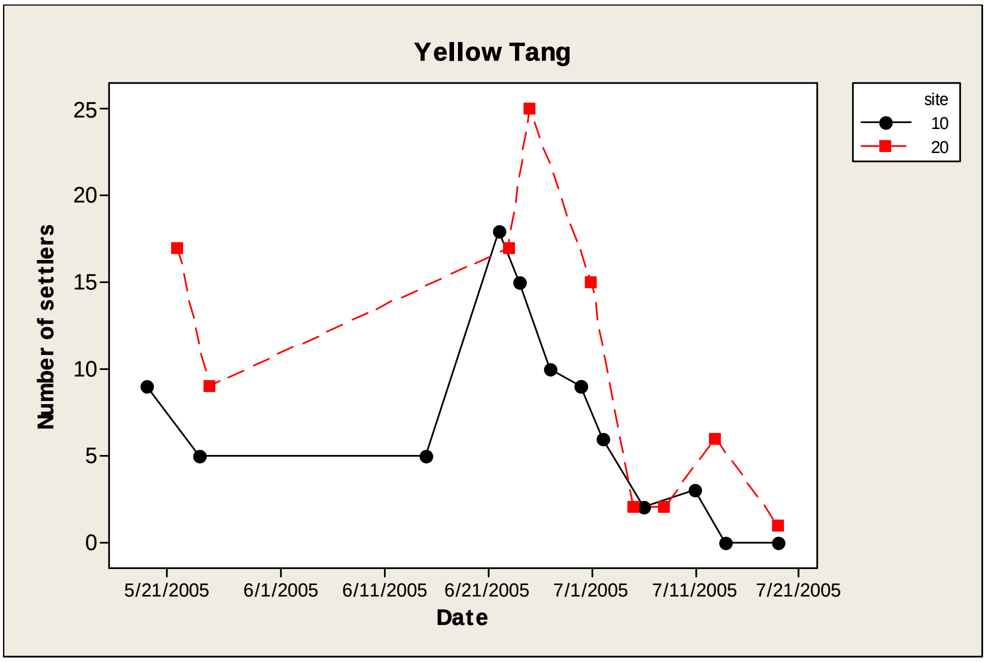


Figure 18. Numbers of recent yellow tang settlers at two sites during summer period in 2005 totaled across all fixed transects at each site for each count. Dominant settlement peaks correspond with full moons during the period.

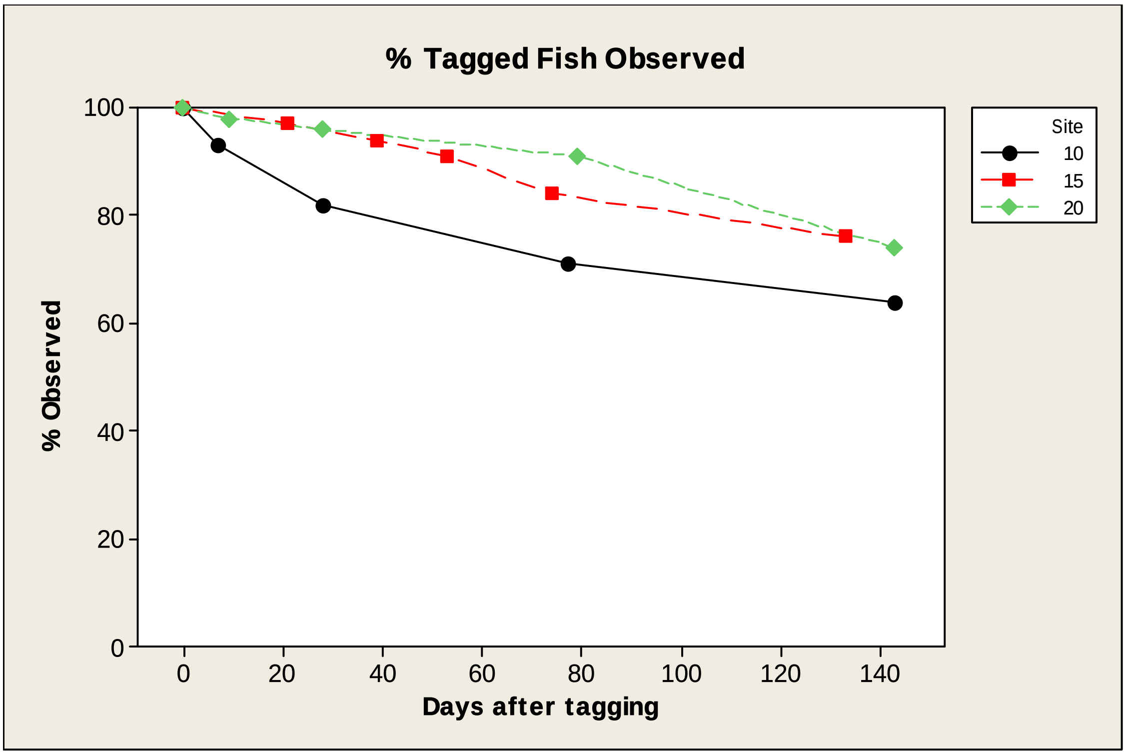


Figure 19. Percent of all yellow tang tagged and released initially that were in the same immediate neighborhood over the first ~5 months after they were tagged.

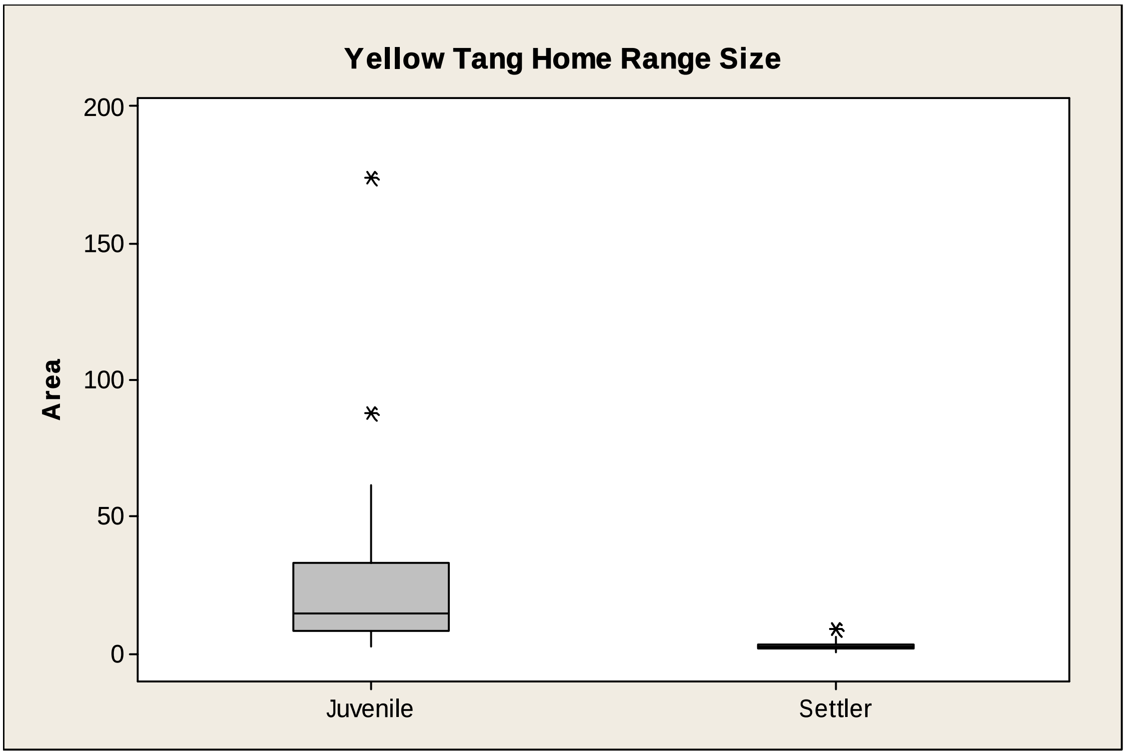


Figure 20. Distribution of home range areas (m^2) measured for yellow tang juveniles and settlers.

Table 1. Sex ratios of fish collected, and minimum and maximum sizes of fish collected of each sex, for all three focal species.

	Yellow tang			Kole			Brown surgeonfish		
Sex Ratio M:F		207:147			87:57			66:52	
		1.43:1			1.53:1			1.27:1	
	TL(mm)	SL(mm)	Wt(g)	TL(mm)	SL(mm)	Wt(g)	TL(mm)	SL(mm)	Wt(g)
Min. Male	69	56	9.5	74	56	9.0	87	62	10.3
Max. Male	194	160	168.4	196	142	189.6	170	123	73.0
Min. Female	78	64	11.9	86	61	13.8	88	64	11.5
Max. Female	177	148	143.0	188	140	179.5	160	116	66.4

Table 2. Associations between yellow tang settler density and benthic habitat characteristics: Pearson Correlations

Pearson Correlation at Site # 10 Wawaloli
Yellow tang settlers and various habitat characteristics

```
Cell Contents:
      Pearson correlation
      P-Value


                  Settlers
Transect            -0.517
                     0.020

Rugosity             0.259
                     0.270

Ave Depth            0.432
                     0.057

CORAL                0.641
                     0.002**

MACROALGAE           0.484
                     0.031

SUBSTRATE           -0.673
                     0.001**

Pocillopora         -0.089
                     0.710

Porites compressa    0.781
                    <0.001**

Porites lobata       0.662
                     0.001**

All Crustose        -0.290
                     0.216

Sand                -0.254
                     0.280

All Turf/bare       -0.649
                     0.002**
```

Pearson Correlation at Site # 20 Ke’ei
Yellow tang settlers and various habitat characteristics

```
Cell Contents:
      Pearson correlation
      P-Value


                  Settlers
Transect             0.004
                     0.986

Rugosity            -0.140
                     0.555

Ave Depth           -0.212
                     0.369

CORAL               -0.009
                     0.969

MACROALGAE           0.050
                     0.834

SUBSTRATE           -0.047
                     0.845

Pocillopora          0.236
                     0.317

Porites compressa    0.449
                     0.047**

Porites lobata      -0.412
                     0.071

All Crustose        -0.248
                     0.291

Sand                -0.192
                     0.417

All Turf/bare       -0.143
                     0.548
```

Table 3. Monthly growth rate estimates from measurements of recaptured elastomer-tagged yellow tang.

Site	Initial TL(mm)	Growth (mm) July to Aug	Monthly growth (mm) July to Dec
20	87.	4.0	
20	88		3.6
20	93		2.6
20	97	3.0	
20	97	2.0	2.2
20	97	3.0	
20	98	6.0	
20	100		1.0
20	107	5.0	
20	119	4.0	2.2
20	137	3.0	
10	75		4.2
10	95		3.8
10	105		2.2