Life History Compendium
of
Exploited Hawaiian Fishes

Prepared for

Fisheries Local Action Strategy
and
Division of Aquatic Resources

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INTRODUCTION

Hawaii has a large and diverse coral reef fishery which includes commercial, recreational, and subsistence fishers. Despite the cultural and economic importance of Hawaii's coral reef fisheries, life-history information for many exploited species is fragmentary or completely unknown in some cases. A detailed knowledge of life history parameters is essential to creating and evaluating fisheries management policies.

The purpose of this compendium was to compile and organize the existing life history information for some of the most heavily collected species into a standardized format. This will provide an important resource for fisheries management in Hawaii while identifying gaps to guide future life history research efforts.

METHODS

Thirteen species from five families were selected for literature review (Table 1). The literature review was conducted in three stages. Firstly, an electronic database search (Aquatic Sciences and Fisheries Abstracts, Google Search) was conducted using species names and synonyms as keywords in conjunction with life history parameters outlined on the following pages (see methods). Upon locating these references, we selected relevant literature from their bibliographies and repeated the process two more times, each time selecting pertinent literature for inclusion in the compendium.

We also conducted a manual search of theses and dissertations from the University of Hawaii at Manoa Zoology Department and contacted labs which do life history work in order to determine which species were currently being worked on or for which there may be un-published data.

All papers which described one or more life history parameters for Hawaiian populations were included in the compendium. Results for studies outside Hawaii were included only when data for Hawaiian populations were not available, were incomplete or differed in quality from the local studies. Studies which contained only habitat or demographic information (e.g., abundance, density and size-structure) were included when appropriate, but by no means is this compendium a comprehensive listing for these types of studies.

With few exceptions, we did not standardize units. Growth and morphometric equations appear as written in the original publication. This was done in order to reduce the possibility of transcriptional and computational errors and because a few authors did not specify units.

Our classification follows taxonomy of Randall [1]. Current valid name followed by reference to taxonomic authority. Reader referred to Mundy [2] for list of synonymies and authors using those synonymies in Hawaii. First Hawaii records from Mundy [1].

Description of life history parameters:

Larval Development: May include a description of larval morphology, development and metamorphosis. In most cases, information included in the compendium is general to the family and not specific to the species of interest.

First Reproduction: Reports the smallest size at which an individual of the species can reach sexual maturity. In general, females are considered mature when ovaries contain vitellogenic (yolked) oocytes. Males are considered mature when the testes shed milt or contain tailed spermatozoa. Most studies contained herein are based on gross observation rather than histological examination.

L_{50}: Reports the size-class at which 50% of individuals of a given sex are reproductively mature (see above).

Batch Fecundity: Reports the mathematical relationship between female size and the number of eggs that can be spawned in a single event. In comparison, annual fecundity (number of eggs spawned each year) is the product of batch fecundity and inter-spawning interval over the length of the spawning season.

Sex Ratio: Physical sex ratio is reported as the ratio of Males:Females, regardless of maturity. Operational sex ratio includes only reproductively mature individuals.

Egg Size: Reports the diameter (in microns, µm) of ovulated or spawned oocytes along the longest axis. May also report average size of earlier-stage oocytes.

Oocyte Development: Describes the size-structure and growth of oocytes within a mature female ovary. Terminology follows Wallace and Selman (1981). Fish are classified as *asynchronous* if oocyte development is random and no dominant size class of oocytes is present within the ovary, *synchronous* if all oocytes grow and ovulate in unison, and *group synchronous* if at least two populations of can be distinguished. The latter is the most common developmental scheme in reef fishes and is often assumed to indicate the ability to spawn multiple batches of eggs in a single spawning season.

Spawning Seasonality: Indicates months or seasons during which spawning has been reported. In most cases, information on spawning seasonality comes from Gonosomatic Index (GSI = gonad wt/(body weight-gonad weight) x 100) or, more rarely, histological examination of female ovaries (e.g., presence of stage IV oocytes or post-ovulatory follicles) In other cases, seasonality may be based on direct observation of spawning.

Inter-spawning interval: Average or minimum time between successive spawns for an individual female. Determined by direct observation or inferred from gonad histology.

Spawning Cue: Where known, reports environmental cues (e.g., lunar, tidal or temperature) which are believed to induce spawning behavior.

Spawning Mode: Reports whether eggs are shed into the water column (pelagic) or laid on the substrate (demersal). With the exception of triggerfishes, most large-bodied (> 100 mm) reef fishes spawn pelagic eggs.

Reproductive Mode: A species is termed *gonochoristic* if the sexes are separate and classified as a *simultaneous hermaphrodite* if an individual can shed mature oocytes and sperm at the same time. *Sequential hermaphrodites* change from one sex to another: *protogynous hermaphrodites* (protogyny) switch from female to male whereas *protandrous hermaphrodites* (protandry) switch from male to female. Protogynous species are termed *monandric* if all males are derived from sex-changed females, whereas *diandry* indicates that males may mature from juveniles or sex-changed females. See Sadovy and Shapiro (1987) for further description of reproductive mode.

Mating System: Indicates whether a male mates with several females (polygyny), a female with several males (polyandry) or if mating is monogamous or random. Mating system is usually determined by direct observation of fish spawning, though it can sometimes be inferred by the degree of sexual dimorphism.

Maximum Size: Maximum reported weight or length for a species.

Maximum Age: Reports the age of the oldest know individual.

Growth Equation: The relationship between age and size, as determined by otolith-based or mark-recapture studies. Unless otherwise noted, growth parameters are reported using the von Bertalanffy growth equation $L_t=L_\infty(1-e^{-k(t-t0)})$ where L_t = Length at time t, L_∞ = maximum asymptotic length, k = growth rate, and t_0 = time when length is theoretically zero.

Mortality: The predictable decline in numbers of individuals in successively older age-classes. *Total mortality* (Z) is the sum of *natural mortality* (M) and *fishing mortality* (F).

Morphometric Relationships: Reports the mathematical relationship between various body lengths or between body length and weight.

Diet: The majority of dietary information in this compendium comes from gut-content studies. Where possible, we report the total number of individuals examined for each study as well as the number of individuals with recognizable prey items. Dietary items may be reported in terms of percent *frequency of occurrence* (%FO), *volume* (%V), *number* (% N) and *index of relative importance* (IRI), which incorporates all three of the previous measurements.

RESULTS

Table 1. Checklist of know life history parameters for thirteen species of exploited Hawaiian fishes. Closed circles indicate that the information comes from Hawaiian studies whereas open circles indicate information from locations outside Hawaii. Triangles indicate that the information supplied is not specific to the indicated species. Asterisks indicate parameters which are undergoing current work in Hawaii.

	1st Reproduction	L_{50}	Batch Fecundity	Sex Ratio	Egg Size	Oocyte Development	Spawning Season	Inter-Spawning Interval	Spawning Cue	Spawning Mode	Reproductive Mode	Mating System	Pelagic Larval Duration	Larval Development	Maximum Size	Maximum Age	Growth Equation	Mortality	Length vs. Length	Length vs. Weight	Diet
Myripristis amaena	●		●		●	●	●						●	Δ		●	●		●	●	●
Sargocentron diadema														Δ							●
Caranx ignobilis	●	●		●	Δ		●		●	●	●			Δ	●	●	●		●	●	●
Caranx melampygus	●	●	●		●	●	●	●	●	●	●			Δ	●	●	●		●	●	●
Pseudocaranx cheilio				●	Δ									Δ		●	●				●
Mulloidichthys flavolineatus	*	●	*	*	*	*	*			●	*			Δ	●	●	●		●	●	●
Parupeneus multifasciatus	●	●	*	●	●	●				●	●		*	Δ	●	●	●	●	●	●	●
Parupeneus porphyreus	●	*	*	●	●	●	●			●	●		●	Δ	●	●	●		●	●	●
Chlorurus spilurus	●			●	Δ		●			●	●	●			●		●		●	●	●
Scarus psittacus	●			●			●			●	●	●			●	○	○		●	●	●
Acanthurus triostegus	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●
Ctenochaetus strigosus	●	*	*	●			●		●			●		Δ	●	●	*		●	●	●
Naso unicornis										●				Δ	●	○	○	○		○	○

HOLOCENTRIDAE

Myripristis amaena **(Castelnau, 1873) [3]**

Neomyripristis amaenus Castelnau, 1873 [4]
Myripristis symmetricus Jordan & Evermann, 1903 [5]
Myripristis argyromus Jordan & Evermann, 1903 [5]
Myripristis praslinus non Cuvier *in* Cuvier & Valenciennes, 1829 [6]
Myripristis pralinius non Cuvier *in* Cuvier & Valenciennes, 1829 [6]

Geographic range: Pacific Ocean from the Ryukyus, the Ogasawara Islands, Micronesia, Belau, New Guinea and the Caroline Islands to the Hawaiian Islands, the Line Islands, Society Islands, the Tuamotus, and Pitcairn Group [2]. No records from Indo-Malaya [2].

First Hawaii record: Jordan & Evermann, 1903 as *Myripristis symmetricus* and *Myripristis argyromus* [5]

General Introduction

Commonly known as ʻūʻū (the generic Hawaiian name for *Myripristis* species), brick soldierfish, and menpachi. Benthopelagic, in or near caves and crevices at 5-25 m [2]. Generally found in less than 10 m [1]. Occurs singly or in schools [7].

In a 1990 survey of the Johnston Atoll recreational fishery, it was typically the species caught in greatest abundance [8]. Fifty-one percent were pre-reproductive, 46% at Puako, Hawaii were pre-reproductive [8].

Fishing is unregulated.

Reproduction and larvae

Spawning mode and appearance at hatching are unknown. No species-level description of *M. amaena* larvae exist; however Leis & Carson-Ewart [9] illustrate the development of *Myripristis* larva and offer the following account of the soldierfishes: Deep head and trunk, but slender tail. Preanal length is 42-70% body length when gut is fully coiled. A small, pigment-covered gas bladder above the anterior portion of gut. Head is only slightly compressed. Snout is initially short and truncate but becomes elongate and bulbous as rostral spine develops. Mouth does not reach to mid-eye, is initially terminal but becomes inferior as rostral complex develops. Gill membranes are free from the isthmus. At ~2.5 mm a large, bifurcate, serrate rostral spine begins to form and reaches maximum relative length shortly after notochord flexion. Larvae with this spine are called rhynchichthys larvae. The spine then decreases in size and disappears by 35 mm. At 1.9 mm, a smooth spine is located at the angle of the preopercle, and the supraoccipital crest has one posteriorly-directed and one small dorsal spine. At 2.4 mm, transverse ribs and weak serrations develop on the posteriorly-directed supraoccipital spine and on the preopercular spine. By 18 mm, the supraoccipital crest has only a slightly raised ridge and a small posteriorly-directed spine. These disappear by 30 mm. Pelvic buds are present at 2.4 mm, with supporting elements appearing by 3.5 mm. Between 4.6 and 5.1 mm, the dorsal, anal and pectoral rays begin to form as dorsal spines ossify. All dorsal, pelvic and anal rays, and 3 of 4 anal spines, are complete by 7.6 mm. The 4th anal spine, pectoral fin and spinous dorsal are fully developed by 8.3 mm. Strongly ctenoid scales form at 6.0-7.5 mm. The lateral line forms at 10 mm. At settlement, the spine at the angle of the preopercle is short and smooth, and the opercular and preopercular margins are strongly serrate. Young larvae have a pigmented gut and several melanophores on the brain; and one to two dorsal, lateral and ventral melanophores on the tail. The tail melanophores disappear as rostral spines form. Pigment covers the whole body except for soft dorsal fin and posterior tail in postflexion larvae. The largest pelagic stages are blue and silver in life, but may become reddish just before settlement.

Based on an assumed settlement mark in a single otolith, Dee & Radtke [10] suggest a larval duration of 115-125 days.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL [8]	149 mm	154 mm	5♂, 11♀	
Age [8]	6 yr	6 yr		
L_{50}				
TL				
FL				
SL				
Age				
Batch fecundity vs:				
Size		$BF = 5.029 \cdot 10^{-20} (SL\ in\ mm)^{10.614}$	12	156-181
Age				
Weight		$BF = 1.447 \cdot 10^{-7} (Wt\ in\ g)^{5.0038}$	12	~150-225
Sex ratio (F:M)				
Mature egg size/volume [8]	0.4 mm diameter			0.40-0.54
Egg development	Group synchronous[a]			
Peak spawning season	April-June		99	[b]
Interspawning interval (# days)				
Spawning Cue				
Spawning mode				
Reproductive mode				
Mating system				

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[a] Based on interpretation of histological section presented in Dee & Parrish, 1994.

[b] A second, smaller peak was seen in January at Johnston Island (Dee & Parrish, 1994).

Growth and mortality

	Male	Female	N	Range
Maximum size				
TL [1]	30 cm			
SL [10]	215 mm			
FL				
Wt				
Maximum age [10]	14 years			
Growth equation [10]	SL_t in mm = $194.28(1-e^{-0.219\ (\text{age in yearst}+0.66)})$		15	44-187
Mortality				
Z				
M				
F				

Morphometric relationships

	Equation	N	Range
TL vs SL [11]	SL in mm = -16.61 + 0.88(TL in mm)		
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt			
SL vs Wt [10]	Wt in g = $0.00003097(\text{SL in mm})^{3.042}$	85	44-190

Diet

Dee & Parrish [8] presented results for 64 specimens for Johnston Atoll, 9 from the Northwestern Hawaiian Islands, 22 from Puako, Hawaii; plus 14 specimens analyzed by Hobson [12] at Kona, Hawaii. Megalops (crab larvae) dominated the diet in frequency of occurrence, number and volume. Next in importance were shrimp and fishes. Feeding is nocturnal.

Additional references

Hayes et al. [11] present size structure of recreational catch at Puako, Hawaii.

Sargocentron diadema (Lacepède, 1802) [13]

Holocentrus diadema Lacépède, 1802 [14]
Holocentrum diadema Lacépède, 1802 [14]
Adioryx diadema (Lacépède, 1802)

Geographic range: Indo-Pacific from South Africa, the Red Sea, and the Chagos Archipelago to Indonesia, southern Japan, the Ogasawara Islands, Australia, the Hawaiian Islands, French Polynesia and the Pitcairn Group [2].

First Hawaii record: Günther, 1873–1910 as *Holocentrum diadema* [15]

General Introduction

Commonly known as ʻalaʻihi (the generic Hawaiian name for squirrelfishes, but see Titcomb [7]), ʻalaʻihi kalaloa (or ʻalaʻihi kanaloa or ʻalaʻihi kakaloa), and crown squirrelfish . Young are called ʻa ʻalaʻihi [7]. Engybenthic in or near crevices and caves of coral reefs from 3-77 m, often in lagoons or bays at < 20 m [2]. It is generally the most common species of *Sargocentron* wherever it is found.

Fishing is unregulated.

Reproduction and larvae

Spawning mode and appearance at hatching are unknown. No species-level description of *S. diadema* larvae exist; however Leis & Carson-Ewart [9] illustrate the development of an unidentified squirrelfish larva and offer the following account of the squirrelfishes: Deep head and trunk, but slender tail. Preanal length is 42-70% body length when gut is fully coiled. A small, pigment-covered gas bladder above the anterior portion of gut. Head is only slightly compressed. Snout is initially short and truncate but becomes elongate and bulbous as rostral spine develops. Mouth does not reach to mid-eye, is initially terminal but becomes inferior as rostral complex develops. Gill membranes are free from the isthmus. At ~2.5 mm a large, serrate rostral spine begins to form and reaches maximum relative length shortly after notochord flexion. Larvae with this spine are called rhynchichthys larvae. The spine then decreases in size and disappears by 35 mm. At 1.9 mm, a smooth spine is located at the angle of the preopercle, and the supraoccipital crest has one posteriorly-directed and one small dorsal spine. At 2.4 mm, transverse ribs and weak serrations develop on the posteriorly-directed supraoccipital spine and on the preopercular spine. By 18 mm, the supraoccipital crest has only a slightly raised ridge and a small posteriorly-directed spine. These disappear by 30 mm. Pelvic buds are present at 3.3 mm, with supporting elements appearing just after flexion. Between 4.6 and 5.1 mm, the dorsal, anal and pectoral rays begin to form as dorsal spines ossify. All dorsal, pelvic and anal rays, and 3 of 4 anal spines, are complete by 7.6 mm. The 4th anal spine, pectoral fin and spinous dorsal are fully developed by 8.3 mm. Strongly ctenoid scales form at 6.0-7.5 mm. The lateral line forms at 10 mm. At settlement, the spine at the angle of the preopercle is short and smooth, and the opercular and preopercular margins are strongly serrate. Young larvae have a pigmented gut and several melanophores on the brain. Pigment covers the whole body except for soft dorsal fin and posterior tail in postflexion larvae. The largest pelagic stages are blue and silver in life, but may become reddish just before settlement.

	Male	Female	N	Range
First reproduction TL FL SL Age				
L_{50} TL FL SL Age				
Batch fecundity vs: Size Age Weight				
Sex ratio (F:M)				
Mature egg size/volume				
Egg development				
Peak spawning season				
Interspawning interval (# days)				
Spawning Cue				
Spawning mode				
Reproductive mode				
Mating system				

Growth and mortality

	Male	Female	N	Range
Maximum size TL [1] SL FL wt	17 cm			
Maximum age				
Growth equation [16]	[c]			
Mortality Z M F				

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[c] Munro & Williams (1985) describe k & L_∞ as 1.47 annually and 153 mm TL, respectively.

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt			
SL vs Wt			

Diet

This squirrelfish is a nocturnal predator. Hobson [12] examined 28 specimens speared at night in Kona, Hawaii. Xanthid crabs were eaten most frequently and in the highest volume. Next in importance (approximately equal to one another) were ophiuroids and megalops (crab larvae). Caridean shrimp and prosobranch gastropods were also eaten frequently, occupying ~6% each of the total prey volume consumed.

CARANGIDAE

Caranx ignobilis **(Forsskål, 1775) [17]**

Scomber ignobilis Forsskål, 1775 [18]
Carangus hippoides Jenkins, 1903 [19]
Carangus ignobilis (Forsskål, 1775)

Geographic range: Tropical Indo-Pacific from South Africa and the Red Sea to southern Japan, the Ogasawara Islands, Australia, New Zealand, Micronesia, the Hawaiian Islands, the Marquesas Islands, and Pitcairn Island [2].

First Hawaii record: Jenkins, 1903 as *Carangus hippoides* [19]

General Introduction
Commonly known as ulua aukea (or ulua kea), giant trevally, white ulua, and giant ulua. Black ulua may be used by fishermen for dark individuals, which sometimes creates confusion with *C. lugubris*. Hawaiian names for stages of growth, from smallest to largest, for *Caranx* are: papiopio (usually shortened to pāpio today- young), pau uʻu (or pauʻu-individuals of intermediate size) and ulua (adult) [7]. Application of these common names varies by island and fishermen, although most fishers consider specimens < 10-15 lbs to be papio and those greater than this to be ulua [20]. Although once part of a large commercial fishery, its availability and sale in local markets has declined in recent years due to concerns about ciguatera toxicity [20][d]. Despite these concerns, *Caranx ignobilis* remains prized among recreational anglers and spearfishermen, with the estimated value of the recreational fishery on this and other large Hawaiian carangids to be $31 million annually [20]. An official "100 plus club" records the number of large ulua caught and registered on each island [21]. The number of registered ulua has increased steadily since the 1980s [21], with the majority of large individuals taken from Hawaii, Oahu, and Maui [20].

Pelagic over sand, rock, and reefs from 1-188 m [2]. Adults are most abundant on forereef [22], exposed fringing reefs and barrier reefs [23] whereas juveniles inhabit protected areas such as sandflats, backreef, lagoons and estuaries [24, 25]. Estuaries, in particular, may be important nurseries for this and other carangid species [24, 25]. Growth rates of juveniles varies seasonally and may be correlated with availability of preferred prey items [21].

May occur singly or in large groups [1, 22]. Young often forage in small schools [26][e]. In the Northwest Hawaiian islands, *C. ignobilis* is the dominant apex predator (up to 39% of the total fish biomass [23]) and is believed to have a profound influence in structuring fish assemblages there [27]. Populations of *C. ignobilis* in the main Hawaiian Islands are significantly depressed [28] as a result of significant fishing pressure.

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[d] Reported commercial landings and sales for *C. ignobilis* in 1998 were 10,149 lbs and 9,455 lbs respectively.

[e] Major (1978) found that juvenile *C. ignobilis* were more successful at capturing schooling anchovies when hunting in small groups than when hunting alone.

A number of acoustic tracking studies have been conducted on *C. ignobilis* in the main [24] and NWHI [29, 30]. The most comprehensive of these [30] tracked 28 individuals on five atolls over five and 12 month periods using passive acoustic telemetry. Their results indicate that individual fish can range as far as 29 km from their capture site, but that most (73%) movements are less than 5 km back-and-forth. They also observed diel, lunar and seasonal patterns in movement, with lunar peaks occurring around the full- and third-quarter moon phases during the summer months [30] when they are presumably spawning [31]. An active tracking study conducted on juvenile *C. ignobilis* (n=5 for max of 125 hours) in Kaneohe Bay (Oahu, Hawaii) found that home range size was from 0.173-0.768 km^2 and that kernel home range size increased with fish weight. Fish were also most active at night and during the crepuscular periods. This same study analyzed mark and recapture data from 289 *C. ignobilis* (13.8-43 cm FL) from Kaneohe Bay. Time at liberty ranges from two days to approximately eight years with 32% of the recaptures within 0.5 km of the capture site, but one individual traveling 70 km in seven years.[f]

Minimum size in Hawaii is 10 inches (must be 16 inches for commercial sale). Daily bag limit is 20 (all species combined).

Reproduction and larvae

Forms large spawning aggregations of 100+ individuals [32]. Schools segregate by sex during pre-spawning period [33]. Males assume a dark coloration during spawning while females are lighter colored [32, 34]. Recruitment of 4" individuals to inshore areas occurs June- December, with peak recruitment August–December [21]. Young initially recruit to sheltered inshore areas such as estuaries then move to deeper water after 1-2 years [24, 25]. Hybridization with the congener *C. melampygus* has been reported [35].

Eggs of carangids are spherical, 0.7-1.5 mm in diameter, and pelagic [36]. Carangid larvae are usually 2.0-4.3 mm long, have a large yolk sac, unformed mouth, and unpigmented eyes [36]. Pigmentation of carangid larvae changed during the yolk absorption stage [36]. No species-level description of *C. ignobilis* larvae exist; however Leis & Trnski [36] illustrate the development of *Caranx* larva and offer the following account of the tribe Carangini: strongly compressed, with 24-25 myomeres. Gut initially straight, but begins to coil by 2.5 mm. The gut reaches 53-68% body length in preflexion larvae. The anus reaches 44-64% body length in postflexion larvae. The gas bladder is conspicuous and located over the gut coil. The snout is initially concave, but becomes convex by the postflexion stage. Small teeth form in preflexion larvae. Two rows of smooth preopercular spines form very early in the preflexion stage (1.8-2.5 mm). These are the last head spines to disappear during development. A supraoccipital crest is present during the early preflexion stage. There are no pterotic spines or ridges. Dorsal and anal fins form at the same time, with ossification occurring during flexion. The caudal peduncle is narrow after flexion is complete.

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[f] This study also provides size-frequency data for 321 *C. ignobilis* captured in Kaneohe Bay.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL [31]		550 mm SL	48	
Age				
L_{50}				
TL				
FL				
SL [31]		600 mm SL	48	
Age				
Batch fecundity vs:				
Size				
Age				
Weight				
Sex ratio (F:M) [31]	1.39:1[g][h]		119	
Mature egg size/volume [36]	700-1500 µm			
Egg development				
Peak spawning season [31]	May-August		43	May-Oct
Interspawning interval (# days)				
Spawning Cue (37)	Lunar			
Spawning mode	Pelagic			
Reproductive mode [37]	Gonochoristic (assumed)			
Mating system				

Growth and mortality

	Sex Unknown	N	Range
Maximum size			
TL			
SL			
FL [31]	1,648 mm[i]		
Wt [31]	86.71 kg		
Maximum age			
Growth equation [31]	L in mm SL $=1838(1-e^{-0.111(t \text{ in yr}-0.097)})$[j]	10	106-1180 mm
[25]	L in mm SL $=2129\ (1-e^{-0.082(t \text{ in yr}+0.173)})$	20	60-1180 mm
Mortality			
Z			
M			
F			

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[g] Based on macroscopic evaluation of fresh gonads. Immature individuals were apparently excluded from the count, so this estimate may be closest to an operational sex ratio.

[h] Williams (1965) reports male-biased sex ratios (1:1.68 F:M; n= 78) for *C. ignobilis* collected off East Africa.

[i] Max length estimated from weight of 86.71 kg.

[j] Based on SEM counts of otolith increments. Otolith increments were assumed to be deposited daily, but this was not validated for *C. ignobilis*. The same study successfully validated daily increment formation in a congener from Hawaii (*C. melampygus*) and provides growth information for *C. ignobilis* based on a captive feeding study.

Morphometric relationships

	Equation	N	Range
TL vs SL [31]	SL in mm = -17.5 + 0.855(TL in mm)	107	
TL vs FL [31]	TL in mm = 35.7 + 1.070(FL in mm)	107	
SL vs FL [31]	SL in mm = 6 + 0.924(FL in mm)	107	
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt			
SL vs Wt [24] [31]	W in kg = $5 \cdot 10^{-5}$(FL in cm)$^{2.7498}$ W = $2.30 \cdot 10^{-5}$(SL in mm)$^{2.977}$	65 118	

Diet

Caranx ignobilis feed primarily on fishes, cephalopods, and large crustaceans (including lobsters) (39). In Hawaii, they are believed to forage more frequently at night (40). This is supported by the presence of several night-active prey items in their diet [31] as well as tracking studies [24].

Several dietary studies have been conducted on *C. ignobilis* in both the NWHI and Main Hawaiian Islands.

Sudekum et al. [31] examined the gut contents of 118 specimens from NWHI. Of these, 68.6% contained identifiable prey organisms. Fishes were most important (80.3% FO, 73.1% V). The top-five families of fishes were (in descending FO): Scaridae (13.6)[k], Carangidae, including opelu, *Decapterus macarellus* (8.6), Labridae (6.2%), Priacanthidae (6.2%), and eels of various families (14.8%). Cephalopods (mostly octopus) accounted for 24.7% and 15.9% frequency and volume respectively, whereas crustaceans (including palinurid lobsters) accounted for 17.3% and 11%.

Meyer et al. [38] examined 19 *C. ignobilis* collected from fishing tournaments on Oahu. In contrast to the above study, they found fish accounted for only 7.3% of prey volume (22.2% frequency of occurrence) whereas crustaceans (especially the crab *Portunus japonicas*) were most important in terms of frequency of occurrence (88.9%) and volume (91.8%).

Smith and Parrish [25] examined the guts of 106 juvenile (50-177 mm FL) *C. ignobilis* collected from an estuary on Kauai. Fish were found in 43.4% of the guts and accounted for 95.1% of total percent volume. The majority of fish were not identifiable to family, though kuhliids, bothids, mugilids, and gobioids were present. Crustaceans were found in 71.1% of the guts, but accounted for only 3.3% of prey volume. These included amphipods, tanaids, isopods, shrimp, stomatopods, copepods and crabs

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[k] The authors state that scarids may be over-represented in their dietary analysis due to the ease of identification of this family due to their unique pharyngeal plates.

Caranx melampygus Cuvier *in* Cuvier & Valenciennes, 1833 [39]

Caranx melampygus Cuvier *in* Cuvier & Valenciennes, 1833 [39]
Caranx stellatus Eydoux & Souleyet, 1850 [40]
Carangus melampygus (Cuvier, 1833)
Caranx hippos non (Linnaeus, 1766) [41]
Caranx latus non Agassiz *in* Spix & Agassiz, 1831 [42]
Carangus forsteri non Cuvier *in* Cuvier & Valenciennes, 1833 [39]
Caranx ascensionis non (Cuvier, 1833)
Caranx melampygus (Cuvier, 1833)

Geographic range: Tropical Indo-transpacific from South Africa and the Red Sea to the Ryukyu and Ogasawara Islands, Australia, New Caledonia, Micronesia, the Hawaiian Islands, Ducie Island, the offshore islands of the eastern tropical Pacific, and southern Baja California to Panama [2].

First Hawaii record: Eydoux & Souleyet, 1850 as *Caranx stellatus* [40]

General Introduction

Commonly called ‘ōmilu (or ‘omilumilu, but see Titcomb [7]), hoshi ulua, bluefin trevally, blue crevally, blue ulua, ulua omilu, and hoshi. Hawaiian names for stages of growth, from smallest to largest, for *Caranx* are: papiopio (usually shortened to pāpio today), pau u‘u (or pau‘u) and ulua [7]. Pelagic but reef-associated, often just above sand or reefs, at 1–190 m [2]. The young often use estuaries as nursery areas [25]. In Hanalei estuary (Kauai), young reside in estuary to ca. 0.7 years of age [25] then disappear, presumably moving into deeper [21] or more exposed habitats. Growth rates of juvenile *C. melampygus* varies seasonally and may be correlated with recruitment of preferred prey items (*e.g.*, small goatfishes) [21].

Forages most often singly or in pairs; occasionally forages in large groups [43]. May form inter-specific feeding associations with goatfishes [12] sharks, barracuda or rays [43].

An acoustic telemetry study [44] conducted at Coconut Island indicates that *C. melampygus* have modest (4596 ± 963 linear meters) home ranges and are more active and during the day [44]. The modest home range is supported by mark and recapture data: 75% of fish were re-captured within 0.5 km of their release location. Time at liberty was not correlated with distance traveled [44][1].

Caranx melampygus account for the majority of large jacks caught by fishers [21, 38]. Once part of a large commercial fishery, sale of *C. melampygus* and other carangids has decreased in the last 20 years due to concerns about ciguatera toxicity [20, 21]. Individuals > 6 inches FL (152 mm) are commonly caught by anglers [21]. Minimum take-home size in Hawaii is 10 inches (must be 16 inches for commercial sale). Daily bag limit is 20 (all species combined).

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[1] This latter statement is supported by our interpretation of data from Tagawa and Tam (2006): distance traveled does not correlate with fish length.

Reproduction and larvae

Eggs of carangids are spherical, 0.7-1.5 mm in diameter, and pelagic [36]. Carangid larvae are usually 2.0-4.3 mm long, have a large yolk sac, unformed mouth, and unpigmented eyes [36]. Pigmentation of carangid larvae changed during the yolk absorption stage [36]. No species-level description of *C. melampygus* larvae exist; however Leis & Trnski [36] illustrate the development of *Caranx* larva and offer the following account of the tribe Carangini: strongly compressed, with 24-25 myomeres. Gut initially straight, but begins to coil by 2.5 mm. The gut reaches 53-68% body length in preflexion larvae. The anus reaches 44-64% body length in postflexion larvae. The gas bladder is conspicuous and located over the gut coil. The snout is initially concave, but becomes convex by the postflexion stage. Small teeth form in preflexion larvae. Two rows of smooth preopercular spines form very early in the preflexion stage (1.8-2.5 mm). These are the last head spines to disappear during development. A supraoccipital crest is present during the early preflexion stage. There are no pterotic spines or ridges. Dorsal and anal fins form at the same time, with ossification occurring during flexion. The caudal peduncle is narrow after flexion is complete.

	Male	Female	N	Range
First reproduction				
TL [31]		325 mm		
FL				
SL				
Age [31]		2 years		
L_{50}				
TL [31]		350 mm		
FL				
SL				
Age [31]		2 years		
Batch fecundity vs:				
Size [31]		$F = 2.286 \cdot 10^{-9} (SL)^{5.359}$	11	328-640 mm
Age				
Weight [31]		$F = 0.923(Wt)^{7.694}$		
Sex ratio (F:M) [31]	1.48:1[m]		119	
Mature egg size/volume [45]	758 ± 17 µm[n]			721-787 µm
Egg development	Group Synchronous			
Peak spawning season [31]	May-July[o]			Apr-Nov
Interspawning interval (# days)	[p]			
Spawning Cue [45]	Possibly lunar (new moon & 3rd quarter)			
Spawning mode	Pelagic			
Reproductive mode	Gonochoristic			
Mating system				

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[m] In contrast, Williams (33) found male-biased (1:1.68 F:M) populations off East Africa.

[n] Although Moriwake et al. (2001) report egg diameter to be 0.758 µm, we assume the diameters were given in mm, not microns.

[o] Moriwake et al. (2001) report that 75% of eggs spawned by *C. melampygus* in captivity were recovered in months May-August.

[p] Moriwake et al. (2001) report that captive female *C. malampygus* typically spawned eight times each season with interspawning intervals as short as five days.

Growth and mortality

	Sex Unknown	N	Range
Maximum size			
TL [1]	100 cm		
SL			
FL			
Wt			
Maximum age			
Growth equation [31]	$SL \text{ in mm} = 897(1-e^{-0.233(t \text{ in yr}+0.044)})$[q]	14	122-660 mm
[25]	$SL \text{ in mm} = 973(1-e^{-0.194(t \text{ in yr}+0.196)})$[r]	20	70-660 mm
Mortality			
Z [46]	0.69		
M [46]	0.27		
F [46]	0.42		

Morphometric relationships

	Equation	N	Range
TL vs SL [31]	$SL = -17.4 + 0.878(TL)$	140	
TL vs FL [31]	$TL = 24.3 + 1.052(FL)$	140	
SL vs FL [31]	$SL = 1.5 + 0.929(FL)$	141	
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt			
SL vs Wt [31]	$W = 2.86 \cdot 10^{-5}(SL)^{2.974}$	140	

Diet

Caranx melampygus is a diurnal piscivore, with peaks foraging at dusk and dawn (46; 12).

Hobson [12] examined six specimens from Kona, Hawaii. Only one individual (collected 3h after sunrise) contained readily identifiable prey items including larval fishes and mysid shrimps).

Sudekum et al. [31] examined 147 individuals from the Northwestern Hawaiian Islands. Eighty-five percent contained identifiable prey items. Of these, 96% contained fish. The most important families were Labridae, Mullidae, Monocanthidae, Pomacentridae, Scaridae, and Priacanthidae.

Meyer et al. [38] examined 264 individuals collected from Kaneohe Bay (Oahu, Hawaii) during fishing tournaments. Fish were most important, occurring in 86.3% of individuals and accounting for 95% of prey volume. Among fish families identified were Labridae, including

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[q] Based on counts of otolith increments. Daily formation of otolith increment formation was validated by the authors using injected tetracycline.

[r] Equation incorporates growth data from Sudekum et al. (1991) and additional juveniles from a Kauai estuary.

Thalassoma duperrey (14.1% frequency of occurrence), Scaridae (9.86%), Mullidae, including *Mulloidichthys flavolineatus* (7%), Blenniidae (6.3%), Synodontidae (4.9%), Gobiidae (7.8%), Pomacentridae, mostly *Dascyllus albisella* (3.4%), and Acanthuridae (2.82%). Crustaceans (alpheid shrimps, stomatopods and crabs) were found in 22.7% of guts, but accounted for only 4.1% of prey volume.

Smith and Parrish [25] examined 90 juvenile (53-165 mm FL) *C. melampygus* collected from a Kauai estuary. Fish were found in 43.4% of the guts and accounted for 95.1% of total prey volume. The majority of fish could not be identified, but kuhliids and gobiioids were present. Crustaceans were found in 85.5% of guts, but accounted for 4.93% of prey volume. These included: tanaids, isopods, shrimp, amphipods, crabs and copepods.

Additional references

Gaffney [20] summarizes data on fishing pressure and management recommendations.
Tagawa and Tam [21] provide tag and release data, and information on growth, recruitment and movement patterns.
Honebrink [37] quite thoroughly reviews taxonomy and biology for this and other Hawaiian carangids, and will be helpful to anyone wishing for a more detailed description of the biology of *C. melampygus* in a single reference.
Masuda and Ziemann [47] state that *C. melampygus* are important predators of cultured threadfin fingerlings (*Polydactylus sexfilis*) released into the wild. They describe the effects of fish size and stress level on predation.

Pseudocaranx cheilio (Snyder, 1904) [1]

Scomber dentex Bloch & Schneider, 1801 [48]
Carangus cheilio Snyder, 1904 [49]
Caranx cheilio (Snyder, 1904)
Caranx delicatissimus Döderlein *in* Steindachner & Döderlein, 1884 [50]
Caranx dasson non Jordan & Snyder, 1907 [51]
Pseudocaranx dentex (Bloch & Schneider, 1801)

Geographic range: Hawaiian Islands [1].

First Hawaii record: Snyder, 1904 as *Carangus cheilio* [49].

General Introduction

Commonly called lehe (but see Titcomb [7]), ulua, white trevally, thicklipped jack, butaguchi, buta ulua, pig ulua. Epi-, and meso-benthopelagic at 1–238 m, more common in the Northwestern Hawaiian Islands [2] where most individuals inhabit depths between 73-181 m [63].

This genus is currently in a state of taxonomic flux. Until Randall [1] recognized *P. cheilio* as a Hawaiian endemic, it was considered part of the Indo-Pacific and Atlantic, *P. dentex*. Much of the information presented below is based on studies of *P. dentex* performed outside Hawaii and should be viewed with caution.

Found midwater [52], and inhabiting reef edge by night [53]. This species is rarely caught in the main Hawaiian Islands [22, 37][s]. Juveniles exhibit strong schooling behavior [54] and are often found associated with flotsam. The sensory and developmental aspects of this behavior have been well-described [54-57].

Pseudocaranx dentex shows ontogenetic change in habitat use and schooling behavior. Immature individuals inhabit sheltered near-shore areas year-round, and typically occur in schools of < 10 individuals. Larger individuals (510-700 mm TL) are typically found on exposed off-shore reefs during the summer spawning season where they aggregate in schools of 20-70. These schools were assumed to be spawning aggregations, but this was not verified. After the spawning season, the aggregations break up and adults leave (assume that they move to deeper habitats). [128].

Afonso [128] studied the habitat use and site fidelity of *P. dentex* populations in the Azores using active tracking (n = 5 for 48 hrs each), passive acoustic telemetry (n=32 for 3 years) and tag-recapture studies (n = 58). Results of his studies indicate that *P. dentex* have large home ranges (up to 370 hectares in a 48 hr track) and can make large (> 10's km) short-term movements. Recaptures (14%) from the tagging portion of the study indicate that movements ranged from 100 m to 52 km over 11-416 days. Individuals inhabiting inshore reefs made predictable along-shore movements, moving northward during first 12 h and southward during the second 12. Fish movement likewise varied seasonally. Counter to their previous hypothesis [59] there was no

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[s] Data from Tagawa and Tam (2006) indicate that *P. cheilio* was the 7th most commonly collected carangid in a state-sponsored mark-recapture program, accounting for just 0.49 % fish captured

evidence of large aggregations during the summer spawning season [128]. Instead, adult fish ranged more widely during the summer and visit adjacent reefs. Afonso [128] hypothesizes that this "visiting" behavior increases mating opportunities and that the lack of spawning aggregations may be a result of fishing pressure.

Pseudocaranx dentex is cultured extensively in Japan [38] where it is among the more economically important carangid species [61]. Also a popular food-fish in the Atlantic.

In Hawaii, minimum size for *P. cheilio* in Hawaii is 10 inches (must be 16 inches for commercial sale)[t]. Daily bag limit is 20 (all species combined).

Reproduction and larvae

Brownell (60) describes larvae of *P. dentex*. Masuda and Tsukamoto (58) describe chronology of sensory system development and associated behavioral changes: Retinas pigmented by day 2 (3.4 mm TL) becoming positively phototaxic by 3 days (3.5 mm). Epithelium pigmented and free neuromasts also present by day 3 [64]. Fin spines complete by day nine. Vitreous humor forms at 10 days (4.3 mm). Seeks areas of low illumination by day 12. Cephalic canal complete by 18 mm. Outer retinal layer complete by 20-25 days (18-21 mm). Scale formation and trunk lateral line form at 23-30 mm.

In the Azores, juvenile *P. dentex* recruit to inshore habitats at 50-70 mm TL, move to deeper waters after reaching sexual maturity, and form aggregations around summits of offshore reefs during the spawning season (62).

	Male	Female	N	Range
First reproduction TL FL SL Age				
L_{50} TL (62) FL SL Age	278 mm	300 mm	360	111-783 mm
Batch fecundity vs: Size Age Weight				
Sex ratio (F:M)	1.14:1 (Seki, 1980) 1.04:1 (62)			
Mature egg size/volume				
Egg development				
Peak spawning season (62)	August			June-Sep
Interspawning interval (# days)				
Spawning Cue				

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[t] A total of 40,522 lbs was landed in 1998, of which 37,953 was sold for a value of $53,643 (38).

Spawning mode	Pelagic		
Reproductive mode	Assumed Gonochorist		
Mating system			

Growth and mortality

	Sex Unknown	N	Range
Maximum size			
TL (20)	940 mm		
SL			
FL	910 cm (Gosline and Brock, 1960)		
Wt			
Maximum age			
Growth equation [126]	FL in mm = $1085\ (1\text{-}e^{-0.258(t+0.12yr)})$	8	340-960 mm FL
	FL in mm = $1232\ (1\text{-}e^{-0.307(t-0.77yr)})$	37	
Mortality			
Z			
M			
F			

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt (65)	$W = 1.070 \cdot 10^{-8}(FL)^{3.0074}$		
SL vs Wt			

Diet

Pseudocaranx cheilio is an opportunistic carnivore which feeds primarily on benthic fishes and invertebrates [63].

Seki [63] examined the guts of 64 *P. cheilio* from the NWHI. Fishes occurred in 68.8 percent of guts and accounted for 64.2% total volume. Twenty families of fishes were identified from gut contents. Most important families were Congeridae, Priacanthidae, and Serranidae. Crustaceans occurred in 53.1% of sampled individuals but accounted for only 4.3% total volume. Crabs (Raptantia) were most important, followed by shrimp (Natantia). Molluscs (mostly cephlapods) were found in 34.4 % individuals and accounted for 9.4% total volume.

Sazima (1998) observed ram feeding in a school of 10 individuals (250 mm FL) of *P. dentex* off the coast of Sao Paulo, Brazil. In a subsequent examination of guts of three museum specimens, she found that two smaller individuals (132-141 mm FL) contained remains of small fishes and benthic crustaceans, whereas a third, large individual (184 mm FL) contained only planktonic mysids. Based on these data, she concludes that *P dentex* feeds primarily on benthic fishes and invertebrates, but may also occasionally filter-feed on planktonic organisms.

MULLIDAE

Mulloidichthys flavolineatus **(Lacepède, 1801) [65]**

Mullus flavolineatus Lacépède, 1801 [66]
Upeneus preorbitalis Swain & Swain, 1882 [67]
Mulloides samoensis Günther, 1874 [68]
Pseudupeneus preorbitalis (Swain & Swain, 1882)
Mulloidichthys samoensis (Günther, 1874)
Mulloides flavolineatus (Lacépède, 1801)

Geographic range: Indo-Pacific from South Africa and the Red Sea to the Ryukyu and Ogasawara Islands, Australia (to southern New South Wales), Lord Howe Island, Micronesia, the Hawaiian Islands, the Marquesas, and the Pitcairn Group [1, 2].

First Hawaii record: Swain & Swain, 1882 as *Upeneus preorbitalis* [67]

General Introduction

Commonly called weke‘ā, weke, weke ‘ā‘ā, yellowstripe goatfish, and white goatfish. Young (to about 6 inches) are called oama. Engybenthic over coral and sand at 1–97 m [2], but usually seen from near shore to about 20 m [1]. Unlike other Hawaiian goatfishes, this species may be found high in the water column [69]. During the day, this species forms inactive aggregations. In shallow waters, these typically consist of 20 to >100 individuals in shallow inlets and channels [70], often with many individuals at rest on the bottom [1]. In deeper waters, the aggregations may contain >1,000 individuals extending more than five meters from the bottom [69]. *Mulloidichthys flavolineatus* has high site fidelity, foraging on sand-flats at night and returning to the same sheltering habitat by first light [70]. Mean nighttime range was 8,267 m^2 (range 5,200-11,600 m^2) whereas daytime range was 2,533 m^2 (range 1,200-3,200 m^2) for three fish tracked in an Oahu Marine Life Conservation District [70]. This same study provides size-frequency data for 323 individuals caught with a purse seine in the MLCD.

M. flavolineatus was the most abundant goatfish in a visual survey of Midway Atoll with 0.71% abundance and 35% occurrence in visual transects. Size ranged from 70-250 mm [71].

In the Red Sea, wrasses frequently accompany *M. flavolineatus* while foraging in the daytime [72]. The goatfish spends more time foraging when accompanied by wrasses than when wrasses are not present. Goatfish may be less efficient when feeding with wrasses because of harassment and frequent forced location changes. Small *M. flavolineatus* tend to feed in larger groups than large individuals.

Young individuals (to about 6 in) are prized as baitfish [70]. Combined daily bag limits for young (under 7 in.) *Mulloidichthys* and *Upeneus* species is 50. There is no bag limit for fishes longer than 7 in.

Reproduction and larvae

Eggs and larvae of *M. flavolineatus* have not been described; however Leis & Carson-Ewart [9] provide the following generalized account of mullid development, based on at least three unidentified goatfish species plus *Upeneus tragula*: Larvae hatch at 1.6-3.4 mm with unpigmented eyes, unformed jaws and a large yolk sac. Larvae are laterally compressed, with 23-25 myomeres. Early preflexion larvae have 5-6 preanal myomeres, early postflexion larvae have ~8, and 10 mm larvae have ~10. The preflexion gut is 30-40% of body length, and postflexion gut is 60% body length. The gas bladder is covered by heavy pigment. The head is rounded dorsally, with a short, steeply-sloped snout. The terminal, slightly oblique mouth extends to the anterior margin of the pupil. At 8-9 mm, small teeth form in the upper jaw, followed closely by teeth in the lower jaw. At the same size, chin barbels originate at the hypohyal symphysis as thickenings along the edge of the branchiostegal membrane, these do not occupy the position under the tip of the lower jaw until settlement. Gill openings are free from the isthmus. Anal-fin elements begin forming during flexion (~4 mm), followed by dorsal rays. Both fins are ossified by 6 mm. During flexion there is a gap of approximately 50% head length between the anus and anal fin origin. This gap closes by 10 mm. The spinous dorsal fin forms after flexion (5.6 mm) and is fully ossified by ~7 mm. Pectoral rays form during flexion and are completely developed by ~8 mm. Pelvic fin buds appear at 5.5 mm and fins are fully formed by 7 mm. Scales appear in larvae ≤13mm. Body pigment changes substantially during yolk absorption: Preflexion larvae have pigment on the dorsal surface of the gut, small melanophores along the ventral midline of the tail, and three melanophores in a triangular pattern on the midbrain; brain pigmentation becomes more extensive during development; a midlateral stripe on the tail and internal melanophores over the notochord form just before flexion; after flexion, rows of melanophores form on the mid-dorsal and mid-ventral tail and trunk, then pigment spreads such that, until settlement, larvae are blue dorsally and silver laterally.

Pelagic larval duration in the southwestern Indian Ocean is estimated at 45-50 days based on counts of pre-settlement otolith rings (n= 118) [73]. The same study described the shape of sagittal otoliths and found stocks of juvenile fishes could be reliably distinguished based on Fourier analysis of otolith shape.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL				
Age				
L_{50}				
TL				
FL				
SL [11]	160 mm	160 mm		116-278 mm
Age				
Batch fecundity vs:				
Size				
Age				
Weight				
Sex ratio (F:M)				
Mature egg size/volume				
Egg development				

Peak spawning season			
Interspawning interval (# days)			
Spawning Cue			
Spawning mode	Pelagic		
Reproductive mode	Gonochoristic (assumed)		
Mating system			

Growth and mortality

	Sex Unknown	N	Range
Maximum size TL [1] SL FL [70] Wt	 40 cm 336 mm 		
Maximum age [70]	12 years		
Growth equation [70]	FL_t in cm = $34.2(1-e^{-0.564(t \text{ in days}-0.564)})$[u]	53	
Mortality Z M F			

Morphometric relationships

	Equation	N	Range
TL vs SL	SL in mm = -4.78 + 0.84(TL in mm)		116-278 mm
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt	W in kg = $0.0087(\text{FL in cm})^{3.21}$	97	
SL vs Wt			

Diet

Muloidichthys flavolineatus feeds on sand-dwelling invertebrates, primarily during nighttime [12]. In the Marshall Islands, fish were the most dominant prey item [74]. However, in Kona, Hawaii bivalves, polychaetes, and amphipods appeared to be most important [12]. The most taxonomically detailed study to date was conducted at Midway Atoll [75]. Of the 31 individuals examined, 18 had full guts which contained a total of 21 prey categories. Polychaetes[v] were the most abundant in terms of percent number, volume, frequency and IRI. Other important prey

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[u] Growth rates were also calculated from a mark and recapture study in a Hawaii MLCD (Coconut Island). The alternate growth rate calculated was k= 0.557.

[v] Sorden (1982) identified 23 species of polychaetes from 16 families in the guts of *M. flavolineatus* with *Armandia intermedia* (Opheliidae) and *Nothria holobranchia* (Onuphidae) comprising 2/3 of the polychaetes eaten.

groups include xanthid crabs, bivalves, gammaridean amphipods, and the tanaid *Leptochelia dubia*. Most of the taxa consumed occur in sand, and sand was frequently found in the guts.

Additional references

Wahbeh [76] reports on food and feeding behavior in the Red Sea.
Wahbeh [77] reports on reproduction in the Red Sea.
Al-Absy [78] reports on growth and morphometric relationships from the Red Sea
H. Leba and K. Cole (UH Zoology Dept) are currently working on a reproductive study of this species. Their analysis is expected to include information on size-at-maturity, sex-ratio, oocyte development, and batch fecundity for Hawaiian specimens.

Parupeneus multifasciatus (Quoy & Gaimard, 1825) [79]

Mullus multifasciatus Quoy & Gaimard, 1825 [80]
Mullus trifasciatus non Lacépède (*ex* Commerson), 1801 [66]
Upeneus trifasciatus non (Lacépède, 1801)
Upeneus velifer Smith & Swain, 1882 (84)
Parupeneus trifasciatus non (Lacépède, 1801)
Pseudupeneus multifasciatus (Quoy & Gaimard, 1825)
Upeneus multifasciatus (Quoy & Gaimard, 1825)
Parupeneus moana (Jordan & Seale, 1906) [81]

Geographic range: Eastern Indian Ocean (Northwestern Australia and Cocos-Keeling Islands) and Pacific from Christmas Island and Indonesia to southern Japan, the Ogasawara Islands, Australia (to New South Wales), Lord Howe Island, Micronesia, the Hawaiian Islands, the Tuamotu Archipelago, and the Marquesas, Norfolk Island and the Pitcairn Group [1, 2].

First Hawaii record: Quoy & Gaimard, 1825 as *Mullus multifasciatus* [80]

General Introduction

Commonly called moano, manybar goatfish, and multibarred goatfish. Hawaiian names for the young are ʻahua or ʻohua [7]. Engybenthic over sand, rock, and reef from 1-161 m [2]. It is usually the most common reef-associated goatfish wherever it is found [1]. Rarely found more than ½ meter above the bottom [69]. Primarily day-active, though some specimens may forage at twilight [12]. This species forages singly or in groups of two to three [69, 75]and is occasionally accompanied by other goatfish species including *P. pleurostigma* [75].

Minimum catch size in Hawaii is 7 in. There is no bag limit.

Reproduction and larvae

Little is known of the reproductive behavior of this species. Lobel [82] observed spawning in March, two days before the new moon. Spawning occurs 1900-2000 [83]. Males hold territories during reproductive season [83]. K. Longenecker & R. Langston (unpublished observation) saw larger fishes (presumably males) 'herding' smaller fish (presumably females) during periods when gonadal analysis revealed active spawning.

Eggs of *Parupeneus* are 0.63-0.93 mm in diameter, spherical and pelagic [9]. Larvae of *P. multifasciatus* have not been described; however Leis & Carson-Ewart [9] provide the following generalized account of mullid development, based on at least three unidentified goatfish species plus *Upeneus tragula*: Larvae hatch at 1.6-3.4 mm with unpigmented eyes, unformed jaws and a large yolk sac. Larvae are laterally compressed, with 23-25 myomeres. Early preflexion larvae have 5-6 preanal myomeres, early postflexion larvae have ~8, and 10 mm larvae have ~10. The preflexion gut is 30-40% of body length, and postflexion gut is 60% body length. The gas bladder is covered by heavy pigment. The head is rounded dorsally, with a short, steeply-sloped snout. The terminal, slightly oblique mouth extends to the anterior margin of the pupil. At 8-9 mm, small teeth form in the upper jaw, followed closely by teeth in the lower jaw. At the same size, chin barbels originate at the hypohyal symphysis as thickenings along the edge of the branchiostegal membrane, these do not occupy the position under the tip of the lower jaw until settlement. Gill openings are free from the isthmus. Anal-fin elements begin forming during flexion (~4 mm), followed by dorsal rays. Both fins are ossified by 6 mm. During flexion there is a gap of approximately 50% head length between the anus and anal fin origin. This gap closes by 10 mm. The spinous dorsal fin forms after flexion (5.6 mm) and is fully ossified by ~7 mm. Pectoral rays form during flexion and are completely developed by ~8 mm. Pelvic fin buds appear at 5.5 mm and fins are fully formed by 7 mm. Scales appear in larvae ≤13mm. Body pigment changes substantially during yolk absorption: Preflexion larvae have pigment on the dorsal surface of the gut, small melanophores along the ventral midline of the tail, and three melanophores in a triangular pattern on the midbrain; brain pigmentation becomes more extensive during development; a midlateral stripe on the tail and internal melanophores over the notochord form just before flexion; after flexion, rows of melanophores form on the mid-dorsal and mid-ventral tail and trunk, then pigment spreads such that, until settlement, larvae are blue dorsally and silver laterally.

	Male	Female	N	Range
First reproduction TL FL [84] SL Age	151 mm[w]	138 mm	50	72-228 mm
L_{50} TL FL [84] SL Age	152 mm	145mm	50	72-228 mm
Batch fecundity vs: Size [84] Age Weight		5,479-21,530 eggs[x]	4	155-193 mm
Sex ratio (F:M) [84]	2:3[y]		50	72-228 mm
Mature egg size/volume [84]	389 µm		4	330-450 µm
Egg development [84]	Group Synchronous			
Peak spawning season	[z]			
Interspawning interval (# days)				
Spawning Cue				
Spawning mode	Pelagic			
Reproductive mode [84]	Gonochoristic			
Mating system				

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[w] Histology-based study. Males were also significantly larger than females.

[x] El Agamy (1990) provides a fecundity curve for *P ciliatatus,* a similar-sized goatfish from Quatar: # Eggs = $0.0018(FL)^{3.092}$

[y] Physical sex ratio (counting mature and immature individuals) for 50 speared specimens from Kaneohe Bay. This study found that the proportion of females in the population described varied predictably with body length [% Females = 141.3 – 0.6.67(FL in mm)], and that all individuals larger than 225 mm FL were male.

[z] Unknown, but Longenecker & Langston (2008) found mature females in March-July and November.

Growth and mortality

	Male	Female	N	Range
Maximum size				
TL [1]	30 cm			
SL [79]	260 mm	179 mm		
FL [84]		197 mm	50	72-228 mm
Wt				
Maximum age [84]	>2 years[aa]		13	
Growth equation [84]	FL in mm = $303(1-e^{-0.00207(t \text{ in days} +49.4)})$[bb]		13	
Mortality				
Z [84]	0.3025 per 16 weeks[cc]		150	
M [84]	0.4439 per 16 weeks		126	
F				

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL			
SL vs FL [84]	SL in mm = -1.98 + 0.92(FL in mm)	50	72-228 mm
TL vs BD			
FL vs BD[dd] [84]	FL in mm =16.96 + 3.32(BD in mm)	50	72-228 mm
SL vs BD			
TL vs Wt			
FL vs Wt [84]	Wt in g = $4.91 \cdot 10^{-6}(\text{FL in mm})^{3.23}$	50	72-228 mm
SL vs Wt			

Diet

Parupeneus multifasciatus feeds diurnally on benthic invertebrates, although juveniles may feed on plankton [12].

Twelve of 14 individuals collected in Kona, Hawaii before or during morning twilight were empty [12]. In the remaining individuals, (2 collected at twilight and 15 in the afternoon) xanthid crabs and caridean shrimps were most important (30.6 and 15.4% volume respectively) followed by crab megalops (8.6%).

The most taxonomically detailed study, was conducted on 20 individuals at Midway Atoll [75]. This study likewise found that crabs and shrimp were most important in terms of percent

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[aa] Age estimates based on counts of otolith increments. Daily deposition of otolith increments in assumed but has not been successfully validated.

[bb] Authors note that growth in males and females may differ but has not been tested.

[cc] Natural mortality was calculated from age structure in a marine reserve, total mortality from age structure in a nearby fished area. Counter-intuitively, total mortality appeared lower than natural mortality alone. Work to increase the range of sites and number of individuals studied is underway.

[dd] BD, as used by Longenecker & Langston (2008) was the distance between the origins of the dorsal and pelvic fins.

number, volume, frequency, and IRI. In descending order of importance: Xanthidae, caridean shrimp, Alpheidae, Portunidae, and *Rhynchinocetes rugulosus*.

A more recent study of 40 individuals also found crabs (raninids and galatheids) and shrimp to be most important, accounting for 70% of the total volume. These were followed by fishes (16.4%, including *Ptereleotris heteropterus*) and stomatopods (3.2%) [85].

Additional references

Longenecker and Langston (in progress) are currently working on completing a more detailed life-history study of *P. multifasciatus* which will include additional growth, fecundity, mortality, and sex ratio data.

Parupeneus porphyreus (Jenkins, 1903) [79]

Pseudupeneus porphyreus Jenkins, 1903 [19]
Parupeneus dispilurus non (Playfair *in* Playfair & Günther, 1867)
Parupeneus fraterculus non (Valenciennes *in* Cuvier & Valenciennes, 1831)
Upeneus porphyreus (Jenkins, 1903)
Parupeneus pleurotaenia non (Playfair *in* Playfair & Günther, 1867)

Geographic range: Hawaiian Islands and Johnston Atoll [2].

First Hawaii record: Steindachner, 1900 as *Parupeneus dispilurus* [19].

General Introduction

Commonly called kūmū, whitesaddle goatfish, and red goat fish. Hawaiian names include kolokolopao (or kolokolopā or makolokolopao) for the spawn; ahuluhulu for small juveniles, kūmū aʻe for larger juveniles, and kūmū for adults [7]. Engybenthic over sand, rock, and reef from 2-140 m [2]. Most typically found low in the water column, < 2 m from the bottom [69]. Feeding by adults is crepuscular or nocturnal, but young feed during the day [86]. Adults shelter in holes in the reef during day and forage over sand and rubble at night, returning to the same hole in the morning. Five fish tracked with acoustic tags at Coconut Island had home ranges from 9,070-35,163 m^2 [87].

Most valuable reef fish in Hawaii [86]; can fetch $15-30/kg [87]. HIMB attempted aquaculture of this species in the 1970s, but the project was stopped when a suitable feed could not be developed [88].

Forbidden to women because the red color suggested menstruation, during which time women were isolated [7]. Today, Hawaii's fishing regulations require a minimum size of 10 in. There is no bag limit.

Reproduction and larvae

Eggs of *Parupeneus* are 0.63-0.93 mm in diameter, spherical and pelagic [9]. Except for the observation of sharply-pointed pharyngeal teeth [86], larvae of *P. porphyreus* have not been described; however Leis & Carson-Ewart [9] provide the following generalized account of mullid development, based on at least three unidentified goatfish species plus *Upeneus tragula*: Larvae hatch at 1.6-3.4 mm with unpigmented eyes, unformed jaws and a large yolk sac. Larvae are laterally compressed, with 23-25 myomeres. Early preflexion larvae have 5-6 preanal myomeres, early postflexion larvae have ~8, and 10 mm larvae have ~10. The preflexion gut is 30-40% of body length, and postflexion gut is 60% body length. The gas bladder is covered by heavy pigment. The head is rounded dorsally, with a short, steeply-sloped snout. The terminal, slightly oblique mouth extends to the anterior margin of the pupil. At 8-9 mm, small teeth form in the upper jaw, followed closely by teeth in the lower jaw. At the same size, chin barbels originate at the hypohyal symphysis as thickenings along the edge of the branchiostegal membrane, these do not occupy the position under the tip of the lower jaw until settlement. Gill openings are free from the isthmus. Anal-fin elements begin forming during flexion (~4 mm), followed by dorsal rays. Both fins are ossified by 6 mm. During flexion there is a gap of approximately 50% head length between the anus and anal fin origin. This gap closes by 10 mm. The spinous dorsal fin forms after flexion (5.6 mm) and is fully ossified by ~7 mm. Pectoral rays form during flexion and are completely developed by ~8 mm. Pelvic fin buds appear at 5.5 mm and fins are fully formed by 7 mm. Scales appear in larvae ≤13mm. Body pigment changes substantially during yolk absorption: Preflexion larvae have pigment on the dorsal surface of the gut, small melanophores along the ventral midline of the tail, and three melanophores in a triangular pattern on the midbrain; brain pigmentation becomes more extensive during development; a midlateral stripe on the tail and internal melanophores over the notochord form just before flexion; after flexion, rows of melanophores form on the mid-dorsal and mid-ventral tail and trunk, then pigment spreads such that, until settlement, larvae are blue dorsally and silver laterally.

Estimated larval duration 41-56 days (mean = 47.4) [88]. Recruitment begins in March [89] with no new settlers visible after June [86]. New recruits 31-37 mm [86].

	Male	Female	N	Range
First reproduction				
TL				
FL [88]		238	125	
SL				
Age				
L_{50}				
TL				
FL				
SL				
Age				
Batch fecundity vs:				
Size [88]		[ee]	6	11991-25953
Age				
Weight				
Sex ratio (F:M)	[ff]			
Mature egg size/volume [88]	800 µm			500-900
Egg development [88]	Group synchronous			
Peak spawning season [88]	December-July		125 ♀,395♂	
Interspawning interval (# days)				
Spawning Cue				
Spawning mode	Pelagic			
Reproductive mode	Gononchorist			
Mating system				

[ee] Moffitt (1979) measured the batch fecundity for six *P. porphyreus* specimens. Range for the data are listed above, however, the data are suspect as they suggest that fecundity decreases with body size.

[ff] No sex ratio given, however, Moffitt (1979) collected 395 male and 125 females in his life history study.

Growth and mortality

	Sex Unknown	N	Range
Maximum size TL [1] SL [88] FL Wt	 51 cm 470 mm		
Maximum age [88]	6 years (Estimated)		
Growth equation [88]	$FL_t = 492(1-e^{-0.538\ yr\ (t+0.446)})$	36	36-385
Mortality Z M F			

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL			
SL vs FL [88]	$SL = -0.21+0.91(FL)$ $FL = 0.24 + 1.10(SL)$	91	40-408 FL
TL vs BD			
FL vs BD			
SL vs BD			
TL vs Wt			
FL vs Wt [88]	$W = 1.31 \cdot 10^{-2}(FL)^{3.153}$	167	None given
SL vs Wt			

Diet

This species feeds nocturnally on benthic crustaceans [12]. Six of 11 specimens speared during the afternoon in Kona, Hawaii, were empty or contained only trace amounts of well-digested prey [12]. Five specimens speared within one hour of sunrise had full stomachs. Xanthid crabs accounted for 65.2% of volume followed by Hippid crabs (10%) and Caridean shrimps (2%) [12].

Mahi [86] described digestive anatomy and examined guts of 198 specimens collected from Oahu. She identified 23 different prey items. Twenty-five percent of all guts were empty, with the majority of these collected later in the day. Guts were most full in the early morning suggesting that this species feeds nocturnally. Fish <60 mm feed mostly on copepods, gammarids, megalops larvae and caprellids. For fish > 110 mm, crabs were most important, followed by isopods, alpheid shrimps, and *Stenopus hispidus*.

Additional references

Holland [90] described the chemosensory system of *P. porphyreus.*
H. Leba and K. Cole (UH Zoology Dept) are currently working on a reproductive study of this species. Their analysis is expected to include information on size-at-maturity, sex-ratio, oocyte development, and batch fecundity.

SCARIDAE

Chlorurus spilurus (Valenciennes, 1840) [1]

Scarus sordidus Forsskål, 1775 [18]
Scarus spilurus Valenciennes *in* Cuvier & Valenciennes, 1840 [91]
Pseudoscarus sumbawensis (Bleeker, 1848)
Callyodon erythrodon (Valenciennes *in* Cuvier & Valenciennes, 1840)
Pseudoscarus vitriolinus Bryan, 1906 [92]
Callyodon sordidus (Forsskål, 1775)
Scarus erythrodon Valenciennes *in* Cuvier & Valenciennes, 1840 [91]
Chlorurus sordidus (Forsskål, 1775)

Geographic range: Central and Western Pacific from the Ryukyu and Ogasawara Islands, Australia (Queensland), Micronesia, the Hawaiian Islands, the Line Islands, east to the Pitcairn Islands and Rapa [1, 2].

First Hawaii record: Steindachner, 1900 as *Pseudoscarus sumbawensis* [93].

General Introduction

Commonly called bullethead parrotfish. Hawaiian names for growth stages of parrotfishes are, from spawn to adults: ʻohua, ponuhunuhunu (or panuhunuhunu), and uhu [7]. Engybenthic over reefs and rubble from 1-9 m [2]. During the day this fish is an active swimmer, often in groups, over coral-rich reefs, migrates in schools at twilight, and is solitary at night, resting in reef crevices (sometimes encased in mucus) [12]. Juveniles may school with other scarids [94].

Formerly included in the Indo-Pacific species *Chlorurus sordidus*, the Hawaiian population was recognized in 2007 as part of a distinct Central and Western Pacific species [1], therefore reports for *C. sordidus* (or synonyms) outside of this range do not apply to the Hawaiian species.

Occurs in three color phases: juveniles are grey to dark brown and often have four narrow whitish stripes on the head and body; the initial phase (which may be females or small, reproductively mature “sneaker” males) is dark reddish brown, with the ventral part of the head and the area around the mouth red, the dental plates are white (this phase can display two longitudinal series of small white spots on the side of the body and a broad white zone posteriorly with a large, round black spot on the base of the caudal fin); terminal males are green with a pink bar on each scale except for on the caudal peduncle, the dental plates are blue-green, the edges of the lips are pink with a submarginal green joining the corner of the mouth and extending across the head below eye level, above this band the head is lavender to pale green, two green bands extend posteriorly from the eye, a broad zone of the body may be suffused with yellow [1].

Minimum legal size in Hawaii 12 in. No bag limit.

Reproduction and larvae

This species has a rather complicated reproductive mode of protogynous diandry: sex changes from female to male, however some individuals in the initial (and typically female) phase develop directly into reproductively active males. The initial:terminal phase ratio is 120:1 around Oahu [95]. Based on macroscopic examination, 6.7% of intitial phase individuals were male [95]. Based on a plot of gonadosomatic index [95], sex changes begins at ~27 cm SL.

Chlorurus eggs are spindle-shaped, 1.5-3.0 mm long, ~0.5-1.0 mm wide, and spawned pelagically [9]. Larvae of *C. spilurus* have not been described; however Leis & Carson-Ewart [9] offer the following account of parrotfish development: Larvae hatch at 1.6-1.7 mm, and have a large yolk sac, unpigmented eyes, and an unformed mouth. Preflexion larvae are elongate, ovoid in cross-section, with a deep caudal peduncle and 25 myomeres. Larvae become increasingly compressed during development. The gut is rugose and extends slightly beyond the midbody. Before flexion, the gut is straight, with a slight constriction at the posterior end. After flexion, the anterior portion of the gut coils. A large gas bladder is located above mid-gut, but moves to the posterior end of the gut before settlement. The mouth is small, nearly horizontal, and no teeth appear before settlement. There are no spines on the head or pectoral girdle. Shortly before flexion, the dorsal rays begin to form in a posterior to anterior direction. Anal rays form shortly after. Ossification of dorsal spines begins by 5.5 mm, again from posterior to anterior. Anal spines and dorsal rays form at 6-7 mm. Pelvic buds develop ~5.8 mm, but elements are not complete until 8-14 mm. All fin spines are short, slender, weak, and unornamented. Scales do not form until after settlement. Larvae have pigment over the gut, immediately anterior to the anus, and 1-12 melanophores along the ventral midline of the tail.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL [95]		~20 cm[gg]		
Age				
L_{50}	[hh]			
TL				
FL				
SL				
Age				
Batch fecundity vs:				
Size				
Age				
Weight				
Sex ratio (F:M)[ii]	112:9		364	
Mature egg size/volume				
Egg development				

[gg] We estimated this pararameter based on increased gonadosomatic index with length and may have overestimated minimum size at first reproduction.

[hh] Gust (135) reports geographic variation in size and age at maturity for populations on the Great Barrier Reef.

[ii] Estimated from Parrish & Howard’s (2008) initial:terminal phase ratio of 120:1, with 6.7% of initial phase as males.

Peak spawning season[95]	June [jj]	75	May-Jul [96]
Interspawning interval (# days)			
Spawning Cue [97]		4078	14:00-15:00
Spawning mode [9]	Pelagic		
Reproductive mode [95]	Diandric, protogynous		
Mating system [97]	Promiscuous or male territory, group	4078	Some pairs

Growth and mortality

	Male	Female	N	Range
Maximum size				
TL [1]	40 cm			
SL[kk]	40 cm	32 cm		
FL				
Wt				
Maximum age [98]	9 years[ll]			
Growth equation [98][mm]	SL_t in mm = $192.95(1-e^{-1.083\ (t\ \text{in years}+0.05)})$		70	98-245
Mortality				
Z				
M				
F				

Morphometric relationships

	Equation	N	Range
TL vs SL	SL in cm = 0.820(TL in cm)	91	
TL vs FL			
SL vs FL	SL in cm = 0.821(FL in cm)	91	
TL vs BD			
FL vs BD			
SL vs BD			
TL vs wt			
FL vs wt			
SL vs wt [95]	Wt in g = $0.04989(\text{SL in cm})^{2.934}$	98	11.1-33.3

Diet

This fish scrapes algae from the surface of dead coral. Hobson [12] examined the gut contents of seven specimens from Kona, all were full of fine benthic algae (constituting <20% of volume), calcareous powder, organic slurry and sand. Hobson saw no evidence of coral feeding.

[jj] This estimate is based on increased gonadosomatic index of individuals that are assumed to have reached reproductive size; however, reproductive size has not been verified. This peak does correspond nicely with observed scarid spawning by Poepoe et al (2003).

[kk] These estimates are based on maximum sizes from a gonadosomatic index plot by Parrish & Howard (2008) the value for males corresponds nicely with a maximum reported size of 40 cm in Randall (2007).

[ll] Estimated for populations on the Great Barrier Reef.

[mm] This equation should be viewed with caution. Gust et al (136) found significant geographic variation (K values varied by a factor of ~2, and L_∞ by 43 mm) in growth on the Great Barrier Reef. Mundy et al (137) also report sex-based growth differences.

Scarus psittacus Forsskål, 1775 [99]

Scarus psittacus Forsskål, 1775 [18]
Pseudoscarus bataviensis (Bleeker, 1857)
Scarus oviceps non Valenciennes *in* Cuvier & Valenciennes, 1840 [91]
Scarus gilberti Jenkins, 1901 [100]
Scarus brunneus Jenkins, 1901 [100]
Scarus jenkinsi Jordan & Evermann, 1903 [5]
Callyodon gilberti (Jenkins, 1901)
Callyodon brunneus (Jenkins, 1901)
Callyodon jenkinsi (Jordan & Evermann, 1903)
Callyodon bataviensis (Bleeker, 1857)
Scarus galena Jordan, 1925 [101]
Callyodon forsteri (Valenciennes *in* Cuvier & Valenciennes, 1840)
Scarus forsteri Valenciennes *in* Cuvier & Valenciennes, 1840 [91]
Scarus taeniurus Valenciennes *in* Cuvier & Valenciennes, 1840 [91]

Geographic range: Indo-Pacific from South Africa and the Red Sea to southern Japan, Australia, Micronesia, the Hawaiian Islands, the Tuamotu Archipelago, and the Marquesas [2].

First Hawaii record: Steindachner, 1900 as *Pseudoscaras bataviensis* [93, 102]

General Introduction

Commonly called palenose parrotfish. Hawaiian names for growth stages of parrotfishes are, from spawn to adults: ‘ohua, ponuhunuhunu (or panuhunuhunu), and uhu [7]. Engybenthic over rock and reef from 1-5 m [2].

Occurs in two distinct color phases: juveniles are similar to initial phase, which is reddish brown to gray with a dark spot at the base of the first membrane of the dorsal fin and a small black and blue spot at the upper base of the pectoral fins; the terminal male is green posteriorly, with pink edges on the scales (more pink and less green on scales anteriorly), the abdomen is pink with a longitudinal series of green spots following the scale rows, a green bands edges each lip, these bands join at the angle of the mouth and continue below the eye, two additional green band extend from the posterior of the eye, the snout is dark purple to lavender-gray [1].

During the day juveniles and females tend to occupy shallow reef flats, usually in aggregations, whereas males tend to be solitary on the reef face [12]. At night, this fish rests encased in a mucus envelope in reef crevices [12].

Minimum legal size in Hawaii is 12 in. No bag limits.

Reproduction and larvae

This species has a rather complicated reproductive mode of protogynous diandry: sex changes from female to male, however some individuals in the initial (and typically female) phase develop directly into reproductively active males. The initial:terminal phase ratio is 77:1 around Oahu [95]. Based on macroscopic examination, 28.6% of intitial phase individuals were male [95]. Based on a plot of gonadosomatic index [95], sex changes begins at ~16 cm SL.

Scarus eggs are spindle-shaped, 1.5-3.0 mm long, ~0.5-1.0 mm wide, and spawned pelagically [9]. Larvae of *S. psittacus* have not been described; however Leis & Carson-Ewart [9] offer the following account of parrotfish development: Larvae hatch at 1.6-1.7 mm, and have a large yolk sac, unpigmented eyes, and an unformed mouth. Preflexion larvae are elongate, ovoid in cross-section, with a deep caudal peduncle and 25 myomeres. Larvae become increasingly compressed during development. The gut is rugose and extends slightly beyond the midbody. Before flexion, the gut is straight, with a slight constriction at the posterior end. After flexion, the anterior portion of the gut coils. A large gas bladder is located above mid-gut, but moves to the posterior end of the gut before settlement. The mouth is small, nearly horizontal, and no teeth appear before settlement. There are no spines on the head or pectoral girdle. Shortly before flexion, the dorsal rays begin to form in a posterior to anterior direction. Anal rays form shortly after. Ossification of dorsal spines begins by 5.5 mm, again from posterior to anterior. Anal spines and dorsal rays form at 6-7 mm. Pelvic buds develop ~5.8 mm, but elements are not complete until 8-14 mm. All fin spines are short, slender, weak, and unornamented. Scales do not form until after settlement. Larvae have pigment over the gut, immediately anterior to the anus, and 1-12 melanophores along the ventral midline of the tail.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL [95]		~10 cm[nn]		
Age				
L_{50}				
TL				
FL				
SL				
Age				
Batch fecundity vs:				
Size				
Age				
Weight				
Sex ratio (F:M) [95][oo]	55:23		1397	
Mature egg size/volume				
Egg development				
Peak spawning season [95]	August-November[pp]			May-Nov[qq]
Interspawning interval (# days)				
Spawning Cue				
Spawning mode [9]	Pelagic			
Reproductive mode [102]	Diandric, protogynous			
Mating system	Polygyny			

[nn] We estimated this parameter based on increased gonadosomatic index with length and may have overestimated minimum size at first reproduction.

[oo] Estimated from Parrish & Howard's (2008) initial:terminal phase ratio of 120:1, with 28.6% of initial phase as males.

[pp] Based on peaks in sparse gonosomatic index plots by Parrish & Howard (2008).

[qq] This adds Scarus spawning observations by Poepoe et al. (2003), which do not overlap with gonadosomatic index plots of Parrish & Howard (2008).

Growth and mortality

	Male	Female	N	Range
Maximum size				
TL [1]	30 cm			
SL [95][rr]	~26 cm	~22 cm		
FL				
wt				
Maximum age [98]	5 years[ss]			
Growth equation [98][tt]	$SL_t \text{ in mm} = 172.10(1-e^{-1.190\ (t \text{ in years}+0.05)})$		57	104-215
Mortality				
Z				
M				
F				

Morphometric relationships

	Equation	N	Range
TL vs SL [95]	SL (cm) = 0.784 TL (cm)	99	4.6-31.3
TL vs FL [95]	FL (cm) = 0.957 TL (cm)	99	4.6-31.3
SL vs FL [95]	SL (cm) = 0.819 FL (cm)	99	4.6-31.3
TL vs BD			
FL vs BD			
SL vs BD			
TL vs wt			
FL vs wt			
SL vs wt	$\text{Wt in g} = 0.03934(\text{SL in cm})^{3.005}$	99	4.6-31.3

Diet

This species scrapes benthic algae from rock surfaces during the day. Hobson [12] examined two specimens and found <20% algae mixed with calcareous powder, organic slurry and sand. There was no evidence of coral tissue or mucus.

[rr] These estimates are based on maximum sizes from a gonadosomatic index plot by Parrish & Howard (2008).

[ss] Estimated from a Great Barrier Reef population.

[tt] This equation should be viewed with caution. Choat & Robertson (2002) report geographic variation on the Great Barrier Reef.

ACANTHURIDAE

Acanthurus triostegus sandvicensis **Streets, 1877 [1]**

Chaetodon triostegus Linnaeus, 1758 [103]
Acanthurus triostegus var. *sandvicensis* Streets, 1877 [104]
Teuthis triostegus (Linnaeus, 1758)
Hepatus triostegus (Linnaeus, 1758)
Teuthis sandvicensis (Streets, 1877)
Acanthurus sandvicensis Streets, 1877 [104]
Acanthurus triostegus (Linnaeus, 1758)

Geographic range: The subspecies is endemic to the Hawaiian Islands and Johnston Atoll; however the species occurs throughout the Indo-Pacific region (except around the Arabian Peninsula) and the eastern tropical Pacific [1, 2].

First Hawaii record: Broussonet, 1782 as *Chaetodon triostegus* [105]

General Introduction

Commonly called manini or convict tang. Young were called ʻōhua liko (tender leaf bud) when transparent and about the size of a postage stamp, ʻōhua kaniʻo when bars appear about a day after settlement, ʻōhua pala pohaku (stone slime) or ʻōhua haʻekaʻeka (grimy looking) when the skin begins to darken, and kakala manini when about half grown [7]. Engybenthic over rock, coral, rubble, or sand from 1-46 m, throughout the rest of its range, the species occurs to 90m [2]. Newly settled fish are abundant in tidepools [1]. Juveniles, which are gregarious and often seen in groups, move into deeper water. Adults can be solitary, in small groups, or in large, dense feeding aggregations. Manini are found close to coral or rocks and a source of algae (food). They are not abundant in areas of heavy coral cover. Schooling behavior is seen during spawning. At night, manini rest on the substrate in a state of torpor [106].

Titcomb [7] reports that Hawaiians would catch the ʻōhua (postage stamp size) "by the million", mix them with salt, and scatter them on lava rocks to dry in the sun. These were stored for future consumption or taken inland for trade. In the 1960s, manini was described as the most abundant and commercially important surgeonfish in Hawaii [106]. It was the second-most abundant species encountered in a recent creel survey of recreational fishers in Waikiki [107].

Minimum catch size in Hawaii is 5 in. There are no bag limits.

Reproduction and larvae

Development has been illustrated and described in detail by Randall [106]: Eggs float in seawater, are transparent, spherical (0.58-0.70 mm in diameter), and contain a single 0.165 mm diameter oil globule. Eggs fertilized and reared in vitro at an average 24°C, hatched ~26 h post-fertilization at a length of ~1.7 mm, had a large yolk sac, unformed mouth, and no eye pigment. Aquarium-kept larvae 42.5-hours-old could maintain (or decrease) depth and avoid approaching objects, whereas 5-day-old larvae were capable of oriented swimming. The 5-day-old larvae had resorbed all yolk and about half of the oil globule. 5.5-day-old larvae appeared to exhibit feeding behavior. Positive phototaxis is inferred for the acronurus stage; this behavior disappears as settlement begins.

Acronuri, ranging from 22.0-29.5 mm SL, move inshore to settle in tidepools at night during May through September, with peaks at the new moon [106]. Otolith increment analysis indicates larval duration is 54 days (L. Basch, D. Shafer, & B. Walsh, unpublished data). Transformation takes 4-5 days [106].

Leis & Carson-Ewart [9] offer the following generalized account of surgeonfish development: Preflexion larvae are strongly compressed and moderate in depth, becoming deep in head and trunk at ~2.3 mm and even deeper following flexion. The tail is much less deep than the trunk. Myomere count is 21-23. The gut is coiled and reaches 44-61% of body length before flexion. A small gas bladder is located above the anterior portion of the gut. Brain case is vaulted. The snout is long and head shape is triangular. The terminal mouth does not reach the eye; small, conical teeth form in both jaws at ~4 mm. Eyes are round, gill membranes are broadly attached to the isthmus, and head spination is extensive. The smallest larvae (~1.8 mm) have a serrate supraoccipital crest. The second dorsal spine and the pelvic spine are first to form (at ~2.3 mm). Both of these are serrate by 2.8 mm, when more dorsal spines form. An anal spine ossifies at 3 mm and becomes serrate shortly thereafter. Dorsal and anal rays form immediately after flexion, and a second anal spine ossifies. Pectoral rays form at 4.6 mm. All supporting elements of pectoral, anal and dorsal fins are present by 5-6 mm. All pelvic elements are present by 8mm. The first dorsal and anal spines are markedly short. At ~5 mm, scales form as small, broad-based lamina projecting upright from a basal plate. At ~ 8 mm, these are arranged in vertical rows. The acronurus stage begins at ~ 17 mm with the formation of the peduncular spine. The lateral line is complete by 24 mm. Before settling, larvae are extremely compressed with head serrations (relatively) reduced in size. Preflexion larvae are moderately pigmented on the brain and gut. The acronurus stage has a silvery gut and the beginnings of bars.

	Male	Female	N	Range
First reproduction				
TL				
FL				
SL [106]		101 mm		
Age				
L_{50}				
TL				
FL[uu] [108]	<70 mm	164 mm	52♂, 70♀	
SL				
Age [108]	<168 d	440 d		
Batch fecundity vs:				
Size [108]		-648,588.17 + (FL in mm)4226.06	18	158-223
Age				
Weight				
Sex ratio (F:M) [108]	57:43[vv]		122	
Mature egg size/volume [106]	~0.70 mm			0.66-0.70

[uu] Manini do not have forked tails; FL as used here is the length to the end of the middle ray of the tail.

[vv] ~2/3 of 291 adults caught in unbaited fish traps in 30-90' of water off Oahu were male (Randall, 1961).

Egg development [108]	Group synchronous		
Peak spawning season [106]	February - June	193	Dec-Jul
Interspawning interval [106]	29.5 days		
Spawning Cue [106]	Full moon	3,863	-12 to +2 d
Spawning mode [106]	Pelagic, group spawning[ww]		
Reproductive mode [108]	Gonochorist		
Mating system			

Growth and mortality

	Sex Unknown	N	Range
Maximum size			
TL [108]	234 mm	188	
SL [108]	183 mm	187	
FL [108]	223 mm	188	
wt [108]	332 g	115	
Maximum age [108]	>4 years[xx]	297	
Growth equation [108]	l_t in mm = $202.798(1-e^{-0.0039276(\text{age in days}-18.6533)})$[yy]	45	54-819
Mortality			
Z [108]	0.68170, quarterly	73	
M [108]	0.53549, quarterly	224	
F [108]	0.14621, quarterly		

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL [108]	FL in mm = 1.796 + (TL in mm)0.939	188	29.5-234.0
SL vs FL [108]	FL in mm = 1.922 + (SL in mm)1.196	187	24.0-183.0
TL vs BD			
FL vs BD [108]	FL in mm = 9.397 + (SL in mm)2.190[zz]	153	14.0-106.7
SL vs BD			
TL vs wt			
FL vs wt [108]	Wt in g = $0.00001214(\text{FL in mm})^{3.1557}$	115	85.0-223.0
SL vs wt			

Diet

Juvenile and adult manini feed almost constantly during the day on fine filamentous algae. Animals in experimental studies preferred the red alga, *Polysiphonia*, and the green *Enteromorpha* [106, 107].

[ww] Observations from the Tuamotu Archipelago.

[xx] Likely much longer. Specimens up to 223 mm were reported, but ages could only be estimated for specimens up to the L_∞ of 200 mm FL.

[yy] Otolith increments are assumed to form daily. Although not statistically tested, growth did not appear to vary by sex or location.

[zz] As the distance between the origins of the dorsal and pelvic fins.

Additional references

Hayes et al [11] provide size distribution of recreational catch at Puako, Hawaiʻi.
Poepoe et al [96] describe the spawning season at Moʻomomi Bay, Molokaʻi.
Sale [109] performed experiments on depth and shelter use by juveniles.

Ctenochaetus strigosus (Bennett, 1828) [110]

Acanthurus strigosus Bennett, 1828 [111]
Ctenochaetus striatus non (Quoy & Gaimard, 1825)

Geographic range: Hawaiian Islands and Johnston Atoll [2].

First Hawaii record: Bennett, 1828 as *Acanthurus strigosus* [111]

General Introduction

Commonly called kole, goldring surgeonfish, goldring bristletooth. Engybenthic over coral, rock, and rubble at 6–113 m [2]; however, it is usually shallow [110] and found in the sub-surge zone [112]. Individuals are usually solitary [110].

Some fragmentary life-history information is reported for *C. strigosus* from throughout the Indo-Pacific. However, a 2001 revision of the genus by Randall & Clements [110] recognized *Ctenochaetus strigosus* as a Hawaiian endemic, making the relevance of studies from the South Pacific and Indian oceans suspect.

It is commercially important, ranking second in aquarium catch records [113]. It also important in recreational/subsistence fishing, and was the most abundant fish in Waikiki creel surveys [107], all were taken by spear.

Fishing is unregulated.

Reproduction and larvae

Recruitment begins in May and is heaviest June through September [114, 115]. Juvenile stage is yellow [1].

Eggs are pelagic [9]. An acronurus larva and recently transformed juvenile were illustrated by Randall [116]. Leis & Carson-Ewart [9] offer the following generalized account of surgeonfish development: Preflexion larvae are strongly compressed and moderate in depth, becoming deep in head and trunk at ~2.3 mm and even deeper following flexion. The tail is much less deep than the trunk. Myomere count is 21-23. The gut is coiled and reaches 44-61% of body length before flexion. A small gas bladder is located above the anterior portion of the gut. Brain case is vaulted. The snout is long and head shape is triangular. The terminal mouth does not reach the eye; small, conical teeth form in both jaws at ~4 mm. Eyes are round, gill membranes are broadly attached to the isthmus, and head spination is extensive. The smallest larvae (~1.8 mm) have a serrate supraoccipital crest. The second dorsal spine and the pelvic spine are first to form (at ~2.3 mm). Both of these are serrate by 2.8 mm, when more dorsal spines form. An anal spine ossifies at 3 mm and becomes serrate shortly thereafter. Dorsal and anal rays form immediately after flexion, and a second anal spine ossifies. Pectoral rays form at 4.6 mm. All supporting elements of pectoral, anal and dorsal fins are present by 5-6 mm. All pelvic elements are present by 8mm. The first dorsal and anal spines are markedly short. At ~5 mm, scales form as small, broad-based lamina projecting upright from a basal plate. At ~ 8 mm, these are arranged in vertical rows. The acronurus stage begins at ~ 17 mm with the formation of the peduncular spine. The lateral line is complete by 24 mm. Before settling, larvae are extremely compressed with head serrations (relatively) reduced in size. Preflexion larvae are moderately pigmented on the brain and gut. The acronurus stage has a silvery gut.

	Male	Female	N	Range
First reproduction TL [117][aaa] FL SL Age	140	100		
L_{50} TL FL SL Age				
Batch fecundity vs: Size Age Weight				
Sex ratio (F:M) [117]	57:87[bbb]			74-196 mm TL
Mature egg size/volume				
Egg development				
Peak spawning season [118]	March-June		160♂, 101♀	Mar-Aug
Interspawning interval (# days)				
Spawning Cue [114]	Sunset			-55 to +5 min
Spawning mode				
Reproductive mode				
Mating system [97]	Promiscuous, group		870	Some pairs

[aaa] Parrish & Claisse (2006) base these estimates on gonadosomatic index values and warn that the values are estimates.

[bbb] Parrish & Claisse (2006) note that males dominate the sex ratio at 130 mm TL and that a large majority of individuals >150 mm TL are male; however, they warn that this pattern may be depth-based.

Growth and mortality

	Male	Female	N	Range
Maximum size[ccc] TL [1] SL FL Wt	24 cm			
Maximum age	18 years[ddd]		136	
Growth equation[eee]			136	74-188 mm TL
Mortality Z M F				

Morphometric relationships

	Equation	N	Range
TL vs SL [117]	TL in mm = -2.40 + 1.36(SL in mm)	202	~62-122 mm
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs wt			
FL vs wt			
SL vs wt [117]	Wt in grams = 0.000045(SL in mm)$^{3.05}$	202	~50-150 mm

Diet

Number and location of specimens examined; summary of diet by number, occurrence, volume

Additional references

Poepoe et al [96] describe the spawning season at Mo‘omomi Bay, Moloka‘i.
Sancho et al. [119] describe pre-settlement behavior of and predation on larvae.

[ccc] Randall (2007) reports a maximum size of 240 cm.

[ddd] Parrish & Claisse (2006) base this estimate on otolith analysis, assuming increments are formed annually.

[eee] Parrish & Claisse (2006) constructed sex-based growth equations but did not provide parameters. Both sexes grow rapidly for the first few years, then much slower for the duration of the lifespan. Small males appear to grow faster than small females, and males reach a larger size than females.

Naso unicornis (Forsskål, 1775) [120]

Chaetodon unicornis Forsskål, 1775 [18]
Naseus fronticornis Lacépède, 1801 [66]
Naseus unicornis (Forsskål, 1775)
Monoceros unicornis (Forsskål, 1775)
Acanthurus unicornis (Forsskål, 1775)

Geographic range: Indo-Pacific from South Africa and the Red Sea to southern Japan, the Ogasawara Islands, Australia, Micronesia, the Hawaiian Islands, the Tuamotu Archipelago, and the Marquesas [2].

First Hawaii record: Commerson *in* Cuvier & Valenciennes, 1835 as *Naseus fronticornis* [121]

General Introduction

Commonly called bluespine unicornfish. The generic Hawaiian name for Naso species is kala; young are called pakalakala [7]. Engybenthic over coral and rock from 1-33 m [2]. Primarily an inshore species and will enter shallow water [1]. These are usually most active during the day [122]. Home range size (minimum convex polygon) averages 3,717 m^2 (range: 325-7650) [122]. Typically forms large schools on reef crests, but is solitary in less rugose habitats [122]. Individuals <20 cm TL dominate the backreef, whereas larger individuals dominate the reef crest [122].

Minimum catch size in Hawaii is 14 in. There is no bag limit.

Reproduction and larvae

Eggs are pelagic [9]. Larvae of *N. unicornis* have not been described; however Leis & Carson-Ewart [9] illustrate the development of a *Naso* species and offer the following generalized account of surgeonfish development: Preflexion larvae are strongly compressed and moderate in depth, becoming deep in head and trunk at ~2.3 mm and even deeper following flexion. The tail is much less deep than the trunk. Myomere count is 21-23. The gut is coiled and reaches 44-61% of body length before flexion. A small gas bladder is located above the anterior portion of the gut. Brain case is vaulted. The snout is long and head shape is triangular. The terminal mouth does not reach the eye; small, conical teeth form in both jaws at ~4 mm. Eyes are round, gill membranes are broadly attached to the isthmus, and head spination is extensive. The smallest larvae (~1.8 mm) have a serrate supraoccipital crest. The second dorsal spine and the pelvic spine are first to form (at ~2.3 mm). Both of these are serrate by 2.8 mm, when more dorsal spines form. An anal spine ossifies at 3 mm and becomes serrate shortly thereafter. Dorsal and anal rays form immediately after flexion, and a second anal spine ossifies. Pectoral rays form at 4.6 mm. All supporting elements of pectoral, anal and dorsal fins are present by 5-6 mm. All pelvic elements are present by 8mm. The first dorsal and anal spines are markedly short. At ~5 mm, scales form as small, broad-based lamina projecting upright from a basal plate. At ~ 8 mm, these are arranged in vertical rows. The acronurus stage begins at ~ 17 mm with the formation of the peduncular spine. The lateral line is complete by 24 mm. Before settling, larvae are extremely compressed with head serrations (relatively) reduced in size. Preflexion larvae are moderately pigmented on the brain and gut. The acronurus stage has a silvery gut. The keris larval stage is about 40 mm total length [1].

Doherty et al. [123] report density-independent settlement mortality of ~61%. Density-dependent post-settlement mortality, ranging from 9-20%, was seen over the following two weeks in a population from Moorea.

Spawning occurred near the surface of a 2.1 m deep aquarium [124].

	Male	Female	N	Range
First reproduction TL FL SL Age				
L_{50} TL FL SL Age				
Batch fecundity vs: Size Age Weight				
Sex ratio (F:M)				
Mature egg size/volume				
Egg development				
Peak spawning season				
Interspawning interval (# days)				
Spawning Cue				
Spawning mode				
Reproductive mode				
Mating system				

Growth and mortality

	Male	Female	N	Range
Maximum size TL [1] SL FL wt	70 cm			
Maximum age [125]	30 years			
Growth equation [98][fff]	SL_t in mm = $385.77(1-e^{-0.489(\text{age in years}+0.14)})$		59	176-494
Mortality Z M F				

[fff] Data from Great Barrier Reef.

Morphometric relationships

	Equation	N	Range
TL vs SL			
TL vs FL			
SL vs FL			
TL vs BD			
FL vs BD			
SL vs BD			
TL vs wt			
FL vs wt			
SL vs wt [125][ggg]	$Wt = 0.00008495(SL\ in\ mm)^{2.843}$	56	50-457 mm

Diet

Five specimens, 298-440 mm long, from the Marshall Islands ate frondose algae (*Dictyota* and *Padina*) [74].

[ggg] Choat & Axe (1996) provide a relationship from Australian specimens, but do not indicate the unit of measurement for weight.

DISCUSSION

Table 1 summarizes the status of life history work on the 13 species covered in this compendium. Existing life history data was most complete for *Acanthurus triostegus sandvicensis* (20 of 21 parameters) and *Caranx melampygus* (17 parameters). Life history information was particularly sparse for *Sargocentron diadema* (2 parameters) and *Psedocaranx cheilio* (6 parameters). Overall average was 11.8 out of 20 parameters. All but two species (*A. triostegus sandvicensis* and *Parupeneus multifasciatus*) lacked one or more pertinent pieces of life history information typically needed to construct a surplus production model (e.g., age-growth data, mortality or L_{50}). Only *C. melampygus* and *A. triostegus sandvicensis* had sufficient information necessary to estimate annual reproductive output (batch fecundity data, sex ratio, L_{50} and inter-spawning interval). Dietary data was available for all 13 species whereas information on mating system and pelagic larval duration was available for only three species.

Of the 28 regulated Hawaiian reef-fish species[hhh], 17 are regulated by size alone. For most, the size at which they enter the fishery coincides with the purported minimum size at maturity or L_{50}. The majority of studies in this compendium determined size at first maturity or L_{50} by visual or gravimetric examination of the gonads. In addition, most did not list distinct values for males and females. In cases where sexes mature at different sizes, using an averaged L_{50} may be misleading to managers, particularly if a goal of management is to maximize female reproductive output. We suggest that future studies should report separate L_{50} values for males and females. We also suggest that researchers “spot check” macroscopic gonadal classifications with histological examination. Longenecker and Langston (unpublished) examined gonads of *A. triostegus sandvicensis* by gross morphology, histological classification, and GSI. Of the 93 individuals for which they provided both gross and histological classifications, six percent were assigned the wrong gender (classified male when female or vice-versa) and 18% were misclassified by maturity (called mature when immature or vice versa) when using gross classification alone. The use of histological sections also allowed them to resolve the gender and maturity of an additional fifteen fish (16%) from smallest size-classes which were classified as juvenile or undifferentiated via gross examination. They also found that plotting changes in GSI vs. size was accurate at predicting female L_{50} but was grossly inaccurate for predicting male L50. Not only will the use of gonad histology improve accuracy of L_{50} estimates, but it will also result in more reliable sex ratio estimates (particularly operational sex ratio) and be used to evaluate ovaries for suitability for batch fecundity analysis.

[hhh] Includes *Kuhlia sandvicensis , K. xenur, Mugil cephalus, Chanos chanos, Naso unicornis , N. brevirostris , N. annulatus, N. hexacanthus, Acanthurus triostegus sandvicensis, Parupeneus multifasciatus, P . porphyreus Polydactylus sexfilis, Albula glossodonta Scarus dubius, S. psittacus S. rubroviolaceus, Chlorurus sordidus , C. perspicillatus, Caranx ignobilis , C. lugubris , C. melampygus , C. sexfasciatus , Carangoides equula , C. ferdau , C. orthogrammus, Aprion virescens* and *Mulloidicthys flavolineatus*

Age-growth information was available for 11 of 13 species. Otolith increment periodicity was purportedly documented for four of these species (*M. amaena*, *C. melampygus*, *C. spilurus,* and *C. strigosus*), though only publications for the first two species contained photos of the marked otolith. Otolith validation can be particularly difficult and time consuming experience because: 1) it involves catching live fish and keeping in captivity 2) marking compounds do not work equally well on all species or sizes 3) marked fish often reluctant to feed due to stress 4) it requires special visualization equipment and 5) it is often not known whether the marking process worked until the end of the study, so if unsuccessful, cannot be repeated. Despite these difficulties, knowledge of otolith increment periodicities is imperative to interpreting growth data, particularly since some of the studies cited in this compendium use annual bands whereas others estimate age from daily increments. Given the time and effort that goes into a successful marking trial, best success may be realized by funding a single study to validate multiple species using several compounds as well as mark and recapture studies.

Mortality estimates were available for only three species, one of which was estimated from the Great Barrier Reef. Despite this, three studies [38, 24, 21] contain or reference large sets of size-frequency data for *C. melampygus* and *C.ignobilis*. When combined with existing growth equations (25, 31) these can be used for estimate absolute mortality rates for these two species.

Much of the existing life-history information comes from populations in the NWHI, particularly for *P. cheilio*. These populations occur at different latitudes/temperatures than MHI specimens and are most are not subject to significant fishing pressure. As such, this information should be applied with caution to MHI species. When possible, we recommend life history studies from MHI to tease-out differences in natural vs. fishing mortality and examine the roll that fishing plays in driving-down L50.

Several studies collected but did not analyze otoliths or gonadal tissues. Creating a central repository for life history specimens would increase the usefulness of collected specimens (e.g. from NWHI cruise). This could include a manual for standardized collection, preservation, and cataloging.

Although most of the species surveyed lacked adequate life history information needed for traditional fisheries management, we did find several studies which included demographic information (size-structure, abundance, & density) which will be useful in constructing surplus yield models once the necessary life history parameters become available.

Approximately 71% of the references cited came from peer-reviewed journals or books. The remainder came from non peer-reviewed books (11%) technical reports (12.5%) and theses/ dissertations (4.5%). Although the lack peer review may cause us to question the quality of the data, the limited availability of these publications is of greater concern. Because they are not indexed on electronic database searches, grey literature references lie below the radar of most researchers. Even if grey literature references are located, the publications have limited circulation, are seldom available electronically and are usually inaccessible to researchers outside the state. This problem could be corrected by encouraging state and federal labs to publish pertinent information from technical reports in peer-reviewed journals. In addition, DLNR may be able to institute a policy requiring all recipients of scientific collecting permits to submit electronic copies of publications (both peer-reviewed and grey literature) to their office at the completion of the study. These titles could be indexed online and electronic copies could be made available by request under the fair-use policy.

SUMMARY OF RECCOMENDATIONS

1) Standardize methodology for estimating key life history parameters (e.g., sex ratio, minimum size at maturity and L_{50}).
2) Encourage additional life history studies for the MHI.
3) Re-evaluate current size-restrictions for species for which L50 is known.
4) Push for increased effort in estimating batch and annual fecundity for important target species.
5) Validate rate of otolith increment deposition for key species using chemical marking techniques.
6) Analyze *existing* data sets to fill in the gaps (for example, estimate total mortality of jacks using existing age-growth and size-frequency data).
7) Encourage publication in peer-reviewed journals.
8) Create a repository and database for Hawaii-based life history studies. This repository could : i) provide a set of written guidelines for the collection of life history data (see #1) ii) store and catalog un-used specimens for future analysis iii) track specimens collected under SAP permits iiii) house an electronic library of life history information iiii) post an up-to-date bibliography of life history publications on the internet iiiii) where allowed by copyright and fair-use laws, provide electronic copies of hard-to-find life history publications and technical reports. iiiii) cross-reference life history studies with relevant demographic studies

LITERATURE CITED

1. Randall, J.E., *Reef and Shore Fishes of the Hawaiian Islands*. 2007, Honolulu: Sea Grant College Program. 546.
2. Mundy, B.C., *Checklist of the fishes of the Hawaiian Archipelago.* Bishop Museum Bulletin in Zoology, 2005. **6**: p. 1-703.
3. Randall, J.E. and D.W. Greenfield, *Revision of the Indo-Pacific holocentrid fishes of the genus Myripristis, with descriptions of three new species.* Indo-Pacific Fishes, 1996. **25**: p. 1-61.
4. Castelnau, F.L., *Contribution to the ichthyology of Australia.* Proceedings of the Zoological and Acclimmatisation Society of Victoria, 1873. **2**: p. 37-158.
5. Jordan, D.S. and B.W. Evermann, *Descriptions of new genera and species of fishes from the Hawaiian Islands.* Bulletin of the U.S. Fish Commission, 1903. **22**: p. 161-208.
6. Cuvier, G. and A. Valenciennes, *Histoire naturelle des poissons. Tome troisieme. Suite du Livre troisieme. Des percoides a dorsale a sept rayons branchiaux et a dents en velours ou en cardes.* Hist. Nat. Poiss., 1829. **3**: p. 1-500.
7. Titcomb, M., *Native Use of Fish in Hawaii*. 1952, New Plymouth: Avery Press Ltd. 162.
8. Dee, A.J. and J.D. Parrish, *Reproductive and trophic ecology of the soldierfish Myripristis amaena in tropical fisheries.* Fishery Bulletin, 1994. **92**: p. 516-530.
9. Leis, J.M. and B.M. Carson-Ewart, *The Larvae of Indo-Pacific Coastal Fishes: An Identification Guide to Marine Fish Larvae*. 2000, Leiden: Brill.
10. Dee, A.J. and R.L. Radtke, *Age and growth of the brick soldierfish, Myripristis amaena.* Coral Reefs, 1989. **8**: p. 79-85.
11. Hayes, T.A., et al., *The coastal resources, fisheries and fishery ecology of Puako, West Hawaii*. 1982, Hawaii Cooperative Fishery Research Unit Technical Report 82-1: Honolulu.
12. Hobson, E.S., *Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii.* Fishery Bulletin, 1974. **72**: p. 915-1031.
13. Randall, J.E. and P.C. Heemstra, *Holocentridae*, in *Smiths' Sea Fishes*, M.M. Smith and P.C. Heemstra, Editors. 1986, Springer-Verlag: Berlin. p. 415-427.
14. Lacepede, B.G.E., *Histoire naturelle des poissons.* Hist. Nat. Poiss., 1802. **4**: p. 1-728.
15. Gunther, 1873.
16. Munro, J.L. and D.M. Willams, *Assessment and management of coral reef fisheries: biological, environmental and socio-economic aspects.* Proceedings of the 5th International Coral Reef Symposium, 1985. **4**: p. 545-578.
17. Paxton, J.R., et al., *Pisces. Petromyzontidae to Carangidae.* Zoological Catalogue of Australia, 1989. **7**: p. 1-665.
18. Forsskal, P., *Descriptiones animalium avium, amphibiorum, piscium, insectorum, vermium; quae in itinere orientali observavit.* Hauniae. Descr. Animalium, 1775: p. 1-164.
19. Jenkins, O.P., *Report on collections of fishes made in the Hawaiian Islands, with descriptions of new species.* Bulletin of the U.S. Fish Commission, 1903. **22**: p. 415-511.
20. Gaffney, R., *Evaluation of the status of the recreational fishery for ulua in Hawaii, and recommendations for future management*. 2000, DAR Technical Report 20-02. p. 1-35.
21. Tagawa, A.W. and C.K.M. Tam, *Hawaii's ulua and papio tagging project 2000 to 2004*. 2006, DAR Technical Report 06-01. p. 1-75.

22. Holzwarth, S.R., et al., *Sharks and jacks in the Northwestern Hawaiian Islands from towed-diver surveys 2000-2003.* Atoll Research Bulletin, 2006. **543**: p. 257-279.
23. Friedlander, A.M. and E.E. DeMartini, *Contrasts in density, size, and biomass of reef fishes between the northwestern and main Hawaiian islands: the effects of fishing down apex predators.* Marine Ecology Progress Series, 2002. **230**: p. 253-264.
24. Wetherbee, B.M., et al., *Use of a marine reserve in Kaneohe Bay, Hawaii by the giant trevally, Caranx ignobilis.* Fisheries Research, 2004. **67**: p. 253-263.
25. Smith, G.C. and J.D. Parrish, *Estuaries as nurseries for the jacks Caranx ignobilis and Caranx melampygus (Carangidae) in Hawaii.* Estuarine Coastal and Shelf Science, 2002. **55**: p. 347-359.
26. Major, P.F., *Predator-prey interactions in two schooling fishes, Caranx ignobilis and Stolephorus purpureus.* Animal Behaviour, 1978. **26**: p. 760-777.
27. DeMartini, E.E. and A.M. Friedlander, *Predation, endemism, and related processes structuring shallow-water reef fish assemblages of the NWHI.* Atoll Research Bulletin, 2006. **543**: p. 237-256.
28. Shomura, R. 1987. Hawaii's marine fishery resources: yesterday (1900) and today (1986). US Dept Comm, NOAA, NMFS, Southwest Fish Sci Center Admin Rep H-87-21, Honolulu, 14 pp.
29. Lowe, C.G., B.M. Wetherbee, and C. Meyer, *Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and giant trevally around French Frigate Shoals and Midway Atoll.* Atoll Research Bulletin, 2006. **543**: p. 281-303.
30. Meyer, C.G., K.N. Holland, and Y.P. Papastamatiou, *Seasonal and diel movements of giant trevally Caranx ignobilis at remote Hawaiian atolls: implications for the design of marine protected areas.* Marine Ecology Progress Series, 2007. **333**: p. 13-25.
31. Sudekum, A.E., et al., *Life history and ecology of large jacks in undisturbed, shallow, oceanic communities.* Fishery Bulletin, 1991. **89**: p. 493-513.
32. von Westernhagen, H., *Observations on the natural spawning of Alectis indicus (Ruppell) and Caranx ignobilis (Forsk.) (Carangidae).* Journal of Fish Biology, 1974. **6**: p. 513-516.
33. Williams, F. 1965. Further notes on the biology of East African pelagic fishes of the families Carangidae and Sphyraenidae. East African Agric. J. 31:141-168.
34. Talbot, F.H. and F. Williams. 1956. Sexual color differences in *Caranx ignobilis* (Forsk.). Nature, London 178:934.
35. Murakami, K., et al., *Two hybrids of carangid fishes of the genus Caranx, C. ignobilis x C. melampygus and C. melampygus x C. sexfasciatus, from the Hawaiian Islands.* Zoological Studies, 2007. **46**: p. 186-193.
36. Leis, J.M. and T. Trnski, *The Larvae of Indo-Pacific Shorefishes*. 1989, Kensington: New South Wales University Press. 372.
37. Honebrink, R.R., *A review of the biology of the family Carangidae, with emphasis on species found in Hawaiian waters*. 2000, DAR Technical Report 20-01: Honolulu. p. 1-37.
38. Meyer, C.G., et al., *Diet, resource partitioning and gear vulnerability of Hawaiian jacks captured in fishing tournaments.* Fisheries Research, 2001. **53**: p. 105-113.
39. Cuvier, G. and A. Valenciennes, *Histoire naturelle des poissons. Tome neuvieme. Suite du livre neuvieme. Des Scomberoides.* Hist. Nat. Poiss., 1833. **9**(1-512).

40. Eydoux, J.F.T. and A. Souleyet, *Poissons*, in *Voyage Autor du Monde Execute Pendant les Annees 1836 et 1837 sur la Corvette La Bonite, Commandee par M. Vaillant. Zoologie*. 1850: Paris. p. 155-216.
41. Linnaeus, C., *Systema Naturae Sive Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis*. 12 ed. Vol. 1. 1766, Holmiae: Laurentii Salvii. 1-532.
42. Spix, J.B.v. and L. Agassiz, *Selecta Genera et Species Piscium Quos in Itinere per Brasiliam Annos MDCCCXVII-MDCCCXX Jussu et Auspiciis Maximiliani Josephi I...* in *Selecta Piscium Brasiliam, Part 2*. 1831. p. 83-138.
43. Potts, G.W., *The predatory behaviour of Caranx melampygus (Pisces) in the channel environment of Aldabra (Indian Ocean).* Journal of Zoology, 1980. **192**: p. 323-350.
44. Holland, K.N., C.G. Lowe, and B.M. Wetherbee, *Movements and dispersal patterns of blue trevally (Caranx melampygus) in a fisheries conservation zone.* Fisheries Research, 1996. **25**: p. 279-292.
45. Moriwake, A.M., et al., *Natural spawning of the bluefin trevally Caranx melampygus in captivity.* Aquaculture, 2001. **203**: p. 159-164.
46. Friedlander, A., et al., *The state of coral reef ecosystems of the main Hawaiian Islands*. 2008, NOAA Technical Memorandum NOS NCCOS 73: Silver Spring. p. 219-261.
47. Masuda, R. and D.A. Ziemann, *Vulnerability of Pacific threadfin juveniles to predation by bluefin trevally and hammerhead shark: size dependent mortality and handling stress.* Aquaculture, 2003. **217**: p. 249-257.
48. Bloch, M.E. and J.G. Schneider, *M.E. Blochii, Systema Ichthyologiae Iconibus cx Illustratum. Post Obitum Auctoris Opus Inchoatum Absolvit, Correxit, Interpolavit Jo. Gottlob Schneider, Saxo. Berolini. Sumtibus Auctoris Impressum et Bibliopolio Sanderiano Commissum*. Systema Ichthyol. 1801. 1-584.
49. Snyder, J.O., *A catalogue of the shore fishes collected by the steamer "Albatross" about the Hawaiian Islands in 1902.* Bulletin of the U.S. Fish Commission, 1904. **22**: p. 513-538.
50. Steindachner, F. and L. Doderlein, *Beitrage zur Kenntniss der Fische Japan's (III).* Denkschr. Akad. Wiss. Wien., 1884. **49**: p. 171-212.
51. Jordan, D.S. and J.O. Snyder, *Notes on fishes of Hawaii, with descriptions of new species.* Bulletin of the Bureau of Fisheries, 1907. **26**: p. 205-218.
52. Tessier, E., et al., *Visual censuses of tropical fish aggregations on artificial reefs: slate versus video recording techniques.* Journal of Experimental Marine Biology and Ecology, 2005. **315**: p. 17-30.
53. DeFelice, R.C. and J.D. Parrish, *Importance of benthic prey for fishes in coral reef-associated sediments.* Pacific Science, 2003. **57**: p. 359-384.
54. Masuda, R. 1995. The ontogeny of schooling behaviour in the striped jack Pseudocaranx dentex. D. Phil. Thesis, University of Tokyo, Tokyo. 199 pp.
55. Masuda, R. and K. Tsukamoto, *The ontogeny of schooling behaviour in the striped jack.* Journal of Fish Biology, 1998. **52**: p. 483-493.
56. Masuda, R. and K. Tsukamoto, *School formation and concurrent developmental changes in carangid fish with reference to dietary conditions.* Environmental Biology of Fishes, 1999. **56**: p. 243-252.

57. Masuda, R. and K. Tsukamoto, *Onset of association behavior in striped jack, Pseudocaranx dentex, in relation to floating objects.* Fishery Bulletin, 2000. **98**: p. 864-869.
58. Vassallo-Agius, R., et al., *Effect of squid meal in dry pellets on the spawning performance of striped jack Pseudocaranx dentex.* Fisheries Science, 2001. **67**: p. 271-280.
59. Afonso, P., et al., *Reproduction and spawning habit of white trevally, Pseudocaranx dentex, in the Azores, central north Atlantic.* Scientia Marina, 2008. **72**: p. 373-381.

61. Masuda, R., and K. Tsukamoto. 1996. Morphological development in relation to phototaxis and rheotaxis in the striped jack, *Pseudocaranx dentex*. Mar. Fresh. Behav. Physiol. 2875–90.
62. Seki, M.P. 1986. Section on *Pseudocaranx dentex*. In: Uchida, R.N. and J.H. Uchiyama (Eds.), Fishery atlas of the Northwestern Hawaiian Islands, p. 96-97. NOAA Tech. Rep. NMFS 38.
63. Seki, M.P. 1984. The food and feeding habits of the white trevally, *Pseudocaranx dentex* (Bloch and Scheider 1801) in the Northwestern Hawaiian Islands. In: Grigg, R.W. and K.Y. Tanoue (Eds.), Proceedings of the second symposium on resource investigations in the Northwestern Hawaiian Islands, vol. 2, p. 192-208. Univ. of Hawaii Sea Grant College Program, Honolulu.
64. Sazima, I., *Field evidence for suspension feeding in Pseudocaranx dentex, with comments on ram filtering in other jacks (Carangidae).* Environmental Biology of Fishes, 1998. **53**: p. 225-229.
65. Randall, J.E., *Mullidae. Goatfishes (surmullets)*, in *FAO Species Identification Guide for Fishery Purposes. The Living Marine Resources of the Western Central Pacific*, K.E. Carpenter and V.H. Niem, Editors. 2001, FAO: Rome. p. 2791-3380.
66. Lacepede, G.G.E., *Histoire naturelle des poissons.* Hist. Nat. Poiss., 1801. **3**: p. 1-558.
67. Swain and Swain, 1882.
68. Gunther, A., *Andrew Garrett's Fische der Sudsee.* Journal des Museum Godeffroy, 1874: p. 58-96.
69. Schumacher, B.D. and J.D. Parrish, *Spatial Relationships Between an Introduced Snapper and Native Goatfishes on Hawaiian Reefs.* Biological Invasions, 2005. **7**: p. 925-933.
70. Holland, K.N., et al., *Movements, distribution and growth rates of the white goatfish Mulloides flavolineatus in a fisheries conservation zone.* Bulletin of Marine Science, 1993. **52**: p. 982-992.
71. Schroeder, R.E. and J.D. Parrish, *Ecological characteristics of coral patch reefs at Midway Atoll, Northwestern Hawaiian Islands.* Atoll Research Bulletin, 2006. **543**: p. 439-460.
72. Lange, R. *A multi-species foraging association: wrasse-induced changes in feeding behaviour of the goatfish Parupeneus forskalii and Mulloidichthys flavolineatus*. in *Tropical Marine Ecology*. 2006. Mangrove Bay, Egypt: University of Tubingen.
73. Pothin, K., et al., *Distinction between Mulloidichthys flavolineatus juveniles from Reunion Island and Mauritius Island (south-west Indian Ocean) based on otolith morphometrics.* Journal of Fish Biology, 2006. **69**: p. 38-53.

74. Hiatt, R.W. and D.W. Strasburg, *Relationships of the fish fauna on coral reefs of the Marshall Islands.* Ecological Monographs, 1960. **30**: p. 65-127.
75. Sorden, C.T., *Trophic relationships of goatfishes (family Mullidae) in the Northwestern Hawaiian Islands*. 1982, University of Hawaii: Honolulu. p. 86.
76. Wahbeh, M.I., *The food and feeding habits of the goatfishes, Mulloides flavolineatus and Mulloides vanicolensis in the Gulf of Aqaba, Jordan.* Senckenbergiana maritima, 1992. **22**: p. 245-254.
77. Wahbeh, M.I., *Aspects of the reproduction biology and growth of two species of goatfish (Mullidae) from Aqaba, Red Sea.* Senckenbergiana maritima, 1992. **22**: p. 255-264.
78. Al-Absy, A.H., *The biometry, weight-length relationships and growth of the goatfish Mulloidichthys flavolineatus (Lacepede) from the Gulf of Aquaba, Red Sea.* Matsya, 1987. **12**: p. 148-152.
79. Randall, J.E., *Revision of the goatfish genus Parupeneus (Perciformes: Mullidae), with descriptions of two new species.* Indo-Pacific Fishes, 2004. **36**: p. 1-64.
80. Quoy, J.R.C. and J.P. Gaimard, *Description des poissons*, in *Voyage Autor du Monde Execute sur les Corvettes de L. M. "L'Uranie" et "La Physicienne," Pendant les Annees 1817, 1818, 1819, et 1820*, L.d. Freycinet, Editor. 1825: Paris. p. 329-616.
81. Jordan, D.S. and A. Seale, *The fishes of Samoa. Description of the species found in the archipelago, with a provisional check-list of the fishes of Oceania.* Bulletin of the Bureau of Fisheries, 1906. **25**: p. 457-488.
82. Lobel, P.S., 1978.
83. Sancho, G., C.W. Petersen, and P.S. Lobel, *Predator-prey relations at a spawning aggregation site of coral reef fishes.* Marine Ecology Progress Series, 2000. **203**: p. 275-288.
84. Longenecker, K. and R. Langston, *A rapid, low-cost technique for describing the population structure of reef fishes*. 2008, Hawaii Biological Survey Contribution 2008-002: Honolulu. p. 1-34.
85. Randall, J.E., 1985.
86. Mahi, C.A., *Food and feeding habits of the kumu, Parupeneus porphyreus*. 1969, University of Hawaii: Honolulu. p. 54.
87. Meyer, C.G., et al., *Movement patterns, habitat utilization, home range size and site fidelity of whitesaddle goatfish, Parupeneus porphyreus, in a marine reserve.* Environmental Biology of Fishes, 2000. **59**: p. 235-242.
88. Moffitt, R.B., *Age, growth, and reproduction of the kumu, Parupeneus porphyreus*. 1979, University of Hawaii: Honolulu. p. 42.
89. Gosline, W.A. and V.E. Brock, *Handbook of Hawaiian Fishes*. 1960, Honolulu: University of Hawaii Press. 372.
90. Holland, K., *Chemosensory orientation to food by a Hawaiian goatfish (Parupeneus porphyreus, Mullidae).* Journal of Chemical Ecology, 1978. **4**: p. 173-186.
91. Cuvier, G. and A. Valenciennes, *Histoire naturelle des poissones. Tome quatorzieme. Suite du livre siezieme. Labroides. Livre dix-septieme. Des Malacopterygiens.* Hist. Nat. Poiss., 1840. **14**: p. 1-464.
92. Bryan, W.A., *Three new Hawaiian fishes.* Occasional Papers of the Bernice Pauahi Bishop Museum, 1906. **2**: p. 22-37.
93. Steindachner, 1900.

94. Crook, A.C., *A quantitative analysis of the relationship between interspecific encounters, schooling behaviour and colouration in juvenile parrotfish (family Scaridae).* Marine and Freshwater Behaviour and Physiology, 1999. **33**: p. 1-19.
95. Howard, K. and J.D. Parrish, *Population biology of parrotfish in Hawaii: Phase II.* 2008, Hawaii Cooperative Fishery Research Unit: Honolulu. p. 1-39.
96. Poepoe, K.K., P. Bartram, and A. Friedlander, *The use of traditional Hawaiian knowledge in the contemporary management of marine resources*, in *Putting Fisher's Knowledge to Work*. 2003, Fisheries Centre Research Report: Vancouver. p. 328-339.
97. Sancho, G., A.R. Solow, and P.S. Lobel, *Environmental influences on the diel timing of spawning in coral reef fishes.* Marine Ecology Progress Series, 2000. **206**: p. 193-212.
98. Choat, J.H. and D.R. Robertson, *Age-based studies on coral reef fishes*, in *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem*, P.F. Sale, Editor. 2002, Academic Press: San Diego. p. 57-80.
99. Randall, J.E., G.R. Allen, and R.C. Steene, *Fishes of the Great Barrier Reef and Coral Sea*. 1990, Bathurst: Crawford House Press. 507.
100. Jenkins, O.P., *Descriptions of new species of fishes from the Hawaiian Islands belonging to the families of Labridae and Scaridae.* Bulletin of the U.S. Fish Commission, 1901. **19**: p. 45-65.
101. Jordan, E.K., *Notes on the fishes of Hawaii, with descriptions of six new species.* Proceedings of the United States National Museum, 1925. **66**: p. 1-43.
102. Bruce, R.W., *On the occurrence of very small terminal phase parrotfishes.* Copeia, 1980. **1980**: p. 887-889.
103. Linnaeus, C., *Systema Naturae*. 10 ed. 1758, Holmiae.
104. Streets, T.H., *Ichthyology.* Bulletin of the United States National Museum, 1877. **7**: p. 43-102.
105. Broussonet, 1782.
106. Randall, J.E., *A contribution to the biology of the convict surgeonfish of the Hawaiian Islands, Acanthurus triostegus sandvicensis.* Pacific Science, 1961. **15**: p. 215-272.
107. Meyer, C., *An empirical evaluation of the design and function of a small marine reserve (Waikiki Marine Life Conservation District)*. 2003, University of Hawaii: Honolulu. p. 134.
108. Longenecker, K., R. Langston, and J.A. Eble, *Reproduction, growth, and mortality of manini, Acanthurus triostegus sandvicensis*. 2008, Hawaii Biological Survey Contribution 2008-006: Honolulu. p. 1-23.
109. Sale, P.F., *Influence of cover availability on depth preference of the juvenile manini, Acanthurus triostegus sandvicensis.* Copeia, 1968. **1968**: p. 802-807.
110. Randall, J.E. and K.D. Clements, *Second revision of the surgeonfish genus Ctenochaetus (Perciformes: Acanthuridae), with descriptions of two new species.* Indo-Pacific Fishes, 2001. **32**: p. 1-33.
111. Bennett, E.T., *Observations on the fishes contained in the collection of the Zoological Society. On some fishes from the Sandwich Islands.* Zoological Journal, 1828. **4**: p. 31-42.
112. Gosline, W.A., *Vertical zonation of inshore fishes in the upper water layers of the Hawaiian Islands.* Ecology, 1965. **46**: p. 823-831.
113. Tissot, B.N., *Adaptive management of aquarium fish collecting in Hawaii.* SPC Live Reef Fish Information Bulletin, 1999. **6**: p. 16-19.

114. Walsh, W.J., *Patterns of recruitment and spawning in Hawaiian reef fishes.* Environmental Biology of Fishes, 1987. **18**: p. 257-276.
115. Tissot, B.N., W.J. Walsh, and L.E. Hallacher, *Evaluating the effectiveness of a marine reserve network in west Hawaii to improve management of the aquarium fishery*. 2004, Final Report to the Hawaii Coral Reef Initiative. p. 1-20.
116. Randall, J.E., 1955.
117. Parrish, J.D. and J.T. Claisse, *Post-settlement life history of key coral reef fishes in a Hawaiian marine protected area network; Phase II*. 2006, Hawaii Cooperative Fishery Research Unit. p. 42.
118. Lobel, P.S., *Ocean current variability and the spawning season of Hawaiian reef fishes.* Environmental Biology of Fishes, 1989. **24**: p. 161-171.
119. Sancho, G., 1989.
120. Borden, W.C., *Phylogeny of the unicornfishes (Naso, Acanthuridae) based on soft anatomy.* Copeia, 1998. **1998**: p. 104-113.
121. Cuvier, 1835.
122. Meyer, C. and K.N. Holland, *Movement patterns, home range size and habitat utilization of the bluespine unicornfish, Naso unicornis (Acanthuridae) in a Hawaiian marine reserv.* Environmental Biology of Fishes, 2005. **73**: p. 201-210.
123. Doherty, P.J., et al., *High mortality during settlement is a population bottleneck for a tropical surgeonfish.* Ecology, 2004. **85**: p. 2422-2428.
124. Arai, H. and T. Sato, *Prominent ornaments and rapid color change: use of horns as a social and reproductive signal in unicornfish (Acanthuridae: Naso).* Ichthyological Research, 2007. **54**: p. 49-54.
125. Choat, J.H. and L.M. Axe, *Growth and longevity in acanthurid fishes; an analysis of otolith increments.* Marine Ecology Progress Series, 1996. **134**: p. 15-26.
126. Williams, H.A. and M.K. Lowe. 1997. Growth rates of four Hawaiian deep slope fishes: a comparison of methods for estimating age and growth from otolith microincrement widths. Can. J. Fsih. Aquat. Sci. **54**: p. 126-136.
127. Wallace, R.A. and K. Selman. 1981. Cellular and dynamic aspects of oocyte growth in teleosts, Sci. Zool., **21** pp. 325–343.
128. Afonso, P. 2007. Habitat use and movement patterns of three sympatric fishes with different life history strategies: implications for the design of marine reserves. Unpublished PhD dissertation. University of Hawaii at Manoa. 200 pages.

129. Freidlander, A., Aeby, G., Brainard, R., Brown, E., Chaston, K., Clark, A., McGowan, P., Montgomery, T., Walsh, W., Williams, I., Wiltse, W. 2008. The state of coral reef ecosystems of the main Hawaiian Islands. pp 219-261. In: J.E. Waddell and A.M. Clarke (eds.), The state of coral reef ecosystems of the United States and Pacific Freely Associated States. 2008. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 569 pp.