

CHARACTERIZING THE LIFE HISTORY AND RECREATIONAL FISHERY OF NABETA,
INIISTIUS PAVO, IN HAWAII

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ABSTRACT

Iniistius pavo is one of five species of razorfish (Labridae), locally referred to as nabeta, that are an important recreationally caught foodfish in Hawai`i. The little documentation on the nabeta fishery shows a serious decline in nabeta catches with no explanation or further research. This study serves to document life history traits and reproductive patterns to fill in the gaps of knowledge of *I. pavo* as well as document trends in the nabeta fishery using social media as a non-traditional source of information. Instagram was datamined using posted catch pictures to determine trends and species associations of nabeta catches and methods were developed to validate the accuracy and repeatability of catch pictures. These methods and the information documented in this study can provide valuable information for management of the nabeta fishery here in Hawai`i and throughout their range.

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CHAPTER 1: INTRODUCTION

1.1 Abstract

Razorfishes are highly valued foodfish species in Hawai`i, though little is known about the fishery as well as their life history. Their Hawaiian name is *laenihi*, but they are more commonly referred to with their Japanese name nabeta, which is used with any of the five *Iniistius* species found in Hawai`i. Fishing for nabeta in Hawai`i is primarily by recreational consumptive fishers for special events such as family events and holiday celebrations, with extra fish sold to seafood distributors and can command a high.

The life history of Hawaiian razorfish is minimally documented. Commercial catch data is non-existent with limited recreational fishery information showing a major drop in yield from 2004 to 2011 (Williams & Ma, 2013). Reproductive behavior, habitat use, and diet of local species has to be inferred from similar species. The lack of information on basic biological traits, such as growth curves, reproductive patterns, etc. makes management very difficult. This project determined life history information on growth and reproductive patterns to better inform management of these species. Further, the project developed methods to use social media to obtain fisheries information from social media when direct creel surveys and the like were not available.

1.2 Review of available literature on *Iniistius* spp.

The *Iniistius* genus, consisting of 18 species found in the Indo-Pacific, is one of two genera of razorfishes in the family Labridae with the second genus, *Xyrichtys*, represented by six Atlantic species, four Eastern Pacific species, and five Indo-Pacific species (Randall & Jonsson, 2008). Formerly classified in the genus *Xyrichtys*, the Indo-Pacific species were reclassified to *Iniistius* (Randall & Earle, 2002). The five species found in Hawaiian waters are: *I. aneitensis*, *I. baldwini*, *I. celebicus*, *I. pavo*, and *I. umbrilatus*. These species range throughout the Indo-Pacific region with the exceptions of *I. pavo* which is found from the Red Sea to the west coast of North America, and *I. umbrilatus* which is known only from the Hawaiian Islands (Randall & Earle, 2002).

Razorfish have thin laterally compressed bodies with a blunt snout that allows them to dive into the sand and travel through it rapidly (Victor et al., 2001). The first two dorsal spines, originating slightly posterior at rear edge of orbit separated by a gap with or without a membranous connection to the third spine, are flexible and can extend twice as long as the dorsal rays depending on the species (Randall, 2007). They are adapted to living in sand beds adjacent to reefs, diving in the sand for refuge from predators and to sleep at night (Tatom-Naecker & Westneat, 2018). Their diet consists of epibenthic crustaceans (amphipods and ostracods), shrimp, and crabs (De Felice & Parrish, 2003). Similar to other labrid species, razorfishes are protogynous living in aggregations of adults with individual female territories within the territory of a dominant male (Randall & Earle, 2002) though this aspect of razorfish life-history has not been documented for all razorfish species.

Razorfishes in Hawaiian waters are found in sandy patches at depths from 6 - 137 m adjacent to coral reefs or rocky substrates (Randall & Earle, 2002). Each of the five razorfish species found in Hawai'i have different species range, preferences for depth, and reproductive behavior. Figure 1.1 illustrates the differences of the local species.

Though the spawning season of Hawaiian razorfishes has not been documented, newly settled juveniles of *I. umbrilatus* have been observed year-round at Kahe Point Oahu, a peak recruitment period was identified in April and May (Randall & Earle, 2002). A mean (\pm SD) pelagic larval duration of 51 ± 7 d (range: 42–67 d) was determined for *I. pavo* from larvae collected in the Indo-Pacific and Eastern Pacific (Victor & Wellington, 2000). Juveniles resemble adults with darkened vertical bars and additional spots on the dorsal rays, however, *I. pavo* juveniles are dark brown mimicking dead leaves moving with the surge on the bottom (Randall, 2005). Juveniles are solitary living in shallower depths and aggregate in groups as adults in single- or multi-species groups (Randall & Earle, 2002).

Documentation of the fishery and life history of razorfishes is limited, especially to those inhabiting Hawaiian waters. There is no commercial fishery, estimations of the recreational catch of *I. pavo* alone from the Hawai'i Marine Recreational Fishing Survey show the annual catch decreasing from 69,308 kg (165,433 individuals) in 2004 to 6,197 kg (9,654 individuals) in 2011 (Williams & Honggauang, 2013). Their weight estimates were derived using conversion factors

from the NOAA PIFSC CRED database to generate biomass estimates from reef fish visual survey data with most length-weight parameters from FISHBASE (Froese & Pauly 2019). The causes for this decline were not discussed, however a decline of 90% by weight indicates a need for investigation.

1.3 Using social media to collect fisheries information

In the absence of commercial fishery and limited primary data on recreational fisheries, researchers have turned to novel sources. For example, the Hawai'i recreational razorfishes fishery has a presence in social media outlets, specifically on the location-based social photo sharing application Instagram, that can be used to glean limited information on catches. The use of text and datamining of social media has been shown to be useful for social and biological research related to fisheries (Monkman et al., 2018). Though this type of data is fraught with biases and limited information, its careful use can provide information on the fishery in the absence of formalized data (Monkman et al., 2018a). The ethical use of this type of data requires anonymization of the data so the human subjects cannot be identified without their explicit approval. Obviously, data mining social media faces even more limitations than traditional creel surveys as information on fishing effort and precise location of catch are not available. Thus, using this information for inferences to the wider populations have to be made with caution.

1.4 Thesis organization

This thesis is organized into the preceding Introduction followed by two draft manuscripts which can exist independently. Each of these papers contains its own abstract, introduction, methods, results, and discussion. Chapter 2 is a draft manuscript entitled: Life history and reproductive pattern of *Iniistius pavo* in Hawai'i (authors: Richard Masse, Ricky Tabandera, Kevin Hopkins, Eva Schemmel, and Timothy Grabowski) while Chapter 3 is a draft manuscript entitled: Characterizing the recreational nabeta (Labridae: *Iniistius* spp.) fishery in Hawai'i using catch pictures from social media (authors: Richard Masse, Ricky Tabandera, and Timothy Grabowski).

CHAPTER 2: LIFE HISTORY AND REPRODUCTIVE PATTERN OF *INIISTIUS PAVO* IN HAWAI'I

2.1 Abstract

Understanding the life history and reproductive patterns of understudied fishes is a critical first step for developing effective fisheries management. In Hawai'i, peacock razorfish, *Iniistius pavo*, is a tropical labrid that is an important food fish which has little life history and fishery information available. What documentation exists on this recreational fishery in Hawai'i shows a large decline in landings though provides no reasoning for this decrease. I examined age, growth, and reproduction of *I. pavo* from otoliths and gonads collected from specimens donated by recreational fishers from the island of Hawai'i. Male *I. pavo* were larger and heavier than females captured around Hawai'i Island. *Iniistius pavo* is a relatively slow growing species ($k = 0.16$) reaching a predicted asymptotic length, i.e., L_{∞} , of 48.5 ± 3.8 cm TL after age-9; however, no individuals older than age 6 were collected during this study. The reproductive phases of *I. pavo* confirmed that the species followed a protogynous hermaphrodite reproductive pattern with sex change estimated to occur at $L_{\Delta 50} = 25.7 \pm 1.3$ cm and $A_{\Delta 50} = 4.0 \pm 0.3$ yrs. This study represents the first assessment of the life history of *I. pavo* and provides a baseline for informing fisheries management decisions in the region.

2.2 Introduction

The biology and life history are important aspects for developing management strategies for understudied species. One such species is peacock razorfish, *Iniistius pavo*. A tropical labrid, *I. pavo*, is one of five *Iniistius* species frequently targeted in the Hawaiian nearshore non-commercial reef and the near-shore bottomfish fishery (Masse et al. *in press*). *Iniistius pavo* is targeted as a foodfish throughout its range in the Indo-Pacific (Randall, 2007) and primarily caught for special events in Hawai'i. Of the five *Iniistius* species occurring in the Hawaiian Islands, *I. pavo* is the most frequently captured by noncommercial fishers (Masse et al. *in press*). Since no recreational fishing license is required in Hawai'i, records of *I. pavo* landings are not reported due to the small-scale size of the fishery. Furthermore, little is known on their biology and life history. Available data are limited but seems to indicate that the population is experiencing a dramatic decline, as evidenced by a 90% reduction in reported *I. pavo* catch

during 2004-2011 (Williams and Ma, 2013). However, there have been no targeted surveys conducted to document growth, age, or reproductive pattern of the species in the Hawaiian Islands or elsewhere throughout its range. With the paucity of data on *I. pavo* and the fishery, base line information on the life history and reproductive biology is needed to inform fisheries managers.

Razorfish are represented by two genera within the family Labridae: *Xyrichtys* spp. which are primarily found in the Atlantic Ocean and Mediterranean Sea, and *Iniistius* spp. found in the Indo-Pacific region (Randall and Earle, 2002). Documentation of the growth, life history, and reproductive patterns of razorfishes is limited and the few studies that have been conducted focused exclusively on *Xyrichtys* spp. Documentation of age and growth observed by otolith examination has only been performed on *X. novacula*, a smaller, temperate species found in the Mediterranean (Cardinale et al., 1998). While sequential hermaphroditism has been confirmed for *Xyrichtys* spp. (De Mitcheson and Liu, 2008) and specifically protogynous sequential hermaphroditism for *X. novacula* (Cardinale et al., 1998), it remains unconfirmed, but suspected, that *Iniistius* spp. follow a similar pattern (Thresher, 1984). Harem spawning behaviors have been reported for both *Xyrichtys* spp. (Marconato et al., 1995; Nemtzov, 1985; Tinicenis and Victor, 1987) and *Iniistius* spp. (Randall and Earle, 2002). Additionally, *Xyrichtys* spp. exhibit sexual dimorphism (Candi et al., 2004) and sexual dimorphism has been observed for *I. pavo* (Randall, 2007).

Due to the differences in the reproductive behaviors between gonochoristic and hermaphroditic species, it is suggested that hermaphroditic species are more vulnerable to fisheries exploitation (Alonzo et al., 2008). Fishing pressures have been shown to alter the size or age at maturity of gonochoristic species (Provost and Jensen, 2015). However, it is difficult to predict how species that are sequential hermaphrodites might respond to fishing pressure without knowledge of their growth rates, age and size at maturation, and age and size at transition (Alonzo and Mangel, 2005; Pears et al., 2006; Provost and Jensen, 2012; Provost and Jensen, 2015). Furthermore, the size selective nature of most fishing pressure can skew sex ratios of sequential hermaphrodite populations resulting in changes to population structure and reproductive output (Provost and Jensen, 2015). With the lack of information on *I. pavo*, documenting the reproductive biology and life history are important to better understand the observed declines in the fishery. Therefore,

the objectives of this study were to determine whether *I. pavo* is a sequential protogynous hermaphrodite and evaluate aspects of its life history in Hawai'i through analysis of otoliths and gonads.

2.3 Methods

2.3.1 Sampling

For this study, *I. pavo* ($n = 116$) were donated by recreational fishers from four areas off the east coast of the Island of Hawai'i near Hilo ($n = 107$), one area off Nā'ālehu ($n = 6$), and one location of the northwest side of Hawai'i near Kawaihae ($n = 3$). Sample collection took place from September 2018 to October of 2020. All fish were caught while angling off a boat over sandy patches ranging from 25 to 35 m depth. The samples were kept on ice and processed within 24 hrs. Fish were measured to the nearest 0.1 cm total length (TL), weighed to the nearest gram (Taylor Precision Products, model 3828, Seattle, Washington), photographed, and gonads harvested. Heads were frozen for later otolith extraction.

Length and weight were recorded with the ranges and means (\pm SE) determined for all *I. pavo* collected. Sex was determined by histological examination of the gonads. A Kolmogorov-Smirnov two-sample test was used to analyze size frequency distributions of both sexes.

The length-weight relationship:

$$W = (aL)^b,$$

where W is the weight (g), L is total length, a is the regression intercept, and b is the regression slope (Ricker, 1975). The length weight relationship was logarithmic transformed:

$$\text{Log } W = \text{Log } a + b \text{ Log } L,$$

The log transformed length-weight relationship (Ricker, 1975) was first established for the total sample group then for males and females. Models were fit using nonlinear least squares. Analysis of covariance (ANCOVA) was used to test the differences in length-weight relationship between the sexes, considering log length was the dependent variable on the independent

variable of log weight with sex as the covariate. All statistical analysis were performed using R version 4.0.1 (R Core Team, 2020).

2.3.2 Age and growth

Sagittal otoliths, hereafter referred to as sagitta, were removed from all specimens, cleaned, and stored dry for later mounting and analysis. One sagitta, selected at random from each sample, was placed in a 40-mm square weigh boat filled approximately one quarter full with dried clear epoxy resin (Bondo 20122, 3M, St. Paul, MN) and secured convex face down to the resin with cyanoacrylate (Loctite, Henkel Corporation, Rocky Hill, CT). The weigh boat was then filled with enough clear epoxy resin to completely cover the sagitta and allowed to dry. An IsoMet low speed saw (Buehler, Lake Bluff, Illinois) was used to excise a 0.5-mm section of the sagitta which included the nucleus. The section was secured to a glass microscope slide using thermoplastic glue (Crystalbond 509, Aremco Products Inc., Valley Cottage, New York). The section was then polished with 400, 800, and 1200 grit (grains cm^{-2}) sandpaper to explore the nucleus on both sides of the section and photographed using a compound microscope fitted with a 14-megapixel digital camera (OMAX, Kent, WA). Initial ageing of each otolith was performed by the author (RM) and later by a second reader (TBG). Otoliths with poorly defined annuli or that were cracked were deemed unusable and discarded. In the case of a disagreement between readers, the otolith was discarded if a consensus could not be reached ($n = 3$). Measurements of annuli from the otoliths (Figure 2.1) were used for back calculations.

The interval between the nucleus and each annulus and the total radius of otolith was measured along the sulcus using functions within package “FSA” (Ogle et al., 2022) run in R v. 0.9.3 (R Core Development Team, 2021). Images of a subset of 85 sagittal otoliths usable for back calculations (males $n = 24$, females = 61) were used to estimate fish length at previous ages. A von Bertalanffy growth model (VBGM) was used according to von Bertalanffy, (1957):

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

where L_t is total length at age t , L_∞ is the mean asymptotic length, k is the growth rate coefficient, and t_0 is the average age where length is zero. Back-calculated lengths at age were estimated from these data using the Dahl-Lea direct proportion method (Lea, 1910):

$$L_i = (R_i/R_c)L,$$

where L_i is the length at age i , R_i is the radius of the otolith at age i , R_c is the radius of the otolith at capture, and L is the length at capture.

2.3.3 Gonad Histology

Gonads were harvested from a subset of 111 of the *I. pavo* samples (males $n = 35$, females $n = 76$) collected for this study. Gonads were extracted within 24 hours of capture, photographed in-situ, then removed, placed in embedding cassettes labeled with an identification number and stored in a 10% buffered formalin and seawater solution. To determine if gonad morphology was consistent along the length of the gonad, sections were taken from anterior, medial, and posterior sections of a sub-sample of males ($n = 4$) and females ($n = 3$). They were then analyzed to compare the reproductive state of each sub-sample. This was done to determine if gamete development was uniform along the length of the gonad. Sex was determined based on the histological sample analysis. For histological assessment, the gonad sections were embedded in paraffin, sectioned at 5 micrometers, and counterstained with haematoxylin and eosin at the John A. Burns Medical School at the University of Hawai'i. The gonad samples were viewed under a compound microscope (OMAX, Kent, WA) at 4x, 10x and 40x magnification and photographed with a 14-megapixel camera (AmScope MU1400, Irvine, CA USA).

Classification of the gonad reproductive phases of *I. pavo* was based on diagnostic criteria of five functional female phases, and two functional male phases (Table 2.1) modified from Brown-Peterson et al. (2011). Immature females were identified as having the presence of primary growth oocytes and having a thin ovarian wall. Female gonads were considered mature in a developing phase with the presence of primary growth oocytes and cortical alveolar oocytes, early vitellogenic oocytes (VT I and VT II) may be present. Spawning capable gonads were identified as having early stage vitellogenic oocytes as well as late stage vitellogenic oocytes (VT III) and may contain post ovulatory follicle complexes and atretic oocytes. Gonads in the actively spawning phase were distinguishable from spawning capable females by having late-stage germinal vesicle migration, hydrated oocytes, or early post ovulatory follicles, and may contain atretic oocytes that have loss a spherical appearance.

Table 2.1. Diagnostic criteria for determining the reproductive phase of functional females, quasi-transitional, and functional individuals of *Iniistius pavo* collected in the waters around the Island of Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods.

Reproductive State	Diagnostic criteria
Functional Female	
Immature	Not Mature Presence of primary growth oocytes (PO): chromatin nucleolus (CN) large germinal vesicle (nucleus) surrounded by thin layer of cytoplasm, perinucleous (PN) nucleus expands and nuclei appear at periphery of oocyte. Thin ovarian wall (OW).
Developing	Mature Presence of cortical alveolar oocytes (CA), appearance of cortical alveoli in the cytoplasm, and/or early vitellogenic oocytes (VTI and VTII) and formation of vitelline membranes. Atresia may be present.
Spawning Capable	Mature Marked by the dominance of late-stage vitellogenic oocytes (VTIII) Identified by increase in oocyte size and uniform distribution of yolk. May Contain postovulatory follicles (POF) and atretic oocytes (A).
Actively Spawning	Mature Presence of germinal vesicle migration (GVM) and hydrated oocytes (HY), VTIII and POFs may be present. Atretic oocytes were identified by loss of Spherical appearance and theca membrane breakdown.
Inactive	Mature Regressing subphase: presence of thick OW, large amounts of space in lumen, and may contain unabsorbed material from previous spawns. Regenerating subphase: presence of PO and oogonia only, thick ovarian wall and/or gamma/delta atresia or old POFs may be present.
Functional Male	
Males with MMC	Mature Presence of melanomacrophage centres (MMC) suggesting sex change, active spermatogenesis with pockets of spermatocysts scattered throughout the gonad. No presence of primary growth oocytes.
Male	Mature Actively spawning with spermatogenesis with pockets of spermatocysts and sperm present in sperm sinus.

Inactive phase: regressing subphase, gonads were determined by the presence of thick ovarian walls and large amounts of space in the lumen and may contain unabsorbed material from past spawns; regenerating subphase, females had only the presence of primary growth oocytes and may have gamma/delta atresia and old, degenerating post ovulatory follicles. Transitional

individuals are characterized by both testicular and ovarian tissues clearly exhibiting degradation of one sexually mature tissue and the proliferation of the other tissue of the other sex (De Mitcheson and Liu, 2008), however none were observed in this study. Males with melanomacrophage centers (MMC) were considered functional males with gonads containing MMC, active spermatogenesis, and the presence of pockets of spermatocytes. Males were classified as having pockets of spermatocytes and sperm in the sperm sinus. A χ^2 -test was used to compare the relative proportion of males and females in the population.

2.3.4 Length at sex change

A logistic regression was used to calculate the TL ($L_{\Delta 50}$) and age ($A_{\Delta 50}$) at sex change against the probability of 50% of *I. pavo* were estimated to be male using the generalized linear model, utilizing the logit link function. Because no immature individuals were collected in our sample, we were unable to assess length or age at maturity.

2.4 Results

2.4.1 Age and Growth

For this study, 116 (males, n = 36, females, n = 80) *I. pavo* were assessed for size (Table 2.2). The length distribution (Figure 2.2) was significantly different between males and females. The mean distribution trended toward the left for males and the right for females ($D = 0.80$, $P < 0.001$).

Table 2.2. Length (TL), weight, and age of *Iniistius pavo* collected from the waters around the Island of Hawai`i between September 2018 – October 2020.

	Length (TL)		Weight		Age	
	Range (cm)	Mean \pm SE (cm)	Range (g)	Mean \pm SE (g)	Range (years)	Mean \pm SE (years)
Males	21.1 - 33.5	27.6 \pm 0.3	172 - 860	456 \pm 97	3 - 6	4.5 \pm 0.7
Females	15.8 - 28.1	21.5 \pm 0.3	72 - 505	218 \pm 97	2 - 6	3.5 \pm 0.8

Length and weight distributions of the males and females overlap (Table 2.3), The mean TL of males was 6.1 cm greater than that of females ($t_{114} = 11.09$, $P < 0.001$). The smallest observed male was 21.1 cm TL and the smallest female was 15.8 cm TL. Age was determined by visual analysis of a subset of 113 sagittal otoliths.

Table 2.3. Length-weight parameters of *Iniistius pavo* collected from waters around the Island of Hawai'i between September 2018 – October 2020. Lengths and weights were log transformed by $\log W = \log a + b \log L$.

	$a \pm SE$	$b \pm SE$	P	R^2
Total	-12.31 ± -0.26	3.28 ± 0.05	< 0.001	0.98
Male	-13.88 ± -0.83	3.55 ± 0.15	< 0.001	0.94
Female	-13.07 ± -0.38	3.42 ± 0.07	< 0.001	0.97

Ages ranged from 2 – 6 yrs, no individuals under age-2 were collected. The linear model (Figure 2.3) demonstrated a strong relationship between the length and weight in this species ($a \pm SE = -12.31 \pm -0.26$, $b \pm SE = 3.28 \pm 0.05$, $P < 0.001$, $R^2 = 0.98$). There was a significant difference detected in the length-weight relationship between sexes ($F_{3,112} = 1735$, $P < 0.001$).

Iniistius pavo growth was described by a VBGM with the following parameter estimates: L_{∞} ($\pm SE$) = 48.7 ± 3.87 cm TL, k ($\pm SE$) = 0.158 ± 0.019 , and t_0 ($\pm SE$) = -0.279 ± 0.064 . The maximum size observed in the sample, 35.5 cm TL, was only 68.8% of L_{∞} as predicted by the VBGM (Figure 2.4). However, the VBGM predicted that individuals would not approach this size before age-9 which was 3 yrs older than the oldest individuals captured during this study. The observed growth rate was low, with individuals reaching an average of 9.0 cm TL after their first year and growing 3.6-5.8 cm annually thereafter.

2.4.2 Gonad histology

Reproductive phases of the gonads were determined by histological assessment based on the diagnostic criteria described in Table 1. A subset of 111 *I. pavo* gonads from the total sample group were successfully harvested and histologically analyzed resulting in a ratio of 2.2:1 (76 females: 35 males). Figure 2.5 illustrates the reproductive phases of *I. pavo* collected for this study. Mature females dominated the gonad histology samples collected ($n = 75$, 67.6%) with only a single immature (2.5A/B) female represented (0.1%). Developing (2.5C/D) females ($n = 5$, 4.5%) and spawning capable (2.5E/F) females ($n = 6$, 5.4%) were the least identified of the functionally mature females while actively spawning (2.5G/H) females ($n = 40$, 36.0%) were the largest proportion. Inactive (2.5I/J) females ($n = 21.6.7\%$) were the second largest grouping with regressing (2.5I) females ($n = 15$) the majority of the inactive females (62.5%) and followed by regenerating (2.5J) females (37.5%). No transitional individuals were identified. Figure 2.6

illustrates male phases. All males ($n = 35$, 31.5%) were classified as spawning capable; males with MMC (2.6A/B, $n = 16$) were observed in 45.7% of the male samples while the remaining males (2.6C/D, $n = 19$) were considered actively spawning (54.3%).

There was 100% agreement in reproductive phase across anterior, medial, and posterior sections of all individuals. The gonad morphology across the anterior, medial, and posterior sections of all males sampled contained spermatogenic tissue and spermatozoa, one sample contained MMC, though no primary oocytes were observed in any of the samples identified as males. The three female gonads samples all were deemed actively spawning, the morphology across the anterior, medial, and posterior sections were consistent for each individual. One female contained only the oocytes in late germinal vesicle migration and germinal vesicle breakdown throughout all three sections of the gonad while the samples from the two remaining individuals contained predominantly hydrated oocytes in all three sections of their gonads.

Based on total length-frequency distribution (Figure 2.7), protogynous hermaphroditism was demonstrated. No males smaller than 22.1 cm TL were observed while the mean TL for males was 6.1 cm greater than females indicating no primary males were identified suggesting monandric protogynous hermaphroditism. One immature female (18.7 cm TL), 75 mature females (16.2 - 26.6 cm TL), 16 males with MMC, and 19 males (23.1 - 28.1 cm TL) were identified by histological assessment. From the samples examined, a sex ratio of 2.22:1 was biased toward females ($\chi^2_1 = 16.69$, $P < 0.001$). Length when there is a 50% probability that an individual is a male ($L_{\Delta 50}$) is 25.7 ± 1.3 cm TL and the age when there is a 50% probability that an individual is a male ($A_{\Delta 50}$) is 4.0 ± 0.3 years (Figure 2.8).

2.4.3 Spawning period

Fish were caught from September 2018 through October 2020 (Table 2.4) though few fish were caught during the winter months due to poor weather conditions and during late summer mostly due to boat availability. Assessing if *I. pavo* spawns throughout the year is difficult to determine due to the lack of samples during the winter and late summer. However, spawning capable or actively spawning females were present from May through November and spawning capable males (Males with MMC and Males) were caught in all months fished suggesting the species has a protracted spawning season.

Table 2.4. Number and reproductive phases of *Iniistius pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods.

Reproductive Phase	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Immature										1			1
Developing										3		2	5
Spawning capable					1	2			1	1	1		6
Actively spawning					1	7			2	30			40
Inactive													
Regressing			4		2	1			5			3	15
Regenerating					1	3			3	2			9
Male with MMC			2		4	2				7		1	16
Male			2		1	4			1	10	1		19

2.5 Discussion

This study fills critical gaps in the life history for *I. pavo*. The life history and reproductive patterns of *I. pavo* seems to be consistent with those of other smaller-bodied labrid species, in that they are relatively short-lived and have a slow growth rate. Sequential protogynous hermaphroditism is common in labrids and my findings confirm that *I. pavo* also follows this reproductive pattern. Documentation of the age structure and growth patterns of tropical and temperate small-bodied labrids in the literature is sparse. However, the age structure and growth patterns of *I. pavo* around Hawai'i Island were consistent with that seen in three tropical species: *Coris auricularis*, *Notolabrus parilus*, and *Ophthalmolepis lineolate* (Lek et al., 2012) and two similarly sized temperate labrids: *L. mixtus* (Matić-Skoko et al. 2013) and *X. novacula* (Cardinale et al. 1998; Candi et al. 2004). *Coris auricularis*, *N. parilus*, and *O. lineolate* are endemic to Australia and reach a maximum TL of 40.0, 49.0, and 40.0 cm respectively with growth coefficients (k) of 0.25, 0.19, and 0.27 respectively (Lek et al. 2012). *Labrus mixtus* ranges throughout the Atlantic Ocean, Adriatic and Mediterranean Seas has a reported $L_{\infty} = 34.2$ cm, $k = 0.224$, and the median length at sex change occurring at 25.2 cm (Matić-Skoko et al. 2013). *Xyrichtys novacula*, found in the Mediterranean, is a smaller fish than *I. pavo*. Its $L_{\infty} = 23.4$ cm and $k = 0.289$, longevity (≥ 5 yrs), and timing of transition from female to male (approximately age 3 and 15 – 17 cm TL (Cardinale et al. 1998; Candi et al. 2004). All species, including *I. pavo*, have short but similar life spans and lower growth coefficients. The lower growth

coefficient found for *I. pavo* may be due to the sample not having larger individuals approaching L_{∞} .

The reproductive phases of *I. pavo* seem to be consistent with those described for other razorfishes. Candi et al. (2004) defined the phases of *X. novacula* in similar groupings to what was identified for *I. pavo*; however, phases were based on updated terminology described by Brown-Petersen et al. (2011). The gonad histology illustrated consistencies in the oocyte development in the ovaries of both species but differed in the identification of transitional gonads. The lack of identifiable transitional individuals in my sample was expected due to the sample size. While our relatively small sample size may account for this lack of transitional individuals, it was sufficient that we should have found transitional individuals based on the rates reported in other studies including labrids (Cardinale et al. 1998; Candi et al. 2004; Matić-Skoko et al., 2013), groupers (Schemmel et al., 2016) and parrotfish (DeMartini and Howard, 2016). In particular, the proportion of transitional individuals found in the temperate species *X. novacula* was greater than found in *I. pavo* (Candi et al. 2004).

Protogynous hermaphroditism is common in serranids (Alam and Nakamura 2008; Pears et al., 2006), scarids (DeMartini and Howard, 2016) and labrids (Kuwamura et al., 2020; Lowe et al., 2021; Shimizu et al., 2022). Our results strongly suggest *I. pavo* also exhibits a protogynous reproductive pattern. The length-weight relationship demonstrated a bimodal length-frequency, males dominate the larger samples, while no males were identified at the smallest lengths. Furthermore, the age- and length-frequencies as well as the back calculations from the VBGM confirmed *I. pavo* males trended to the larger TL and ages. The bimodal length-frequency observed in *I. pavo* around Hawai'i Island is consistent with that seen in other small-bodied labrids exhibiting protogynous hermaphroditism, such as *L. mixtus* (Matić-Skoko et al., 2013) and *X. novacula* (Cardinale et al. 1998; Candi et al. 2004) are consistent with the suggested protogynous hermaphroditism in *I. pavo*. Our data also suggests *I. pavo* are monandric protogynous hermaphrodites. Monandric protogynous hermaphrodites, when males are only derived from changing sex from male to female (De Mitcheson and Liu, 2008), exhibit the bimodal length-frequency seen in *I. pavo* and *X. novacula* (Cardinale et al. 1998; Candi et al. 2004).

Finally, results from the gonad histology suggest that *I. pavo* demonstrate an asynchronous mode of ovarian development. Asynchronous ovarian development, or batch spawning, is defined as having either determinate or indeterminate fecundity, exhibit various levels of asynchronous oocyte development, and have the ability to spawn multiple batches of oocytes during the spawning season (Brown-Peterson et al. 2011). Gonad histology of the *I. pavo* samples demonstrated a batch spawning pattern by the presence of primary growth and secondary growth oocytes along with hydrated oocytes in samples determined to be actively spawning. This coincides with the similar razorfish species *X. novacula* demonstrating an asynchronous mode of ovarian development (Candi et al. 2004).

While I was not able to confirm year-long spawning due to gaps in our sampling series and limited sample size, my results do suggest that at a minimum, *I. pavo* has a protracted spawning season. Spawning capable and actively spawning females were caught from May through November indicating a possible spring to late fall spawning period. However, inactive though functionally mature, females either in the regressing or regenerating phase were found in almost all months. Similarly, spawning capable males, either with MMC or without, were observed every month of sampling. There was a high proportion of spawning capable females as compared to other female phases. This is likely do to one sampling event, where most of the individuals were actively spawning (24 October, 2020, day eight in the first quarter).

2.6 Management implications

This study is the first to document baseline life history information and confirmation of the reproductive patterns of *I. pavo* which may be used to inform future management of the species. Information from a local seafood distributor indicated a marketable or preferred weight of approximately 340 g (Helene Rousselle, pers comm.) for *I. pavo*. My results suggest larger females (mean \pm SE, 218 \pm 97 g) and the majority of males (mean \pm SE, 456 \pm 97 g) are targeted by the fishers. Additionally, the market weight coincides with an age greater than four years which is older than the average female (3.5 \pm 0.8 yrs) and male (4.5 \pm 0.7 yrs) indicating the fishers also target older individuals. The market size could drive the exploitation of the larger more reproductively successful individuals can cause age- and length-truncation (O'Malley et al., 2019) and impact age and length at sex change (Provost and Jensen, 2015). My work serves

as a foundational study that can be used to facilitate research on the impacts of fishing on *I. pavo* in our study area and provide a baseline information for research in other areas around Hawai'i and throughout their range.

CHAPTER 3: CHARACTERIZING THE RECREATIONAL NABETA (LABRIDAE: *INIISTIUS* SPP.) FISHERY IN HAWAI'I USING CATCH PICTURES FROM SOCIAL MEDIA

3.1 Abstract

The advent of smartphones, social media, and angler applications have increased the data available to fisheries managers and have proven to be useful tools in numerous situations. Catch pictures, like those posted to Instagram accounts, can contain usable information as to the seasonality, catch rates, species caught, and species associations from fishers to better inform fishery managers, but their utility has not been fully explored. Therefore, I used catch pictures collected from the recreational nabeta, i.e., *Iniistius* spp., fishery from Hawaiian nearshore waters. I identified the nabeta fishery as year-round, primarily via angling from boats, fishers do not differentiate between species but fish for the nabeta species as a complex, what nabeta and other bottomfishes associate with each other, and fisher preference of the local nabeta fishery. Furthermore, I demonstrated the reliability, repeatability, and validity of using catch pictures as a valuable fishery management tool through a reader experience level-based study. I showed how catch pictures are a simple and efficient method of collecting fishery-dependent data when viewed by even inexperienced or minimally trained readers can be used to support currently used angler applications and fishery based online platforms and to be used as a valid means of collecting basic fisheries data characterizing a fishery for which it is unlikely other sources of data exists or are otherwise unable to get.

Key Words: Small-scale recreational fishing, Catch pictures, Data mining social media, Smartphone applications, *Iniistius* spp.

3.2 Introduction

Recreational fishing in near-shore marine and inland freshwater environments is growing in importance though is understudied and undervalued by most governments (Zeller et al., 2008; Elmer et al., 2017; Arlinghaus et al., 2019). Globally, approximately 10% of the population of industrialized nations, estimated to be over 220 million people (Cooke, Steven J., Cowx, 2004; Arlinghaus et al., 2015), participate in recreational fishing, defined as the capture of aquatic animals that do not constitute the fisher's primary source of nutrition and are not sold or traded

on any market (FAO, 2012). Recreational fishing typically targets the largest individuals of high trophic-level species, potentially causing cascading trophic effects and truncated age and size structures (Lewin et al., 2006; Arlinghaus et al., 2019). Although the potential impacts of recreational fishing to freshwater and coastal marine ecosystems are well-documented, relatively little catch and usage data are collected by management agencies for some recreational fishing species (Cooke, Steven J., Cowx, 2004; Ihde et al., 2011; Arlinghaus et al., 2015). Data collection on recreational fisheries can be limited by several factors, including low economic importance of targeted species (Pereira and Hansen, 2003), fishers being too diffuse and dispersed for traditional intercept survey techniques (Arlinghaus et al., 2019), or the perception that recreational fishers have less impact than commercial fishers of the same species (Lewin et al., 2006). Traditional creel surveys are effective sources for collecting fisheries information; however, for smaller and/or more dispersed marine and freshwater recreational fisheries it is difficult for interviewers to intercept anglers using private access points (Pereira and Hansen, 2003). Data generated from telephone surveys suffer from recall bias, misidentification of targeted species, and difficulty in getting sufficient responses to constitute a representative sample of fishers (Ashford et al., 2010).

The relative paucity of data focused on recreational fisheries and the challenges involved in collecting data have necessitated the development of innovative data collection methods. With the advent of smart phones, social media platforms, and angler applications colloquially known as angler apps, text and data mining of online sources of fisheries information have become a useful tool to gather information on recreational fisheries (Gutowsky et al., 2013; Monkman et al., 2018). Fishery based smartphone applications, termed angler apps are being used in North America and Europe to collect data in support of fisheries research and management (Venturelli et al., 2017); Bradley et al. (2019) identified over 70 angler applications worldwide that record seasonality and spatial harvest data records as well as information on discards and basic life history data from recreational fisheries. These fisheries-specific applications generate large amounts of useful biological information and landings data; however, they require active participation from fishers and the development of software for specific sites. Social media outlets, such as YouTube, Facebook and Instagram, are publicly available resources that gather large amounts of information through text and photographs; however, data mining is required to extract fisheries information. Text and data mining is defined as the extraction of information

from a data set that is not readily apparent and not always easily obtainable (Barbier and Liu, 2011), but it can provide insights on fisheries that would be difficult or impossible to obtain otherwise. For example, text and data mining YouTube posts from Mediterranean spearfishermen has been used to identify differences in the mass of catches by recreational anglers and spearfisherman from differences in the seasonal upload patterns (Sbragaglia et al., 2019). YouTube, along with other media outlets, were used to track invasion pathway and timing of channel catfish *Ictalurus punctatus* presence within the Guadiana drainage of Portugal (Banha et al., 2017). In Angola and Mauritania, YouTube posts were used to assess recreational fisheries catches and produced estimates comparable to those of official surveys, suggesting that the posts can be incorporated into the monitoring of recreational fishing activity (Belhabib et al., 2016). However, Instagram posts have yet to be utilized as a resource for fishery information.

Instagram is a social media platform that has the potential to provide information on recreational fisheries through the use of catch pictures. Launched in 2010, Instagram is a relatively new form of capturing and sharing photographic information that has yet to attract significant interest from the research community (Hu et al., 2014). Instagram is a photo and video sharing social networking application that allows users to instantly upload photographs and short videos from their smartphones as posts to their account that can be shared publicly or privately within user groups. Since its introduction in 2010, Instagram's popularity has grown from 10 million users in the first year to over one billion monthly users as of August 2021 (Instagram, 2021). Users post catch pictures to their account using the “#” symbol to describe the pictures and tag or mention other users using the # symbol and associated key word. Instagram also allows other users to comment on posted photographs. Fishers use Instagram to post pictures of their catch to share with their followers and often use the # tag system to identify the species caught, fishing method, and gear type, e.g., fishing from a boat or from shore, angling or spearfishing, etc. Whereas posts on social media outlets, such as YouTube and Facebook, are focused on the fishing event or how the catch was prepared for a meal, posts on Instagram are often simply the catch from a fishing event. Catch pictures from Instagram potentially offer near real time catch data and include additional information related to species associations in multi-species fisheries, gear type, and fishing methods that can be used to characterize a recreational fishery.

Instagram offers an opportunity to resource managers to gather data on a recreational fishery where no fishery data is available, such as the nabeta fishery in Hawai'i. Nabeta is the Japanese word applied locally in Hawai'i to both the peacock razorfish, *Iniistius pavo*, specifically and generally to the five labrid species in the genus *Iniistius* that occur in Hawaiian nearshore waters: whitepatch razorfish, *I. aneitensis*; Baldwin's razorfish, *I. baldwini*; bronzespot razorfish, *I. celebicus*; blackbar razorfish, *I. umbrilatus*; and *I. pavo*. While the five razorfish species, referred to collectively as nabeta, are a local delicacy that are targeted by recreational fishers for personal consumption; they are not often sold commercially and thus represent a small component of the Hawaiian nearshore bottomfish fishery. Nabeta are caught primarily by angling from boats (including kayaks), spearfishing, or angling from shore for family gatherings and special events by recreational fishers and not considered sustenance species. Even though nabeta do not appear in commercial landing reports, they are occasionally offered for sale in local markets (Helene Rousselle, Hilo Fish Company, pers. comm.). In Hawai'i recreational fishing licenses are not required therefore little information is collected on the nabeta fishery. The limited data available on nabeta landings indicates a steep decline in catch rates, decreasing 90% from 69,308 kg (165,433 individuals) in 2004 to 6,197 kg (9,654 individuals) in 2011 (Williams and Ma, 2013) though the current status of the fishery is unknown. Due to the relatively small size of the fishery, species-specific creel surveys or telephone surveys are unlikely to be a high priority for resource-limited management agencies despite the precipitous decline in landings. Therefore, assessing trends in the composition and landings of the nabeta fishery in Hawaii will require innovative methods.

My objectives are to examine catch pictures posted on Instagram of nabeta as a source of information to characterize the nabeta fishery in Hawai'i and assess the accuracy and precision of data collected from catch pictures. For the first objective, text and data mining of Instagram posts to #nabeta from 2012 to July of 2021 was used to gather data on seasonality, species, and catch sizes of the nabeta fishery in Hawai'i. For the second objective, a group of readers of varying levels of experience identifying nabeta and other species found in the nearshore waters of Hawai'i were asked to identify the species composition of identical staged catch pictures of known compositions in varying types of catch pictures to determine the rates of errors in species identification and assess the factors that impact the probability of readers of different experience levels making an error.

3.3 Methods

3.3.1 Collection of catch data from Instagram posts

For the purposes of this study, I examined Instagram posts that included the #nabeta tag which identified suitable catch pictures of the five *Iniistius* spp. found in Hawaiian waters. The Main Hawaiian Islands were the sampling area for the purposes of this study though *Iniistius* spp. are found throughout the Pacific and Indian Oceans (Randall, 2007). While specific locations could be inferred from a few posts, e.g., #maui, this was not consistent in the dataset and so posts were analyzed as representing the fishery for the Main Hawaiian Islands. Nabeta is the Japanese name for the peacock razorfish, *I. pavo*, though in Hawai`i nabeta is used locally to refer to the five *Iniistius* spp. found in Hawaiian waters. Instagram posts, though not labeled as exclusively from Hawai`i, were identifiable as from Hawai`i either through the user identification or stated location and all species of nabeta were found in Hawaiian waters. Other # tags were examined, e.g., #HawaiiFishing, #OffshoreFishing, #BottomFishing, #kayakfishing, #luckywelivehawaii, #kayak, and various # listing of taxa, though no additional nabeta catch picture posts were generated. Using #nabeta, we identified over 2000 posts from September 2012 to July 2021 which included catch pictures including nabeta, prepared nabeta filets, as well as other non-fish related posts. The total of #nabeta posts were filtered to include only pictures representing catches from fishing events that included at least one of the nabeta species.

I recorded the Instagram user, date of the post, species caught, number of fish of each species, fishing method, and the picture type for each post. Instagram users were assigned a unique alphanumeric code in order to track multiple posts by a single user. All of the Instagram posts used in my study were publicly available and therefore considered be in the public domain (Monkman et al., 2018). However, the framework for the ethical use of social media in fisheries research proposed by Monkman (2018) was followed. Fishing method was not specifically listed in the Instagram posts though could be inferred by the inclusion of additional hashtags, e.g., #3prong for spearfishing, #kayak for angling from a kayak, information provided in the comments, e.g., “There is first for everything in this case, catching nabeta from shore,” the condition of the fish, e.g., presence of injury consistent with being speared; or the presence of the gear used in the image. Unless otherwise stated, it was assumed that the fishing was done from a

boat. Catch pictures represent a single day's fishing event in a limited area, the gear used to catch the fish, the picture represents the whole catch, and the posts were within a day of returning to shore. These assumptions were supported by the expert opinion of a local fishing expert with a YouTube channel dedicated to nearshore fishing (CJ Kow, pers. comm.). I was unable to determine the number of fishers involved in catching effort, the exact location of the fishing event, or the catch per unit effort more precisely than the number of fish per trip.

Catch pictures posted on Instagram vary in quality and may not represent the entire catch, show a selected portion of the catch, or were haphazard and not all fishes were identifiable which necessitated a selection protocol to be developed such that all pictures used for the study conformed to a format common to all pictures. For this protocol I used three criteria in determining whether a catch picture was included for analysis: 1) the catch picture must have at least one fish identifiable as nabeta; 2) the catch picture must show the total catch; and 3) the fish displayed are intact and not on cooking/kitchen surface. The first criterion was that the picture must include a nabeta that can be positively identified as they are the focus of this study. The second criterion assumes the entire day's catch is included in the picture and visible, pictures with portions of a fish could indicate additional fish or fishes were part of the catch but not identifiable and could not be documented. The final criterion was established to eliminate pictures showing what is assumed to be a portion of the catch that was selected for cooking, i.e., the largest fish or the preferred species, and not representing the entire catch. Instagram posts with catch pictures conforming to these criteria were selected for this project.

Instagram posts of catch pictures typically include one or two pictures of all the fish or fishes caught that trip arranged or randomly displayed. Catches were photographed in a cooler or on a flat surface either from above or at an angle. Posts sometimes included an item for size context, e.g., beverage can or bottle, currency (US dollars); the boat or gear used for the trip; and/or the fishers. Catch pictures posted on Instagram exhibit considerable variability in several factors that have the potential to influence the ability of a reader to accurately count and identify all the fishes featured in them. How the catch was displayed, what the catch was displayed on or in, and what perspective the picture was taken from all have the potential to influence the accuracy and precision of the data collected. Therefore, catch pictures for this study were classified by three factors and two levels for each factor and described as "Picture Types" (Figure 3.1). The first

factor considered was how the fish or fishes are displayed, organized (O) or random (R). Pictures with some effort made to organize the catch were deemed “Organized”, while pictures with the catch left haphazard were considered “Random”. The second factor was what surface the catch was displayed in or upon, on a flat surface (F) or in a cooler (C). Flat surfaces included: on the transom or deck of a boat, on pavement, on a table, or in the grass. Otherwise, the fish were displayed in a cooler that may have more vertical depth than flat surfaces. The final factor was the perspective that the picture was taken, perpendicular (P) or at an angle (A) to the displayed catch. Perspective, in this case, indicated a catch photographed either from the perpendicular to slight angle, identified as perpendicular, or at an estimated angle between 45-90° from horizontal, identified as angle.

Each picture was examined by a single reader (RM) who recorded the date of the post (year and month), the apparent fishing method (angling from shore, a kayak, or a boat, or spearfishing), the picture type (O vs. R; F vs. C; P vs. A), and the number of each species of nabeta. Other species appearing in the pictures were identified to the lowest taxonomic level possible and counted.

3.3.2 Assessment of precision and accuracy of reader counts of catch pictures

I assessed the types and frequency of errors in counting and identifying fish made by readers of differing experience levels using staged photographs replicating the types of photographs posted to social media sites, such as Instagram. Photographs used to assess reader errors were staged following the factors of display, surface, and perspective as described above representing the eight picture types (Figure 3.1). Five catch pictures were staged for each of the eight picture types using a pool of 176 nabeta representing all five species. The staged pictures contained images of 620 fish, the fish in the pictures were randomly drawn from the pool of 176 individuals that were repeatedly redrawn *I. aneitensis* (8.5%, $n = 53$), *I. baldwini* (17.1%, $n = 106$), *I. celebicus* (1.5%, $n = 9$), *I. pavo* (63.2%, $n = 393$), and *I. umbrilatus* (9.5%, $n = 59$). These proportions roughly represent the capture rates of fish donated for this study. The number of individuals ($n = 5-45$) and species ($n = 1-5$) were randomly assigned to each staged photograph.

A group of independent readers ($n = 17$), self-identified as either novice ($n = 5$), intermediate ($n = 7$), or fisher ($n = 5$), was asked to collect data from the staged photographs. Novice readers

identified themselves as having no knowledge of Hawaiian fishes and no angling experience, intermediate readers had some knowledge of Hawaiian fishes though little or no angling experience, and fishers identified as having expert levels of knowledge of Hawaiian fish and experience angling for nabeta. Each reader was supplied with the same information and training resources before recording their observations. Species identification sheets including one of the species with four Instagram catch pictures with that species, a picture of the fish live in situ, and two pictures of the species (male and female) pinned to a board for documentation for another study were provided. Each identification sheet also included a list of the five most identifiable morphologic characteristics of each species for effective identification. A video describing how to read the species identification cards and how to interact with the validation test was also provided. The readers reviewed the material independently without communication with other readers or the authors. Each reader was given a unique reader identification number, for anonymity, and provided with a file containing the staged photographs randomly ordered for reader. The readers were instructed to identify each nabeta by species or mark as unknown for nabeta not identifiable to the species level.

3.3.3 Statistical Methods

I used a principal component analysis (PCA) on the presence of the five nabeta species in the Instagram posts catch pictures to investigate nabeta associations. The PCA was selected to help explore nabeta associations based on the presence of one or more species in a catch picture considered to be one fishing event. Each picture was analyzed for its composition of species. All species were identified and enumerated for use in the analysis. Due to the variation in observed fish, the correlation matrix was used as it is less sensitive to variations in the dispersion of the data. The dataset was first used with only nabeta observations to determine the associations among the five nabeta across the collection of catch pictures. The dataset with the nabeta and non-nabeta species was then used to determine the associations of the nabeta and the other species represented in the catch pictures. For both analyses, the PCA was performed using the package “factoextra” version 1.0.7 (Kassambara and Mundt, 2020). The results of all PCAs were visualized in biplots indicating the associations of the fishes across all the catch pictures.

For the first reader assessment analysis, the focus was to compare the probability of readers with varying experience in making an error in the count of fish in a staged picture based on difficulty of picture and the picture type. A dataset was created with the readers' observations of the number of the five species plus unknown in each picture and were compared to the known composition of each validation picture. Errors represented the difference between the observed number and actual number of a species recorded for each validation picture. The three sources for error could be in the form of: misidentifying a species of nabeta, marking a fish as unknown, or not assigning a species or unknown to a fish in the staged picture. A picture was deemed in error regardless of the number of errors, thus a picture with an error or several errors was recorded as "1" and images where no error occurred were recorded as "0". This dataset was termed the binary dataset. To analyze the factors the probability in making an error a logistical regression was performed using a generalized linear model (GLM) with a logit link function:

$$\text{Logit}(\text{error total}) = \beta * \text{num_fish} + \text{obs_level} + \text{display} + \text{surface} + \text{perspec}$$

The logit link function was used to relate the explanatory values to the response distribution. Reader level (categorical), display (categorical), surface (categorical), perspective (categorical) were the independent variables, with difficulty (the number of fishes in the staged picture, continuous) and error (binary) were the dependent variables.

To assesses how misidentification of species occurred with each other and the interaction between individual species and the numbers of errors a PCA was conducted. The second dataset, the integer dataset, was constructed based on comparing the reader's observation of each species against the know values. This dataset included the reader identification, picture identification number, the number of fish, reader level, and the numeric severity of the errors. The extent of the disidentifications was recorded as absolute value of the difference between the reader's observations of the numbers of each species to the know values for each staged picture. A correlation matrix was used to account for the different scales of the errors of species identification, the number of fishes in the pictures, and reader level. All analyses were conducted using R version 4.0.1 (R Core Team, 2020).

3.4 Results

3.4.1 Analysis of catch data from Instagram posts

I examined a total of 2057 photographs posted to Instagram from 120 unique accounts using #nabeta during September 2012 - July 2021 (Figure 3.2). The frequency of posts increased through 2015 before stabilizing at 24 ± 3 (mean \pm SE) posts per year through 2020. The first seven months of 2021 were represented by 6 posts. A total of 177 posts had catch pictures that were deemed usable based on the criteria described above. Most accounts posted only once ($n = 91$) or twice ($n = 20$) during 2015-2021, while two accounts posted each 11 and 15 times.

Angling was the most common method used for catching nabeta; therefore, unless self-identified as spearfishing, the remaining posts were classified as angling either from a kayak or a boat.

Angling from a kayak was identified 15.8% ($n = 28$) of the time, angling from shore 0.2% ($n = 3$), spearfishing 0.5% ($n = 9$), the remainder angling from a boat 77.4% ($n = 137$). There was a total of 41 additional fish species, representing 14 families, that were also pictured in the posts.

Instagram users predominantly posted catch pictures of organized catches on flat surfaces (Table 3.1).

Table 3.1. Picture types from nabeta *Iniistius* spp. captured from Hawaiian nearshore waters and posted to the social media site, Instagram, during 2012-2021. The method of display, organized (O) or random (R), the display surface, flat surface (F) or in a cooler (C), and the photograph perspective, perpendicular (P) or at an angle (A) divided the catch pictures into eight categories. Number of posts indicates the total number of posts of this picture type and the percentage of posts indicates the percentage of the total 177 Instagram posts examined for this study.

Picture Type	# of Posts	% of Posts	Picture Type	# of Posts	% of Posts
OFP	98	55.4	RFP	5	2.8
OFA	57	32.2	RFA	3	1.7
OCP	4	2.3	RCP	11	6.2
OCA	0	0.0	RCA	2	1.1

The size of catch in the posts, the number of individuals of all species or taxa in a catch picture, ranged from one fish to 153 fishes, with one to five fishes represented in 23.2% ($n = 41$) of the posts, six to 10 at 24.9% ($n = 44$), 11 to 20 at 28.8% ($n = 51$), and 21 or greater at 20.9% ($n = 37$). Nabeta as the only fishes in the catch pictures ranged from one to 31 individuals and were identified in 16.9% ($n = 30$) of the posts while posts containing more than 50% of the catch pictures made up 61.0% ($n = 108$) of the posts.

Photographs of nabeta were posted every month, suggesting that the nabeta fishery is year-round. However, there were two increases in posting frequency during March to April and August to January relative to the rest of the year. *Iniistius pavo* was the most frequently occurring species in posted photographs, both in total and on a monthly basis. Monthly catches of *I. pavo* (Figure 3.3A) had a lower median catch per month though monthly catch totals were more consistent across the months and had more months with larger catches represented by the outliers.

Photographs containing *I. aneitensis* and *I. baldwini* were posted consistently throughout the year, though at much lower rates than *I. pavo*. In contrast, photographs containing *I. celebicus* and *I. umbrilatus* were rarely and inconsistently posted. There was greater variability in the median number of posts per month containing these other *Iniistius* spp. (Figure 3.3B). The relative proportion of photographs posted containing *I. pavo* vs those containing the other *Iniistius* spp. was not consistent across months ($\chi^2_{11} = 154.6, P < 0.001$).

Single-species catches of nabeta represented about 82% of the posts examined and tended to consist of *I. pavo*. However, there was evidence of species associations in the 18% of posts containing two or more species. *Iniistius aneitensis*, *I. baldwini*, and *I. umbrilatus* had a high probability of co-occurring in multi-species catches (Figure 3.4). In contrast, *I. pavo* and *I. celebicus* were negatively correlated with each other and exhibited little relationship with the other three-species. Both *I. pavo* and *I. celebicus* exhibited a relatively high probability of being present in single-species catches (Figure 3.4, Table 3.2), though the relative rarity of *I. celebicus* makes any associations, or lack thereof, between it and the other nabeta species difficult to determine.

Table 3.2. Number of posts per nabeta species, *Iniistius* spp. from Instagram posts of nabeta during 2012-2021. Total posts at the bottom indicate the total number of posts per month pooled across the years of the study. Monthly numbers represent the appearance of each species in a post each month pooled across the years of study with the total number of posts in which each species appears. Multi spp. Indicates the total number of posts that a species appears with other nabeta species while Single spp. indicates the total number of posts in which that species is the only nabeta species is represented in a post.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total posts	% of posts	Multi spp	Single sp
<i>I. aneitensis</i>	1	2	4	0	0	2	1	1	6	1	3	5	26	14.7	23	3
<i>I. baldwini</i>	3	0	5	3	3	1	1	1	2	3	4	1	27	15.3	18	9
<i>I. celebicus</i>	0	0	1	0	0	1	0	0	2	2	1	0	7	4.0	4	3
<i>I. pavo</i>	16	5	17	12	11	11	5	13	15	14	16	21	156	88.1	27	129
<i>I. umbrilatus</i>	0	0	2	0	0	0	0	1	1	1	0	2	7	4.0	5	2
Total Posts	18	6	20	13	13	11	6	14	17	18	19	22	177			

Posts containing nabeta that also contained less than 25% other species comprised 33% of the photographs examined, suggesting that nabeta are a targeted fishery though other fishes are caught as a species of opportunity (Figure 3.5). The occurrence of *Iniistius pavo*, *I. aneitensis*, *I. baldwini*, and *I. umbrilatus* in photos posted to Instagram were largely independent of the occurrence of reef fishes, such as *Lutjanus fulvus*, *L. kasmira* and mullid goatfishes. When present in posts containing other species, *Iniistius pavo* co-occurred with coastal pelagic species such as *Decapterus macarellus* and juvenile carangids, known locally as papio. Similarly, multi-species posts containing *I. aneitensis*, *I. baldwini*, and *I. umbrilatus* also tended to include pelagic species, such as *Coryphaena hippurus* and *Acanthocybium solandri*.

4.3.2 Analysis of assessment of precision and accuracy of reader counts of catch pictures

Reader counts of staged photographs indicated that this method is highly accurate and when errors occur, they tend to be conservative. Readers across all experience levels identified over 98% of the fishes in the staged photographs (Table 3.3) with none of the 17 readers overcounting fishes in a photograph.

Table 3.3. Results of the reader observations from the staged catch pictures averaged for the three reader groups: Novice, Intermediate, and Fisher. Actual indicates the total number of nabeta appearing in all of the staged catch picture as well as the total number of unknown observations in the staged catch pictures. Fishes observed represents the total averaged number of fishes observed for the reader groups as compared to the actual total number of fishes as a percentage. Unknown observations were used when a nabeta was identified but not to the species level and are shown as the average number of unknown observations of the reader group number of as compared to the total number of unknown selections as a percentage.

Reader Group (mean)	Fishes Observed		Unknown Observations	
	Total obs	% obs	Total obs	% obs
Actual	620.0		0.0	
Novice (n = 5)	609.2	98.3	38.4	6.2
Intermediate (n = 7)	613.3	98.9	20.4	3.3
Fisher (n = 5)	619.0	99.8	8.6	1.4

When errors in fish counts occurred, readers were able to identify a nabeta but were unable to identify to the species level marking unknown six percent or less of the time. The probability of a reader making an error was shown to be influenced by several factors, particularly how the fish were organized, the number of fish in the picture, and the experience of the reader (Figure 3.6). The probability of a reader making an error was higher ($Z_{679} = 3.49$, $P < 0.001$) for pictures

where the fish were displayed randomly (mean \pm SE: 11.0 \pm 0.6) than for those in which the fish were displayed in a more orderly fashion (mean \pm SE: 4.3% \pm 0.6). The probability of readers making an error also increased as the number of fishes in the staged pictures increased ($\beta = 0.08$, $Z_{679} = 5.7$, $P < 0.001$). Reader experience level had the greatest impact not only on the fish counts but the factors of display and number of fishes. Novice and Intermediate readers had similar probabilities of committing errors in fish counts and were not significantly different ($Z_{679} = -1.86$, $P = 0.6$) while fishers had a significantly different ($Z_{679} = -4.57$, $P \ll 0.001$) probability of committing an error in counting as compared to the Novice and Intermediate reader group. Fishers were able to accurately identify the greatest number of fish. This group made errors at a significantly lower rate of 0.3% of the time whereas the Novice and Intermediate group committed an error in counting 4.2% of the time. Finally, the surface type the fish were placed on ($Z_{679} = -1.90$, $P = 0.60$) and perspective, or orientation of the camera relative to the fish, ($Z_{679} = -1.02$, $P = 0.30$) did not influence the probability of a reader making an error.

Reader experience level also had an impact on errors in nabeta misidentification. Errors in misidentification made across all reader levels suggest that *I. aneitensis*, *I. baldwini*, and *I. pavo* were most often mistaken for each other. *Iniistius celebicus* and *I. umbrilatus* were not often misidentified as the previous group but misidentified as each other (Figure 3.7). However, the proportion of errors decreased relatively evenly with increasing reader experience level. Fishers tended to make the least number of errors in misidentification though their errors were mostly with *I. pavo* potentially due to the high numbers of *I. pavo* represented. The proportion of nabeta displayed in the staged catch pictures roughly represented the capture rates of the fish donated for this study and were similar to the species composition from the analysis of catch pictures from the Instagram posts.

3.5 Discussion

Data mining Instagram posts has revealed several previously unknown aspects of the nabeta fishery in Hawai'i. Instagram posts indicate the nabeta species, considered a nearshore bottom fish, are targeted year-round, which was not unexpected given that nearshore fishing occurs throughout the year in Hawai'i (Ma and Ogawa, 2016). Further, Instagram posts indicate nabeta are primarily captured as part of a targeted fishery and not incidentally by bottom fishers

targeting other species. Instagram posts identify species in catch pictures using # and the local name of the species. Though nabeta appear in other posts, such as #bottomfishing, #kayak, and #shorefishing, no additional posts were identified where nabeta were not specifically called out which indicated the importance of fishers posting a nabeta in their catch. Other bottom fishes, represented by low numbers in the catch pictures, seem to be caught opportunistically while fishing for nabeta. Conversely, the less common posts labeled with #nabeta, i.e., posts with large numbers of other bottom fish species with few nabeta, potentially indicate a bottom fishing event that included opportunistic catches of nabeta. The catch pictures showed catches dominated by bottomfish species with few nabeta were typically associated with hard substrates while catch pictures dominated by nabeta were primarily species that prefer sand and mud bottoms. Fishers are likely targeting sand patch habitats in areas with few other species indicating that they are going out specifically for nabeta. The nabeta fishery is dominated by one species, *I. pavo*, which is the largest of nabeta species (Randall, 2007); however, it seems unlikely that the fishers are cognizant or concerned by this as we observed no attempt to distinguish or differentiate between the five constituent species in the Instagram posts. Even wholesalers do not differentiate species on the rare occasions that nabeta are available commercially (Helene Rousselle, Hilo Fish Company, pers. comm.). The lack of differentiation among nabeta species suggests fishers target nabeta for size as opposed to other traits, such as taste, as no posts comment on catching the “tasty” nabeta. Therefore, it is not clear whether the dominance of *I. pavo* in the fishery reflects its abundance relative to that of the other four species or that anglers preferentially target it due to its larger size. Local fishers tend to focus their effort on finding and fishing locations they refer to as “big nabeta” sand patches (RM, unpublished data). The information gathered from Instagram posts is not, on its own, sufficient to support management decisions. However, in the absence of other data on the fishery, information gathered from Instagram does provide a baseline that can be used by fishery managers to design a management program and better articulate data needs.

The nabeta fishery in Hawai'i is an example of an understudied recreational fishery lacking baseline data where social media can help inform management. Popular social media platforms, such as YouTube and Facebook, have posts and videos regarding nabeta, though their posts focus primarily on the event of fishing or how nabeta are prepared for a meal and lack comparable data that can be used to provide information on a fishery. However, Instagram posts

of catch pictures offer real time data on the fishery. Examination of Instagram catch pictures posted using #nabeta, enabled us to identify undocumented trends in the nabeta fishery that provide a baseline for fishery managers to develop management strategies. For example, Instagram posts indicate that nabeta fishing is conducted primarily via angling from a boat suggesting that boat ramp surveys might be an effective way of intercepting fishers to collect fisheries dependent data. The nabeta fishery had not previously been identified as seasonal, but Instagram posts indicated that even though the nabeta fishery is year-round, there was a reduction of posting activity in the winter, likely driven by poor weather and sea state conditions, that could offer managers a relatively painless opportunity to implement a closed season. Catch pictures from Instagram clearly show that *I. pavo* represent the majority of the nabeta species caught either as a large single species catch or associated with other nabeta species. Based on the high proportionality of *I. pavo* in catch pictures, population and biological studies could be focused specifically on the one species to best determine the impacts of recreational nabeta fishing.

Though the use of catch pictures is still a relatively novel approach for gathering fisheries data, this approach can be used to build on existing smartphone applications used to collect fisheries data or generate information used to identify trends previously unknown in understudied fisheries. Information derived from social media and online angler apps, as it is employed in fisheries, has been shown to be an accurate, repeatable, and cost-effective method of collecting data (Papenfuss et al., 2015; Belhabib et al., 2016; Banha et al., 2017; Sbragaglia et al., 2019). Angler apps smartphone applications for collecting fishery-dependent data, allow fishers to record details of their fishing trips and catches (Martin et al., 2014; Venturelli et al., 2017). Studies have shown that the data derived from angler apps were comparable to creel and mail surveys (Papenfuss et al., 2015; Jiorle et al., 2016). Bradley et al. (2019) reports over 70 recreational angler apps from around the world that collect data on smaller freshwater and marine fisheries however, catch pictures are not utilized in these applications. Data on angler apps provide temporal and location-based information (Papenfuss et al., 2015), however the use of catch pictures is not included in angler apps. Inclusion of catch pictures could document real time fishery-dependent data and data mining catch pictures could provide additional seasonal information, especially those pictured posted over successive years. Venturelli et al. (2017) identify user retention, reader bias, and data quality as challenges to using angler applications and recommends these applications to streamline the data entry and create easy applications to

use. Increasing user retention can improve data quality (Gundelund et al., 2020) and ease of use is important because fishers are more interested in fishing than inputting data (Venturelli et al., 2017). Catch pictures are an easy way for fishers to engage with angler application increasing user participation and could promote user retention. The results from our analysis of nabeta Instagram catch pictures suggest anglers taking and posting catch pictures and is an easy and natural behavior for fishers. The inclusion of catch pictures could take advantage of this behavior improving the easy of data entry and user retention while providing reliable and useable data.

Data mining catch pictures posted on social media sites is a passive method for collecting data, i.e., the users who post on social media provide information they decide to include, a proactive method for collecting data from catch pictures, requesting data such as location or fishing effort, could create biases or decrease user retention. Collection of user inputted fishery-dependent data can lead to biases in data omissions, non-reporting of zero catches possibly to attempt to influence management policy (McCluskey and Lewison, 2008; McCormick et al., 2013), or angler apps posts skew more from urban areas and toward younger anglers (Papenfuss et al., 2015). Additionally, the size of the catch could be biased in the posts, however, from the data collected, we demonstrated that small catches, i.e., under 10 individuals, were represented in 48.0% of the posts suggesting that there was not a bias toward smaller catches. While my data likely suffers from many of the same biases, our validation efforts indicated that observers do not introduce significant error or bias to the data set in the process of identifying and counting fishes pictured in the posts. Even in a multi-species fishery composed of superficially similar species, our data suggest that the observers provided with relatively minimal training produce reliable and repeatable data that is as accurate as other sources of data. Data quality is influenced by aspects of quality of the picture and reader experience, but when designing a study using social media if this is taken that into account when training readers, the data collected from catch pictures are a valuable tool for fisheries managers.

The passive data harvesting method is limited to what the posters chose to disseminate or what is limited by the social media platform. Posts that don't identify nabeta using #nabeta could exist though not represented in this search. Additional information that can be collected from the catch pictures could provide additional information such as sex and size and of the individual fish. Items in the catch picture, such as beverage container that has a known measurement, can be

used for rough estimates of length using imaging software. Sex of the individuals, if the species is sexually dimorphic, may be able to be determined from analysis of the catch pictures. Finally, if the posts are not temporally limited, trends in the size of the stock may be evident or at least suggest information to be targeted for further study. Passive data mining of social media posts, specifically as demonstrated in this study for nabeta, is limited but represented a great leap forward in data on the fishery where nothing was known. A proactive method for collecting data from catch pictures could include information that is more fishery-dependent by requesting actual fish sizes, fishing effort, or locations but may have an impact on user participation. Conversely, a fishery manager could use a proactive method to target this information by offering incentives, such as a monthly raffle for submitting qualifying catch pictures, to gather more usable fishery data. Regardless of the method of collecting data, this study demonstrates that the use of catch pictures is a valid source of accurate, repeatable, and valid data for understudied recreational fisheries.

Small scale recreational fisheries can suffer from a paucity of fisheries related data either due to challenges in collecting data or budgetary restrictions. In this study we have identified nabeta is a year-round fishery, of the five nabeta species *I. pavo* are the most predominant though we could not identify if they were being targeted, and anglers specifically target nabeta. Additionally, we demonstrated data mining social media is a useful tool for fisheries where we don't have information for and that are unlikely to generate the large-scale studies that would be needed to fully understand the fishery and catch pictures are a resource that can be used by even inexperienced readers to inform fisheries managers of species associations and trends in the fisheries. We have demonstrated that the use of catch pictures can be a valuable resource for smaller freshwater and marine recreational fishery managers to either mine social media outlets like Instagram for historical or current information or can be used to develop a cost effective and user-friendly way to collect baseline data on an otherwise data poor, multispecies fisheries.

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Figures



Species	Male	Female	Juvenile	Range	Depth	Reproductive behavior
<i>I. aneitensis</i>				Western Indian Ocean to Hawaiian Islands ¹	6-91 m ¹ 4-35 m ² 92 m (submersible) ²	Females: Individual territory Males: Sequentially visit female territories for spawning ¹
<i>I. baldwini</i>				Red Sea to Hawaii ¹	18-32 m ¹ 73-137 m (trawls) ²	Females: Individual territory Males: Sequentially visit female territories for spawning ¹
<i>I. celebicus</i>				Indo-Pacific to Hawaii ¹	7.5-15 m ¹	Females: Foraging groups Males: Males join female groups for spawning ¹
<i>I. pavo</i>				Red Sea to Hawaii to Eastern Pacific from Gulf of California to Panama ¹	8-100 m ¹	Females: Individual territory Males: Sequentially visit female territories for spawning ¹
<i>I. umbrilatus</i>				Hawaii ^{1,2}	6-40 m ¹	Females: Individual territory Males: Sequentially visit female territories for spawning ¹

Figure 1.1. Available information on the five *Iniistius* spp. in Hawaiian waters. Male, female, and juvenile pictures, Randall, 2007 and courtesy of Keoki Stender, www.marinelife.com, represent what has been documented for the species. Range, depth, and reproductive behaviors are from ¹ Randall, 2007 and ² Randall & Earle, 2002.

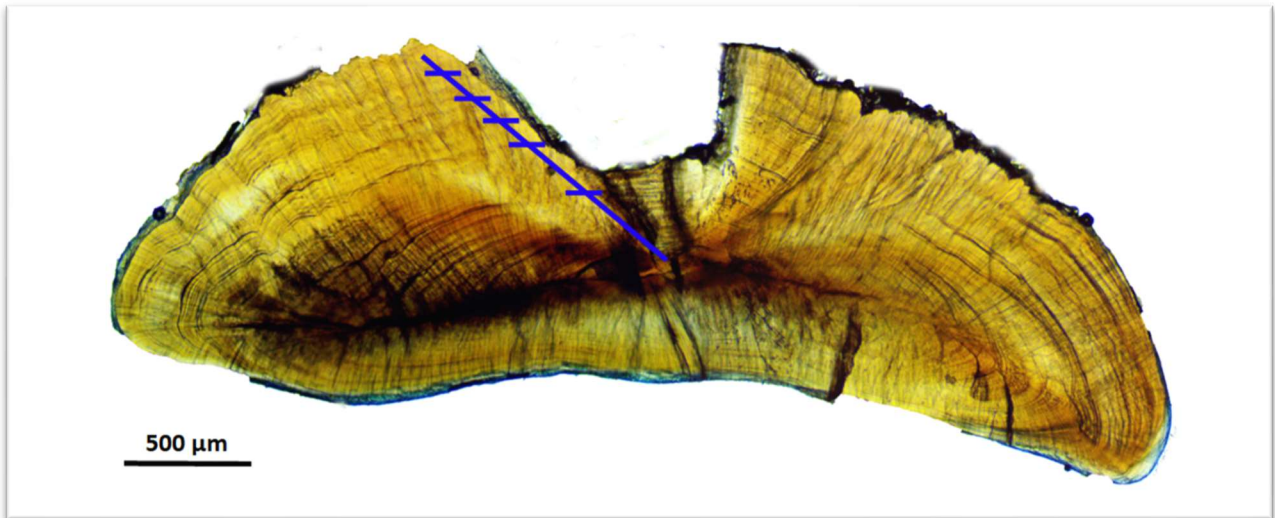


Figure 2.1. Example of otolith from *Iniistius pavo* (30.0 cm TL) collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat. Blue bar indicates the angle in which the radius of the otolith at each annuli was estimated, the blue hash lines indicate the annuli.

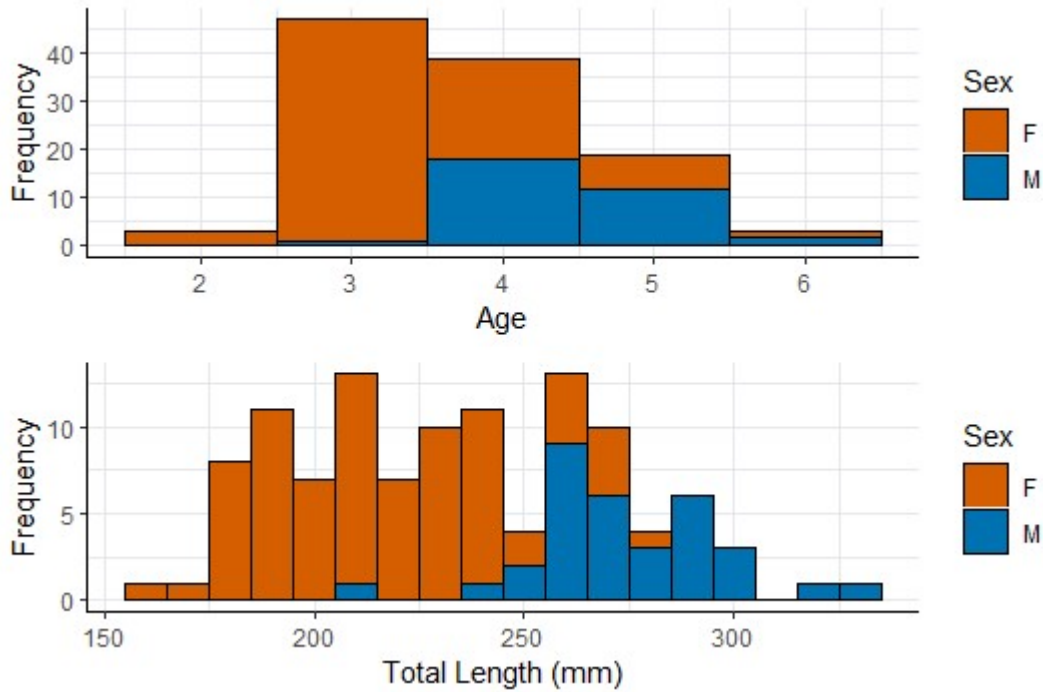


Figure 2.2. Age and length (TL) calculated from otoliths from *Iniiustus pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods. Fish lengths were collated into 10 mm bins, age bins were one year.

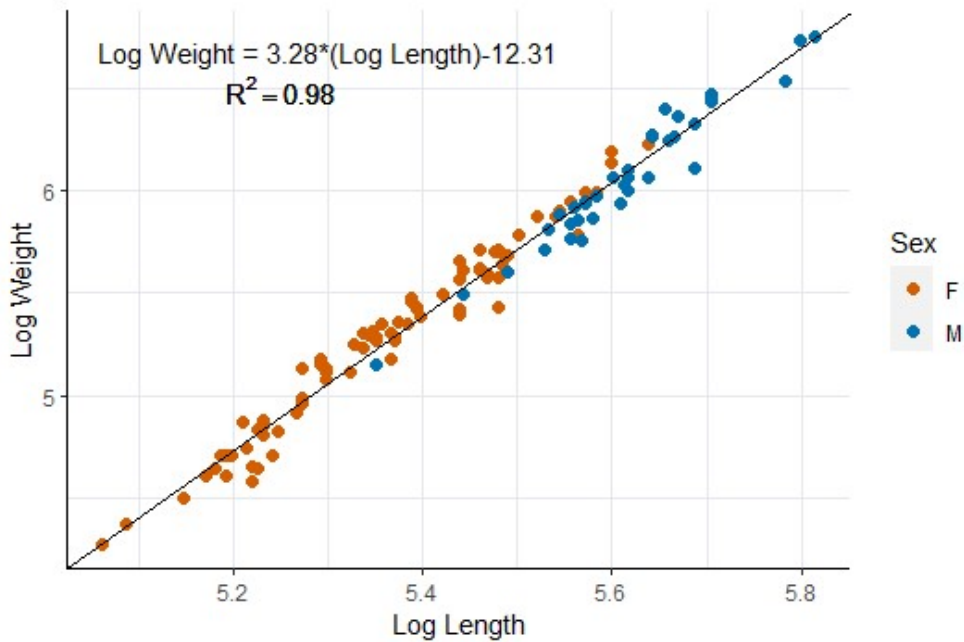


Figure 2.3. Length-weight relationship of 116 *Iniiustus pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods.

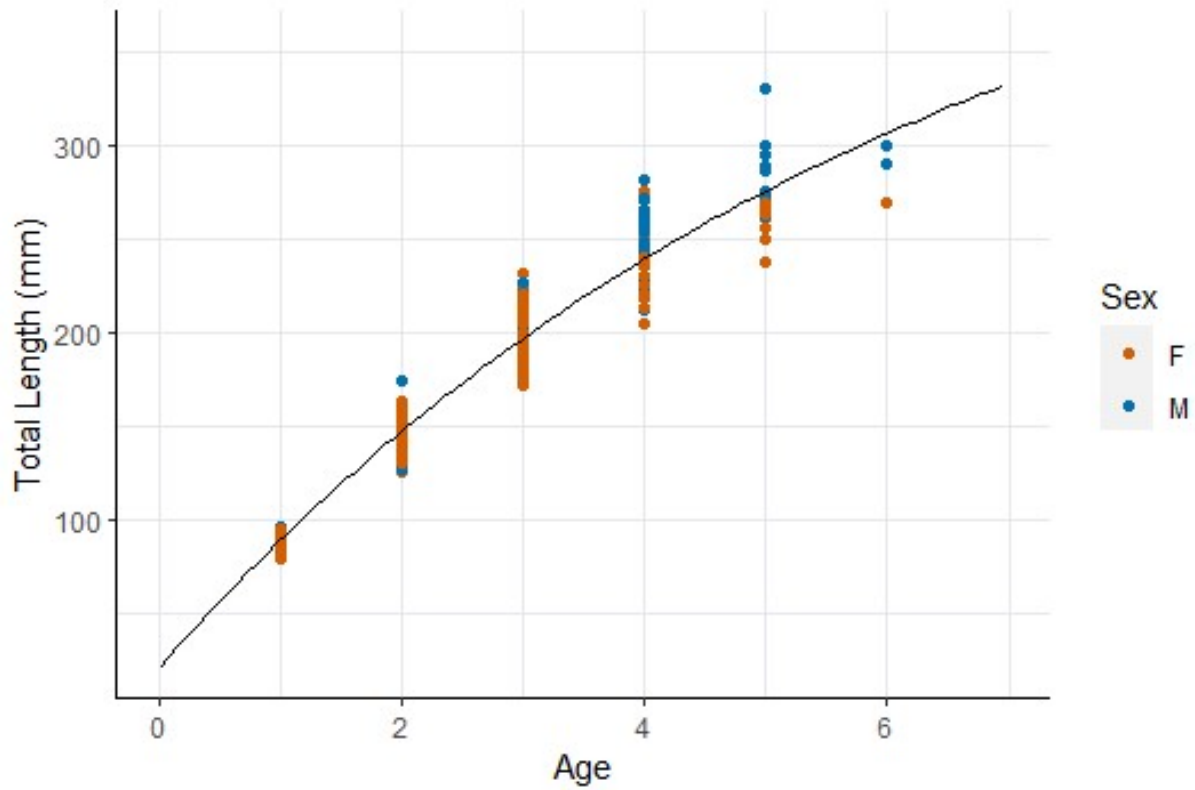
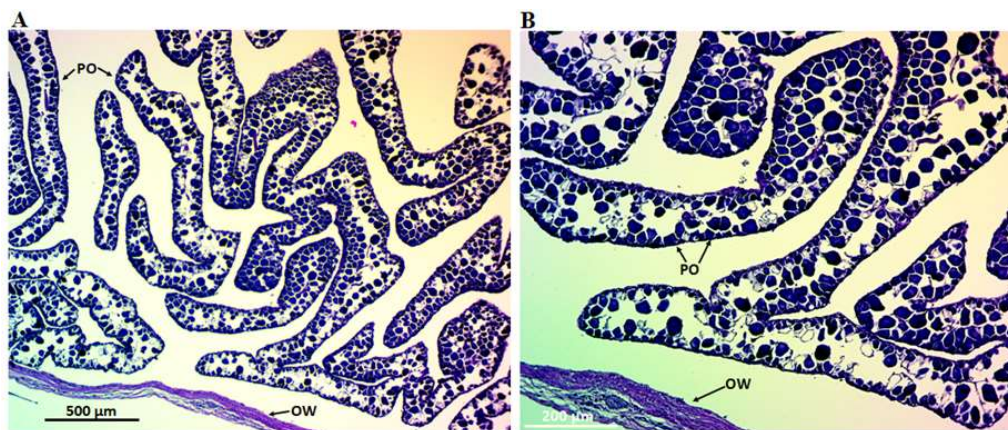
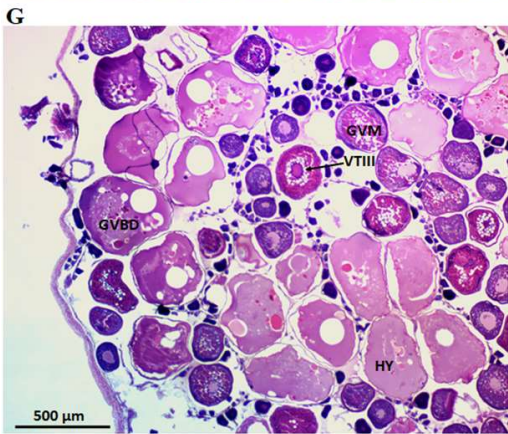
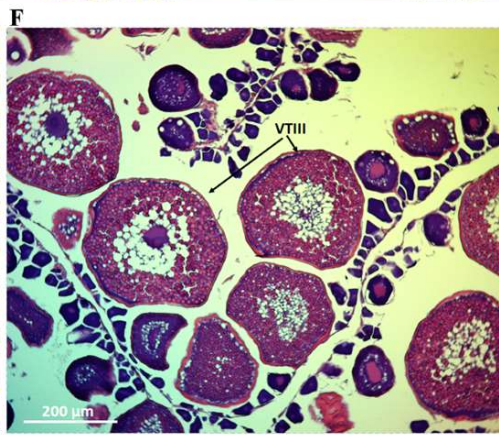
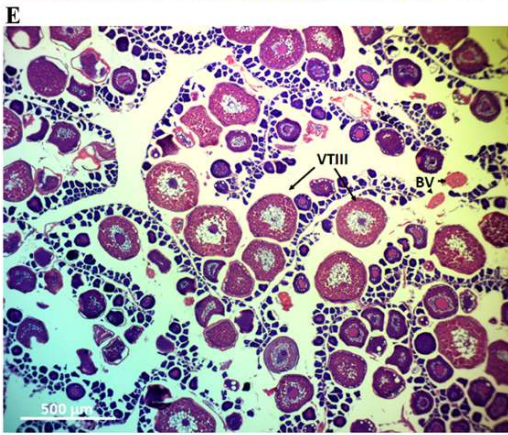
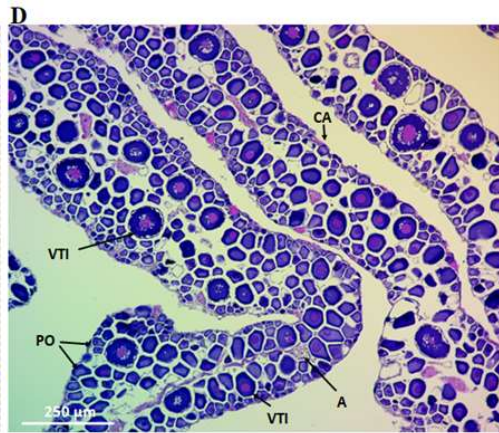
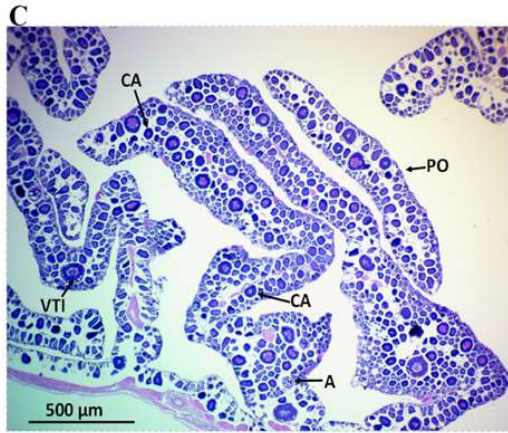


Figure 2.4. Von Bertalanffy growth curves fitted on back-calculated size-at-age data of *Iniistius pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods.





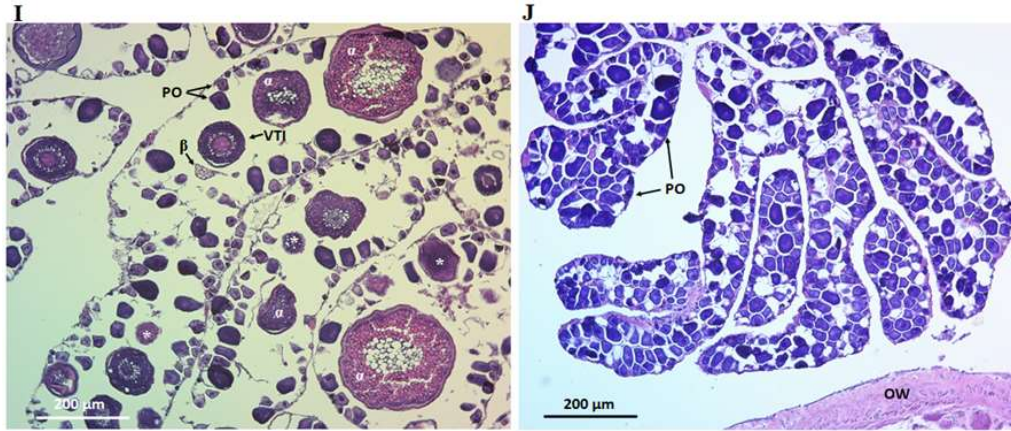


Figure 2.5. Reproductive phases of functional females *Iniistius pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods. 2.5A/B Immature female (18.7 cm TL) with primary growth oocytes (PO: oogonia, chromatin nucleolar, perinucleolar) and thin ovarian wall (OW). 2.5C/D Developing female (cm TL) with cortical alveolar oocytes (CA), early vitellogenic oocytes (VTI), and atretic oocytes (A). 2.5E/F Spawning Capable female (21.1 cm TL) with late-stage vitellogenic oocytes (VTIII) and the presence of atretic oocytes and blood vessels (BV). 2.5G/H Actively Spawning female (21.2 cm TL) with hydrated oocytes (HY), oocytes in late germinal vesicle migration (GVM) and germinal vesicle breakdown (GVBD). 2.5I Regressing (20.0 cm TL) with α and β atretic oocytes, asterisk (*) indicates atretic unyoked follicle. 2.5J Regenerating female (27.0 cm TL) with thick ovarian wall and primary growth oocytes.

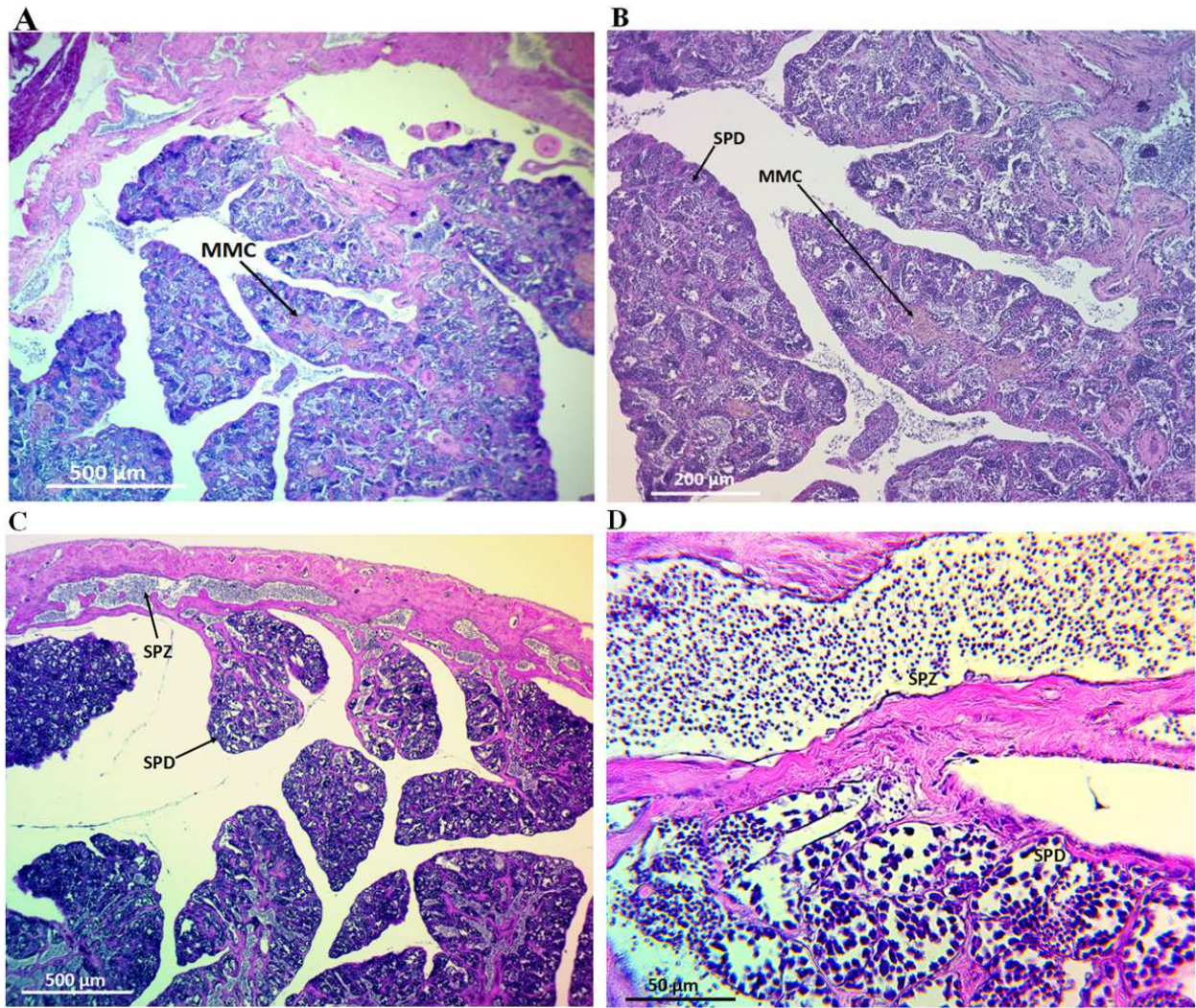


Figure 2.6. Reproductive phases of functional male *Iniistius pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods. 2.6A/B Male (25.2 cm TL) gonads with melanomacrophage centers (MMC), spermatids (SPD). 2.6C/D Male (28.1 cm TL) with spermatids and spermatozoa (SPZ).

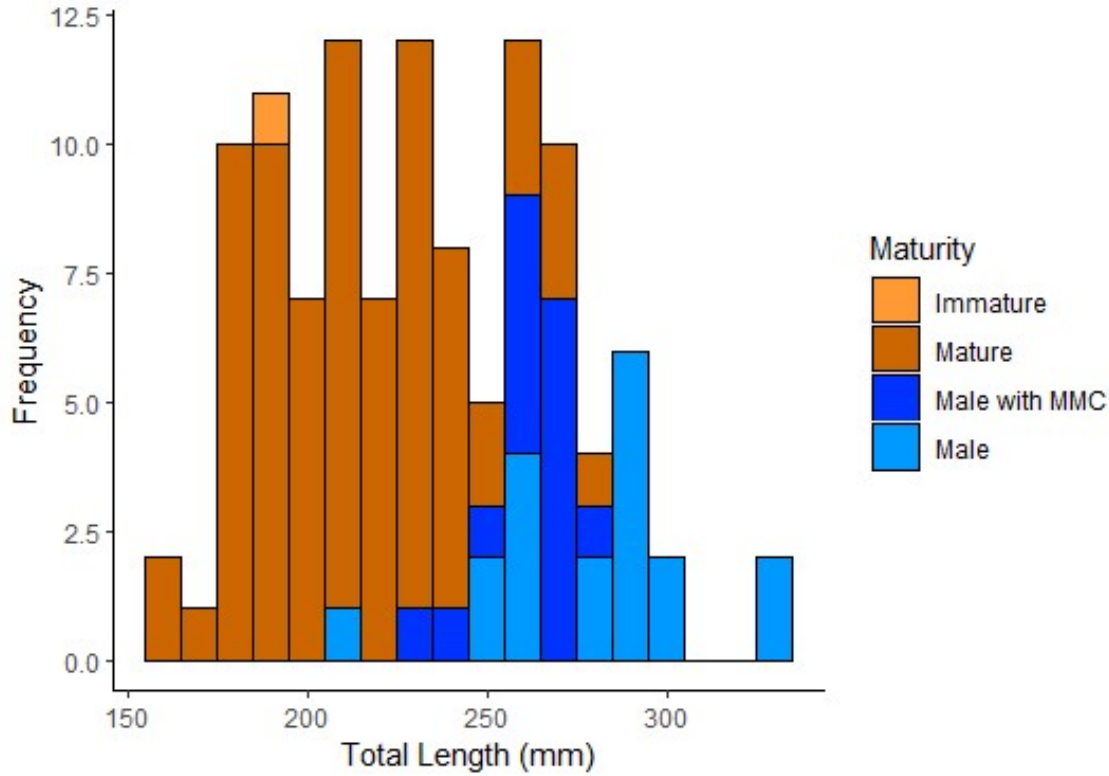


Figure 2.7. Total length-frequency distribution of immature and mature *Iniistius pavo* collected in the waters around Hawai'i between September 2018 – October 2020. Fish were captured angling from a boat using hook and line methods.

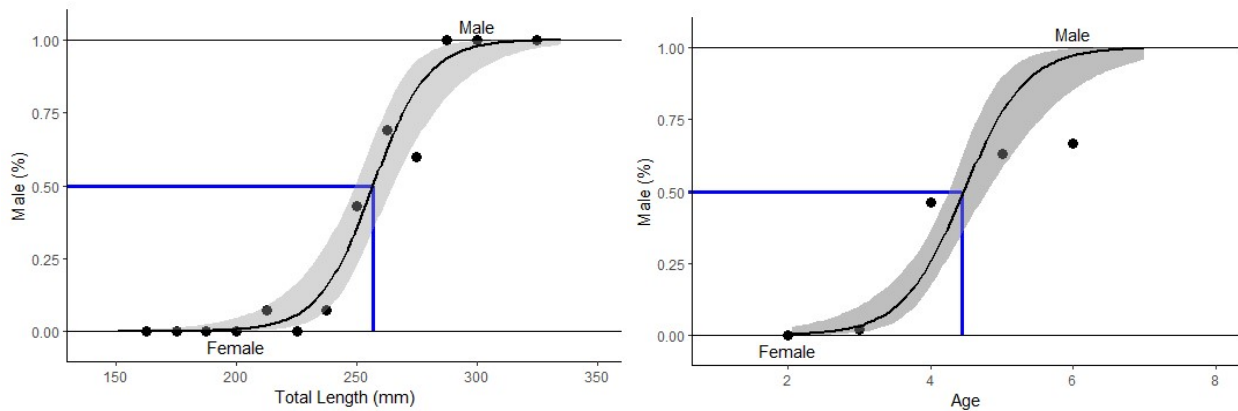


Figure 2.8. Cumulative frequency (%) from logistic regression of *Iniistius pavo* collected in the waters around Hawai'i Island between September 2018 to October 2020. Fish were captured angling from a boat using hook and line methods. Length (TL) and age (years) at sex change ($n = 111$). A, length (TL) at sex change ($L_{\Delta 50} = 25.7$ cm) and age at sex change ($A_{\Delta 50} = 3.97$ years).



Figure 3.1. Examples of the eight types of photographs of nabeta *Iniistius* spp. captured from Hawaiian nearshore waters and posted to the social media site, Instagram, during 2012-2021. These photographs were classified as (A) organized/flat surface/perpendicular, (B) organized/flat surface/angle, (C) organized/cooler/perpendicular, (D) organized/cooler/angle, (E) random/flat surface/perpendicular, (F) random/flat surface/angle, (G) random/cooler/perpendicular, and (H) random/cooler/angle. Photographs were taken by author (RM) and staged to replicate photographs posted to Instagram.

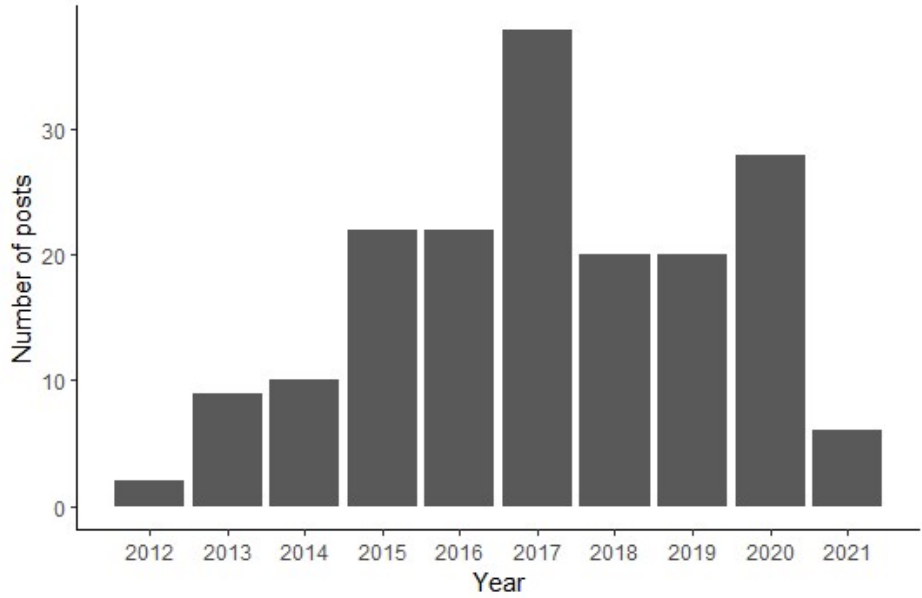


Figure 3.2. Histogram of the number of catch pictures posted on Instagram using #nabeta. Posts containing this tag span from the first posts in September of 2012 to July of 2021 ($n = 177$).

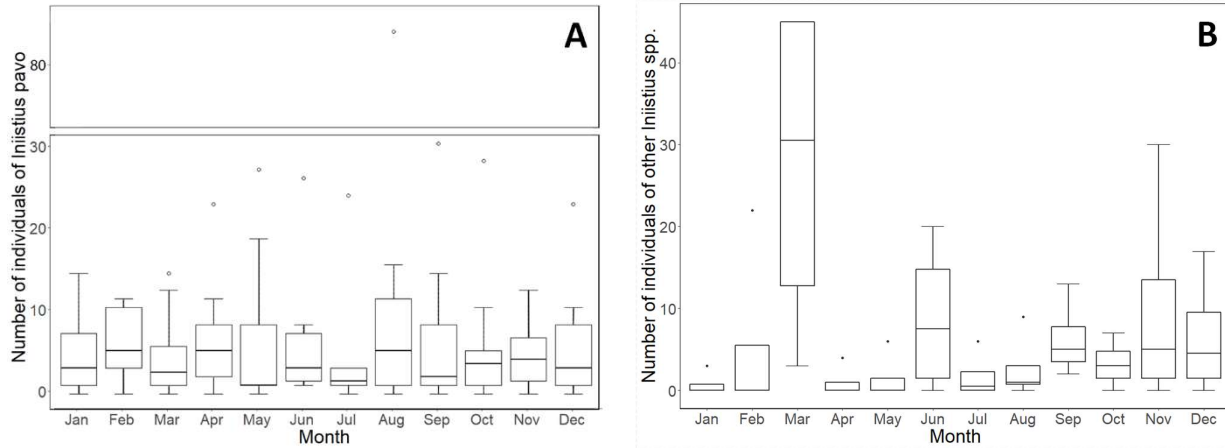


Figure 3.3. Box plots of monthly catch rates of nabeta, *Iniistius* spp., from Instagram posts during 2012-2021. Bold centerlines represent the median within each box. The lower 25 and upper 75 percentiles are noted by the upper and lower bounds of the box. Upper and lower error bars represent the 10th and 90th percentiles. Records beyond these limits are denoted by empty circles. 3.3A) *I. pavo*, 3.3B) *I. aneitensis*, *I. baldwini*, *I. celebicus*, and *I. umbrilatus*.

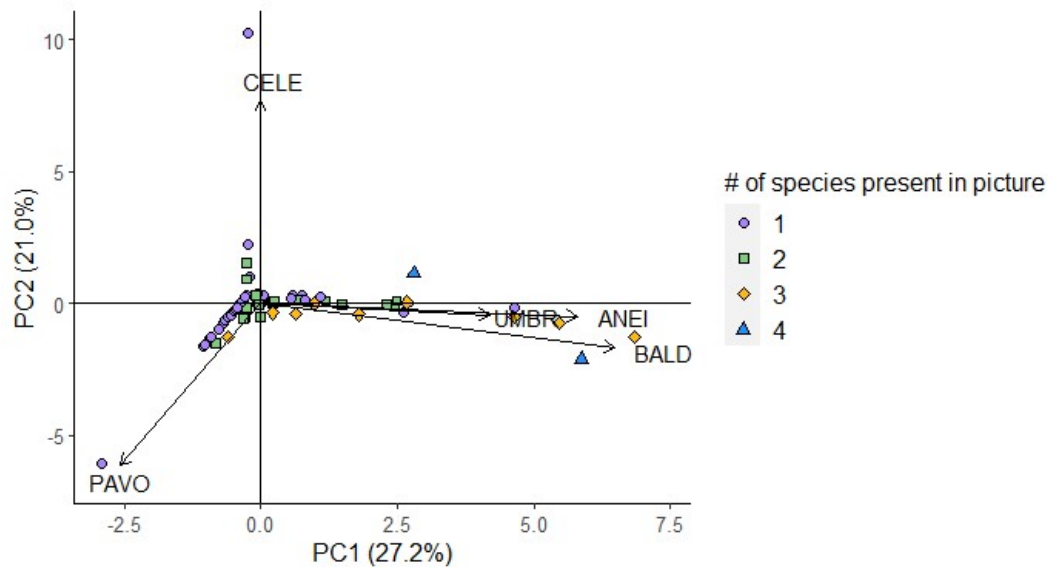


Figure 3.4. Biplot of nabeta, *Iniistius* spp., observations from Instagram catch pictures posted from 2012 to 2021. Eigenvectors describe species loadings. Points indicate catch pictures; the colored shapes indicate the number of nabeta species identified in the catch picture. The first two principal components accounted for 48.5% of the variance. To reach greater than 80% explanatory power four principal components were required. PC1 represents a positive correlation of three species: *I. aneitensis* (ANEI), *I. baldwini* (BALD), and *I. umbrilatus* (UMBR). PC2 was primarily driven by *I. celebicus* (CELE) and *I. pavo* (PAVO) that are negatively correlated with each other. CELE and PAVO are un-correlated to the three species grouping that comprise PC1.

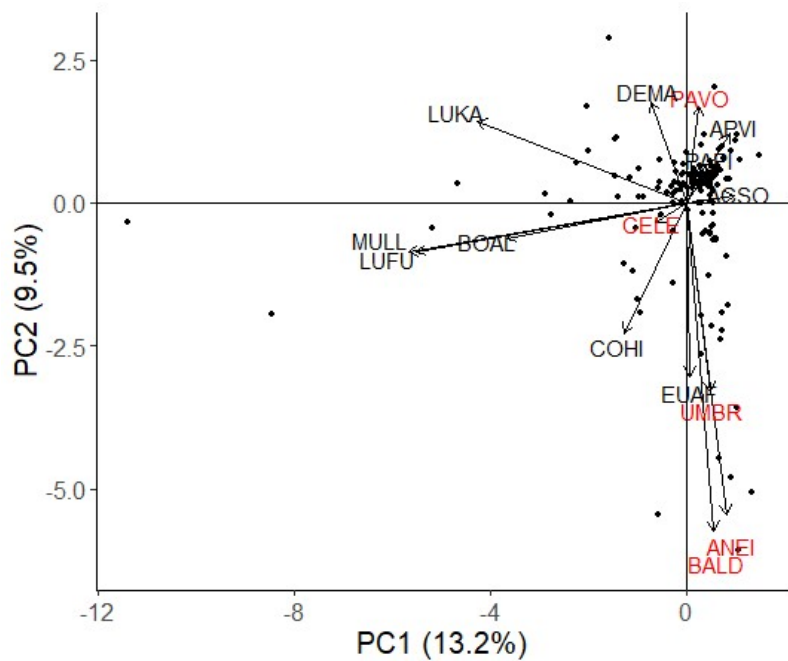


Figure 3.5. Biplot of nabeta and non-nabeta species observation in Instagram catch pictures. Eigenvectors describe species loadings. Points indicate catch pictures. It took 11 PCs to explain greater than 80% indicating low explanatory power. The first two principal components described 22.7% of the variance with PC1 capturing (13.2%) and PC2 (9.5%). Nabeta species (in red): *I. aneitensis* (ANEI), *I. baldwini* (BALD), *I. celebicus* (CELE), *I. pavo* (PAVO) and *I. umbrilatus* (UMBR). Non-nabeta species and taxa (in black) appearing in greater than 5% of Instagram posts: wahoo *Acanthocybium solandri* (ASCO), green jobfish, *Aprion virescens* (APVI), Hawaiian hogfish, *Bodianus albotaeniatus* (BOAL), dolphinfish, *Coryphaena hippurus* (COHI), mackerel scad, *Decapterus macarellus* (DEMA), mackerel tuna, *Euthynnus affinis* (EAUF), blacktail snapper, *Lutjanus fulvus* (LUFU), bluestriped snapper, *Lutjanus kasmira* (LUCA). Species of Mullidae (MULL) and Carangidae (PAPI) were grouped together due to similarities in trophic levels and difficulties in positive identifications.

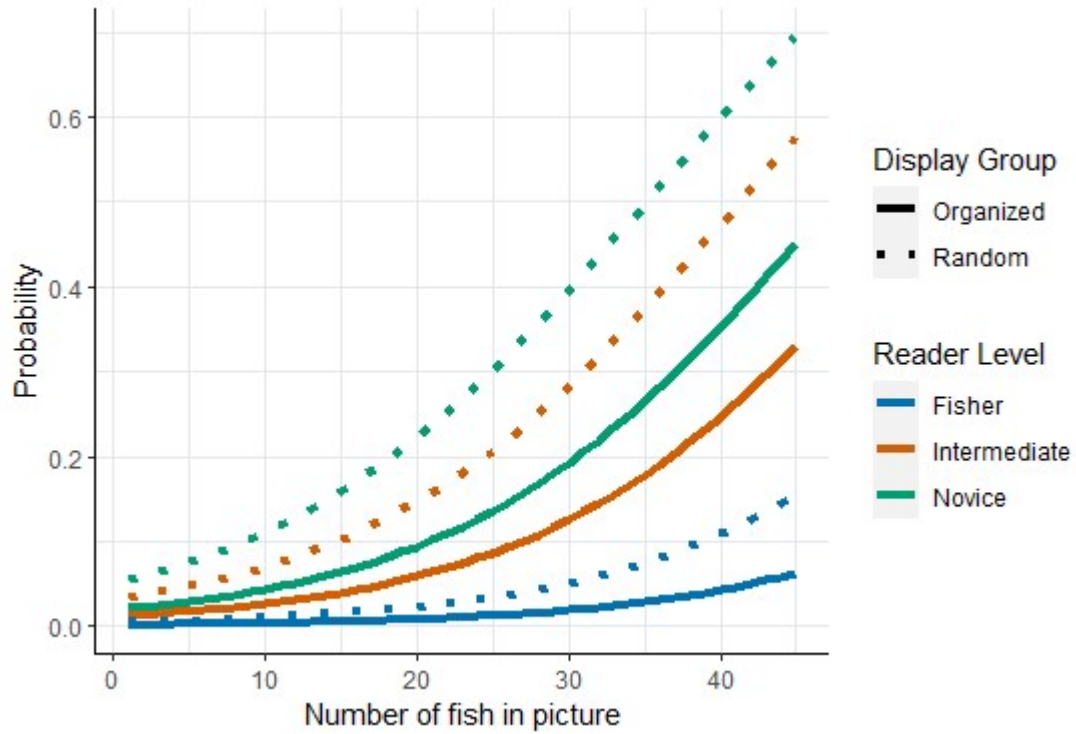


Figure 3.6. Logistic regression model describing the relationship of probability of making an error across varying number of fishes. Reader Level is represented by differences in colors and Display Group is signified by dotted lines. The overall model $Z_{679} = -7.59, P < 0.001$.

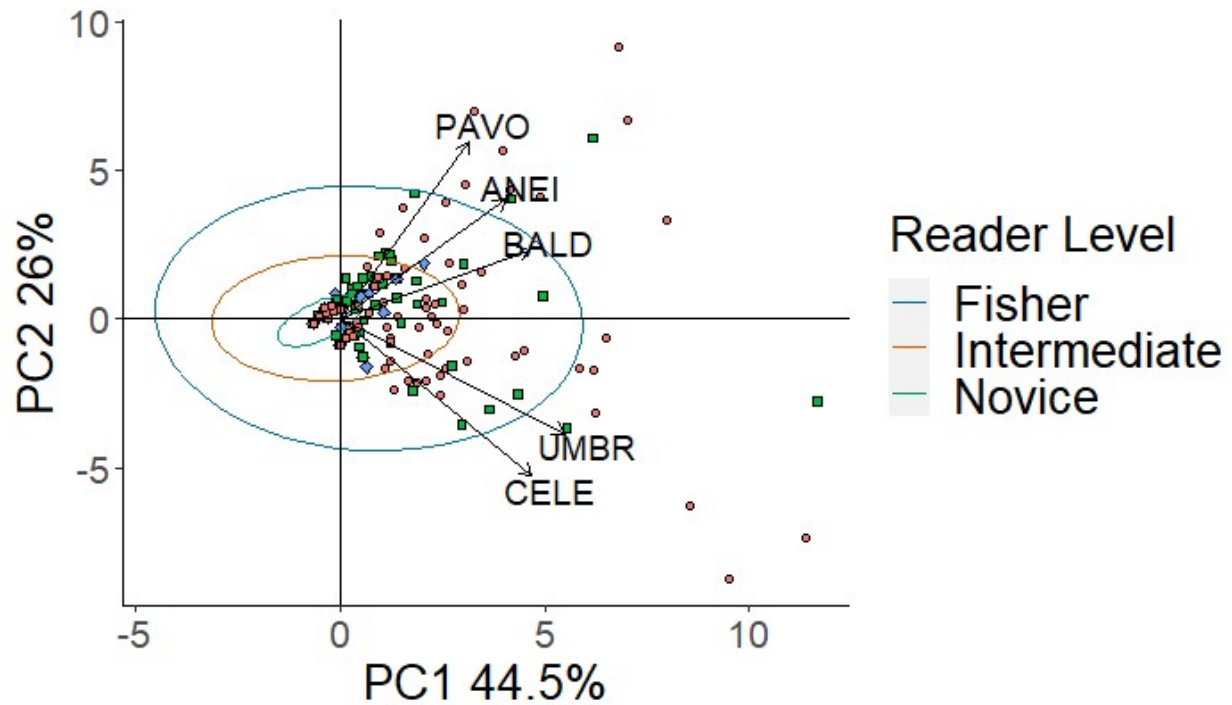


Figure 3.7. Biplot of reader errors in observation from staged catch pictures. Eigenvectors describe species loadings. Points indicate reader observations, reader levels are indicated by colored circles for Novice, squares for Intermediate, and diamonds for Fishers. PC1 represents increasing errors across all species. PC2 composed positive grouping of ANEI (*I. aneitensis*), BALD (*I. baldwini*), and PAVO (*I. pavo*) and a negative grouping of CELE (*I. celebicus*) and UMBR (*I. umbrilatus*). The ellipses describe the 95% confidence interval for each reader skill level.