ORIGINAL ARTICLE

Life history characteristics and status of the Pacific yellowtail emperor, *Lethrinus atkinsoni* (Seale 1910), in the Commonwealth of the Northern Mariana Islands

Michael S. Trianni[1] | **Edward E. DeMartini**[1] | **Brett M. Taylor**[2]

[1]National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, Hawaii, USA

[2]UOG Marine Lab, University of Guam, Mangilao, Guam, USA

Correspondence
Michael S. Trianni, National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, HI 96818, USA.
Email: mtrianni@ymail.com

Abstract

Life history characteristics of the Pacific yellowtail emperor, *Lethrinus atkinsoni*, were described from commercial samples in the Commonwealth of the Northern Mariana Islands spanning a 28-month market sampling period. Derived statistics pertaining to growth, life span, mortality and reproductive features were obtained through analyses of sectioned sagittal otoliths and gonad tissues. Maximum age observed was 18 years, with females attaining 50% sexual maturity at 3.3 years at a fork length of 20.9 cm; too few male specimens precluded male maturation estimates. We concluded that the species exhibited an undetermined sexual pattern as no evidence of prior female function was observed in mature males. No annual spawning periods were identifiable. Early growth rates estimated by settlement size-constrained VBGF models using fish landed by the nighttime commercial spear fishery (NCSF) were rapid. Exploitation rates indicated very low-to-moderate levels of exploitation. Boat-based fishing efforts from the NCSF captured the larger individuals of the species, whereas shore-based efforts captured the vast majority of individuals representing sizes generally below that of the estimated 50% maturation level. Extensive fishery-independent in situ diver observations indicated the species may have a restricted range. Expanded fishery-dependent collection of *L. atkinsoni* specimens and studies of its movement ecology at Saipan would provide additional input for fishery management, as well as a formal stock assessment which juvenile-biased catches indicate are necessary.

KEYWORDS
age and growth, exploitation, Lethrinidae, Mariana Islands

1 | INTRODUCTION

The sustainability of fisheries worldwide has been the focus of attention in recent years as many small-scale fisheries are considered data-deficient (Pilling et al., 2009). As a result, formal stock assessments cannot be applied to those fisheries (Nadon & Ault, 2016); subsequently, traditional management measures cannot be confidently used (Bentley & Stokes, 2009). This has led to the development of methods of determining stock status for data-deficient fisheries (Berkson et al., 2011; Chrysafi & Kuparinen, 2015; Dick & MacCall, 2011) and the development of related harvest strategies (Dowling et al., 2015; Hordyk et al., 2015). The multispecies nature of coral reef

fisheries exacerbates the status evaluation of data-deficient fisheries, producing a variety of priorities and approaches towards improving sustainability (Johnson et al., 2013; Kittinger, 2013; McClanahan et al., 2015). One important response to the deficit of information on coral reef fisheries has been the support for studies on age and growth (Choat & Robertson, 2002), reproductive status and maturity milestones (Sadovy, 1996).

Emperor fishes of the family Lethrinidae are distributed throughout the tropical Indo-Pacific Region, with species of the genus *Lethrinus* supporting important coral reef fisheries (Carpenter & Niem, 2001). As a result of the prevalence of *Lethrinus* spp. in fisheries landings, numerous studies have been undertaken in recent decades to characterize life history parameters for this group (e.g. Currey et al., 2013; Ebisawa & Ozawa, 2009; Grandcourt et al., 2010), most importantly female size and age at maturity, which can then be utilized in determining species stock status(Trianni 2016; Taylor et al. 2017). Supporting information

Since 2011, the NMFS Pacific Islands Fisheries Science Center (PIFSC) has supported coral reef fisheries monitoring and research through the funding of bio-sampling programmes (BSP), part of the parent, national NOAA NMFS Commercial Fisheries Bio-Sampling Program, that collect species-specific commercial fisheries data in the central and western Pacific US jurisdictions. The Commonwealth of the Northern Mariana Islands (CNMI) BSP has provided a long-term sampling and monitoring protocol for the Saipan-based commercial nighttime free-dive spear fishery (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018) and has increased life history research on Saipan-landed coral reef fish, including emperors (Taylor et al., 2017), which has expanded prior research on that group in the Mariana Archipelago (Taylor & McIlwain, 2010; Trianni, 2011; Trianni, 2016).

The Lethrinidae are typically characterized as protogynous hermaphrodites (Young & Martin, 1982), where males are derived from mature females; however, for some species, the designation of the specific type of hermaphroditism appears complex (Sadovy de Mitcheson & Liu, 2008). For example, Ebisawa (2006) and Taylor et al. (2017) noted that as *Lethrinus obsoletus* might exhibit 'juvenile hermaphroditism', where immature individuals exhibit characteristics of both early male and early female cell lines and subsequently develop as either mature females or males which, from a functional standpoint, is gonochorism (Sadovy de Mitcheson & Liu, 2008). Like many lethrinids, the Pacific yellowtail emperor, *Lethrinus atkinsoni*, is a ubiquitous species inhabiting seagrass beds and sandy areas of lagoons and outer reef slopes in tropical and subtropical environments (Carpenter & Niem, 2001). Ebisawa (1999) observed divergent expressions of sexual function in *L. atkinsoni* among the Ryukyu Islands of Japan, with a population from Okinawa exhibiting 'functional' protogynous hermaphroditism (males derived from mature females), and a population from Yaeyama exhibiting functional 'gonochorism', following Sadovy de Mitcheson and Liu (2008).

This paper first uses an extensive survey of commercial landings and purchased fishery samples to generate estimates of age and growth and sexual maturation parameters and then utilizes those estimated parameters in concert with other available data to preliminarily evaluate the fishery status of *L. atkinsoni* in the CNMI.
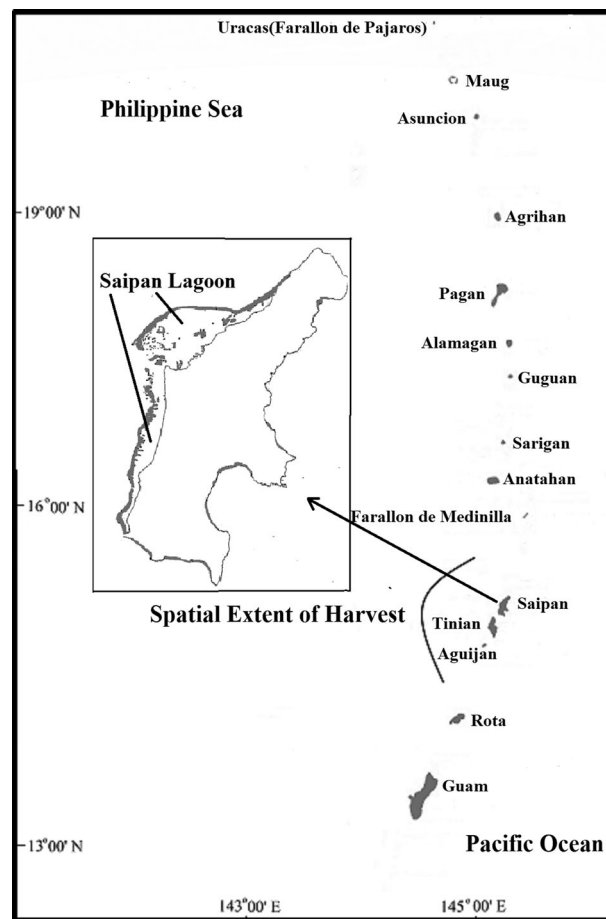

FIGURE 1 The Mariana Archipelago highlighting the spatial extent of the Commonwealth of the Northern Mariana Islands (CNMI) nighttime commercial spearfishing fishery.

2 | MATERIALS AND METHODS

2.1 | Study site and sampling protocols

Data on commercial reef fisheries were collected on Saipan (Saipan, CNMI) (15°14′N, 145°43′E) through the NOAA-funded CNMI BSP (PIFSC Life History Program) which acquired nighttime commercial spear fishery (NCSF) landings from fish vendors (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018). Fish are purchased directly from spear fishers at vendor business locations during the course of a night, and these landings are subsequently sampled by NOAA-funded staff at the vendor locations prior to movement to roadside stands for sale. The fishery landings sold by these vendors during the period of sampling for *L. atkinsoni* were primarily captured from coral reefs surrounding Saipan (85.3%), Tinian (8.0%), Rota (0.7%) and the uninhabited islands of the CNMI (6.0%; Figure 1). A variety of data attributes associated with each sample are collected, including but not limited to date, general capture location, trip type and species composition. Survey methods and sampling protocols are described by Sundberg et al. (2015).

From January 2012 to May 2014, monthly averages of 31 specimens of *L. atkinsoni* were purchased from commercial vendors. Following collection, specimens were iced and subsequently processed. During processing, measurements of fork length (FL, nearest 0.1 cm) and total body weight (TW, g) were obtained. Sagittal otoliths and gonads were surgically removed from each specimen and stored for subsequent processing. Otoliths were cleaned with ethanol and stored dry in labelled plastic vials. Gonads were weighed to the nearest 0.001 g (gonad weight [GW]) and macroscopically identified as either female or male. Entire gonads or sections (1 cm thick) of gonadal material from the midsections of gonad lobes were removed and stored using individually labelled histological cassettes in a 10% buffered formalin solution. In instances where gonads were very small, the entire gonad was retained.

2.2 | Reproduction

A subsample of 785 specimens from a total of 4235 measured individuals was randomly selected for histological processing of gonads. Fixed sections of gonadal tissue were processed at the John A. Burns School of Medicine at the University of Hawaii. Sections were imbedded with paraffin wax, sectioned transversely at 6 μm and stained on microscope slides with haematoxylin and eosin following standard protocols (DeMartini et al., 2014). Samples were viewed under compound and stereo microscopes to determine sex and maturity stages based on criteria and terminology following DeMartini et al. (2014) and Brown-Peterson et al. (2011), with functional female maturity identified by the presence of yolked or more developed oocytes in ovaries. Length (FL, cm; LM_{50}, LM_{95}) and age (year; AM_{50}, AM_{95}) milestones at 50% and 95% maturities were determined for females by partitioning individuals into 1-cm length and annual age bins. The proportion mature in each bin was fitted to a logistic regression model employing maximum likelihood, weighted by the square root of bin sample size:

$$P = \frac{1}{1 + e^{(a-bX_f)}}, \tag{1}$$

where a and b are fitted model constants, P is the per cent mature per length or age bin and X_f is the length or age bin. Confidence intervals for maturity estimates were generated from 1000 bootstrap resamples.

A gonado-somatic index (GSI) was calculated as the ratio of gonad-to-gonad-free body weight, GSI = ((gonad weight/[total weight − gonad weight]) × 100) for each individual. Trends in GSI were examined monthly to evaluate spawning periodicity, assuming that peak GSI values indicate spawning periods.

2.3 | Age and growth

A random subsample of 476 specimens was selected for age analysis. A selected sagittal otolith from each sample was weighed to the nearest 0.0001 g and bonded to a glass slide using thermoplastic glue

(Crystalbond 509) with the core positioned just inside the edge of the slide with the sulcal ridge perpendicular to the slide edge. The otolith was then ground down to the otolith core along the longitudinal axis to the edge of the slide using a 600-grit diamond lap on a grinding wheel. The otolith was then removed and re-bonded with the ground surface facing down and subsequently abraded to produce a thin ($\leq$220 μm) transverse section encompassing the core material. Otolith annuli along the face of the transverse sections were counted on a stereo microscope using both transmitted and reflected light. For each otolith, annuli were independently enumerated until age counts came into agreement. Confirmation of the general location of the first annuli was accomplished by examining daily increments from a subsample of specimens. Transverse otolith sections were successively polished with 9, 3 and 0.3 μm lapping films until optimum clarity of daily increments was achieved when viewed by a compound microscope.

Several studies have validated patterns of annual deposition of translucent and opaque increments in otoliths for a number of species belonging to the genus *Lethrinus* (Andrews et al., 2011; Grandcourt, 2002; Grandcourt et al., 2010), including *L. harak* and *L. obsoletus* from the Mariana Islands (Taylor & McIlwain, 2010; Taylor et al., 2017). Currey et al. (2013) also reported age and growth estimates for *L. atkinsoni* based on annual increments, as did Ebisawa and Ozawa (2009) using a burnt otolith technique.

The estimation of growth parameters was derived from length-at-age data using two forms of the von Bertalanffy (1938) growth equation (VBGF); the original represented as

$$L_t = L_\infty - (L_\infty - L_0)\, e^{-K_t} \tag{2}$$

and the commonly used model version:

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right), \tag{3}$$

where L_t is the predicted mean FL at time or age t, L_∞ is the mean asymptotic FL, K is the growth coefficient that describes model curvature, t_0 is the theoretical age at which length is equal to 0 and L_0 is the FL at birth. L_0 was anchored to a size at the settlement of 1.7 cm (Nakamura et al., 2010) in order to capture early growth rate because fish smaller than 12 cm FL were not sampled from the fishery. Length-at-age data from boat- and shore-based specimens were also fitted by anchoring settlement size, and growth curves were tested for equality using the analysis of the residual sum of squares (ARSS) method developed by Chen et al. (1992). Additionally, pooled length-at-age data were fitted without constraint by the commonly used version of the VBGF model.

2.4 | Mortality and exploitation

An age-length key (Isermann & Knight, 2005) was created to estimate age groups for sampled length-frequency data from the CNMI BSP. These data were, in turn, used to obtain estimates of the annual instantaneous rate of total mortality (Z) for *L. atkinsoni*, determined with the

age-based catch-curve (CC) method (Beverton & Holt, 1957), in its linearized form:

$$\ln(C_t) = \ln(N_0) - Z_t, \qquad (4)$$

where C_t is the catch in year t, N_0 is recruitment into cohort and Z_t is the instantaneous rate of Z at age t. The descending limb of the plot of the natural logarithm of relative abundance versus age (time) was used to estimate Z with the exclusion of derived age groups beyond the first age class where one or fewer individuals were observed (Dunn et al., 2002). Additionally, Z was estimated by using the maximum likelihood estimator for CCs developed by Chapman and Robson (Chapman & Robson, 1960; Robson & Chapman, 1961) and hereinafter referred to as the CR model:

$$Z = -\log\left(\frac{T}{n+T-1}\right), \qquad (5)$$

where n is the total number of fish observed on the descending limb of the CC, defined as fully recruited; T represents the fish ages on the descending limb of the CC, where the first fully recruited age is set to zero.

The instantaneous rate of natural mortality (M) was estimated using the predictive equation derived by Hoenig (1983) for fish, which relates the maximum age observed in a stock to M:

$$\ln(M) = 1.46 - 1.01 \times \ln(t_{max}) \qquad (6)$$

and an updated version of that equation by Then et al. (2015):

$$\ln(M) = 1.717 - 1.01 \times \ln(t_{max}), \qquad (7)$$

where t_{max} is the maximum age observed in the population.

Fishing mortality (F) was derived as the difference between total instantaneous mortality and natural mortality, as $F = Z - M$. The exploitation rate (E) was computed as $E = F/Z$ (Gulland, 1971), where an E value at or near 0.5 reflects full exploitation.

2.5 | Additional data sources

Data from supplementary fishery-dependent and independent sources were reviewed for information on the location and size structure of *L. atkinsoni*. Data from historical sampling of the NCSF utilizing scuba and surface-supplied air (both here referred to as 'scuba') covering the period 1992–96 (Graham, 1994) were searched for data on harvest location and size structure of *L. atkinsoni*. Available data from fishery-independent sources were examined to determine the geographic and depth range of *L. atkinsoni* sightings in the CNMI, with data files examined from the PIFSC Coral Reef Ecosystem Program's (CREP) Mariana Archipelago Rapid Assessment and Monitoring Protocol (MARAMP) (Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center, 2017a, 2017b, 2017c) and the CNMI Bureau of Environmental and Coastal Quality's (BECQ) Marine Monitoring Team (Johnston et al., 2015).

3 | RESULTS

3.1 | Specimens and principal data sources

Reported landings from the NCSF for the time period 2011–14 were dominated by shore-based fishing efforts totalling 87% of reported trips, with 77% of shore-based landings harvested from the leeward aspect of Saipan (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018). In this study, 67% of the 4235 *L. atkinsoni* measured at vendors were from shore-based trips, with 86% recorded as coming from Saipan Lagoon. Of the 931 specimens of *L. atkinsoni* randomly purchased for life history processing and analysis, 81% came from Saipan Lagoon. Altogether, the lethrinids comprised 8.2% by weight and 7.5% by a number of sampled landings from the CNMI BSP during the sampling period, with *L. atkinsoni* contributing 28% by weight and 36% by number of all lethrinids landed. Overall, *L. atkinsoni* contributed 2.6% by number and 2.3% by weight to the NCSF sampled landings during the period of this study. On Guam, *L. atkinsoni* contributed 1.4% of the total sampled catch by number and 0.3% by weight (Guam Biosampling Program).

3.2 | Maturation and spawning seasonality

A total of 785 specimens were histologically staged. Of these, 648 were females (including developing and mature), 61 were either developing or mature males (Figure 2), 71 were staged as 'undifferentiated/immature-bisexual' (hereafter also referred to as either 'bisexual' or 'bisex') and 6 were unclassified individuals. Figure 2 shows mature female ovary and a mature male. Some male specimens were observed to have brown bodies, which are possible atretic oocytes, although their presence alone is insufficient to warrant evidence of sex change as brown bodies may arise from other causes (Sadovy de Mitcheson & Liu, 2008). Given no other evidence of prior mature female function in mature males, we conclude that *L. atkinsoni* in the CNMI exhibits an undetermined sexual pattern. The bisexual category was necessary because immatures included specimens whose gonads contained both primordial ovarian and testicular tissues, a phenomenon typified by a genus of serranine seabasses (Sadovy & Domeier, 2005) but also recognized in other lineages (Sadovy de Mitcheson & Liu, 2008). The frequencies of female maturation stages and GSI values by month for the period January 2012 through April 2014 are shown in Figure 3. Conclusive evidence of a peak spawning season for *L. atkinsoni* in this study as seasonal variation in GSI in months between years was considerable, and although some months did exhibit maturation stages suggestive of possible peak spawning, those months lacked adequate sample sizes.
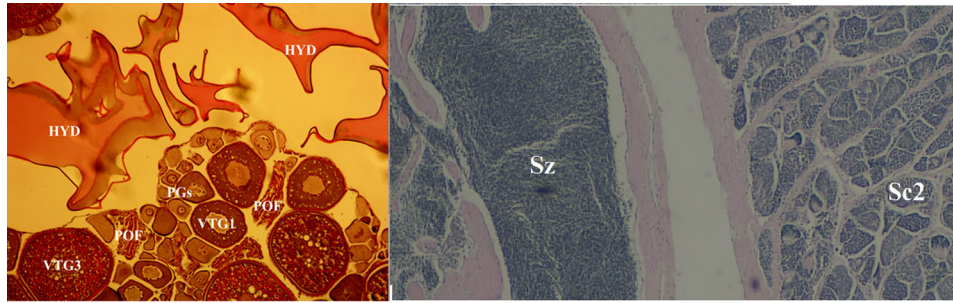
FIGURE 2 Top left: Mature actively spawning female showing several stages of oocyte development (HYD, hydrated oocyte; PG, primary growth oocytes; POF, post ovulatory follicle; VTG1, primary vitellogenic oocyte; VTG3, tertiary vitellogenic oocyte). Top right: Mature male (Sc2, secondary spermatocyte; Sz, spermatozoa). *Source*: Terminology adopted from DeMartini et al. (2014) and Brown-Peterson et al. (2011).
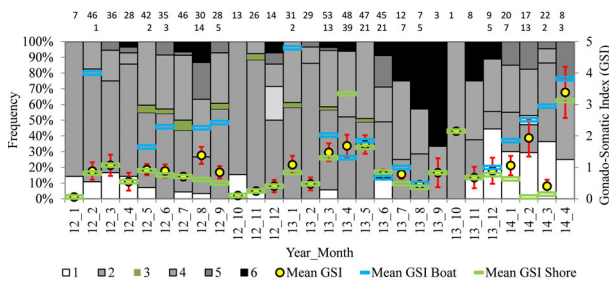

FIGURE 3 Graph of the frequency of female maturation stages against gonadal somatic index values by year and month with mean and standard errors calculated separately for fish caught by shore- and boat-based fishing efforts. Numbers at top of graph are monthly sample size with numbers directly below samples from boat-based fishing effort. Maturation codes: 1 = immature bisexual; 2 = primary or unyolked secondary growth (CA = cortical alveolar; immature); 3 = maturing vitellogenic (immature); 4 = fully vitellogenic (functionally mature); 5 = actively spawning; 6 = resting. *Source*: Classification modified from DeMartini et al. (2014).

3.3 | Sex-specific size distributions and length- and age-specific maturity

About 80% of the females, 73% of the males and 97% of undifferentiated/bisexual-immature and unclassified individuals were reported as having been harvested from Saipan Lagoon. Females averaged 21.3 cm FL and ranged in size from 12.4 to 34 cm FL, whereas males averaged 23.6 cm FL and ranged in size from 16.4 to 31.4 cm FL. Individuals staged as immature-bisexual averaged 16.3 cm FL and ranged from 14 to 20 cm FL. Opaque zones were consistently visible using reflected light for the subsample of 476 specimens aged (Figure 4). The oldest individual aged was an 18-year female, whereas the oldest male aged was 15 years. Immature bisexual individuals ranged in age from 1 to 4 years. Males ranged in age from 2 to 15 years with a mode of 4 years, whereas females ranged from 1 to 18 years with a mode of 2 years. The LM_{50} for females was estimated at 20.9 cm FL, with 95% bootstrapped confidence intervals of 20.6 and 21.3 cm FL, whereas the LM_{95} was estimated to be 23.5 cm FL, and with 95% bootstrapped confidence intervals of 22.8 and 24.6 cm FL. There were too few males sampled in this study to generate an
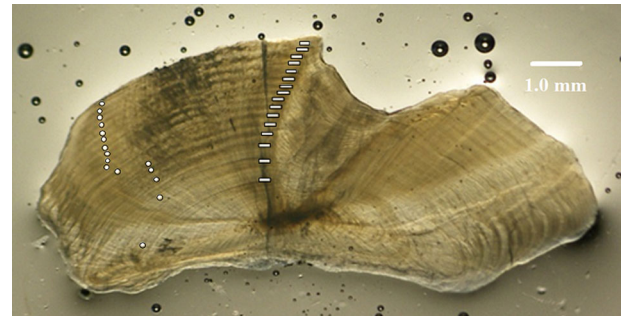

FIGURE 4 Photomicrograph of a transverse section of a sagittal otolith from a 31.2 cm fork length (FL) female *Lethrinus atkinsoni*, viewed under reflected light, estimated to be 16-year old. Opaque annuli are indicated by the white dots and lines.
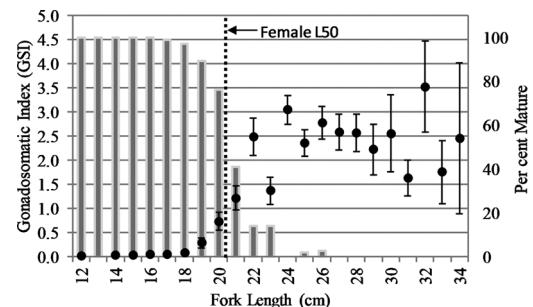

FIGURE 5 Mean gonadal somatic index values with standard error bars and per cent immature by length of *Lethrinus atkinsoni* sampled for reproductive analysis from the Saipan-based nighttime commercial spear fishery for the period January 2012–April 2014. Dotted vertical line indicates female LM_{50}.

estimate of size at maturity. GSI values for female *L. atkinsoni* increased with a decrease in the percentage of immature individuals at length (Figure 5), and, although male GSI values appeared to increase to a similar size as females, the small sample size of males along with the inability to generate a statistical estimate of size at maturity negated further analysis. The female AM_{50} was estimated at 3.3 years, with 95% bootstrapped confidence intervals of 3.1 and 3.6 years, and the

TABLE 1 von Bertalanffy parameter estimates for *Lethrinus atkinsoni* for specimens sampled during 2012–14, from Saipan-based nighttime commercial spear fishery.

Model	L_∞	K	t_0
Unconstrained	30.6 (5.63)	0.195 (0.016)	−2.678 (0.259)
Constrained	26.3 (2.37)	0.606 (0.02)	
Constrained-boat	27.7 (2.41)	0.546 (0.03)	
Constrained-shore	25.2 (2.93)	0.674 (0.026)	

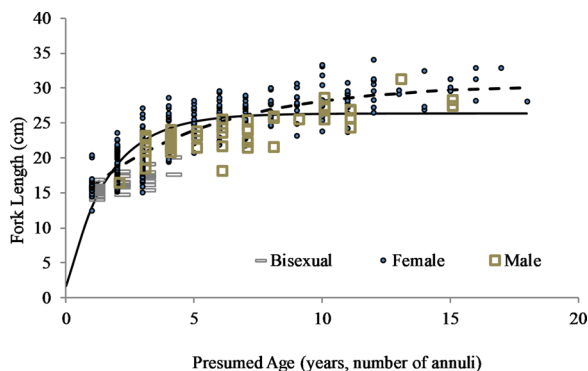*Note*: Standard error of estimate in parenthesis.

FIGURE 6 The original von Bertalanffy growth model constrained to size at settlement (1.7 cm) and fit to length at age data of *Lethrinus atkinsoni* collected from the Saipan-based nighttime commercial spear fishery in the Commonwealth of the Northern Mariana Islands. Constrained model fit to size at settlement (1.7 cm) depicted by solid line, and unconstrained model fit depicted by dashed line.

AM_{95} was estimated at 5.2 years. It was not possible to estimate age at maturity for males, although the youngest mature male was 3-year old.

3.4 | Growth- and age-based fishery statistics

The VBGF results for the fitted constrained and unconstrained models are shown in Table 1. The constrained VBGF model had an L_∞ estimate of 26.3 cm FL and a K estimate of 0.606; the fitted model portraying length at age by male, female and bisexual is depicted in Figure 6. The unconstrained model results were an L_∞ of 30.6 cm FL, a K estimate of 0.195 and a t_0 estimate of −2.678. The ARSS comparison found the constrained boat- and shore-based VBGF growth curves to be indistinguishable. Total mortality was estimated as 0.344 by the CC regression and 0.323 by the CR model. Natural mortality estimated by the Hoenig (1983) empirical model using the observed maximum age of 18 years was 0.232, resulting in estimates of fishing mortality ($F = Z − M$) of 0.112 (CC) and 0.091 (CR). Point estimates for exploitation rates derived from M using the Hoenig (1983) model were 0.325 (CC) and 0.282 (CR), indicating a moderate level of exploitation, where optimal exploitation is $E = 0.5$ (Gulland, 1970). Estimate of M using the updated model by Then et al. (2015) resulted in a value of 0.300 and subsequent F estimates of 0.044 (CC) and 0.023 (CR), which, in turn,
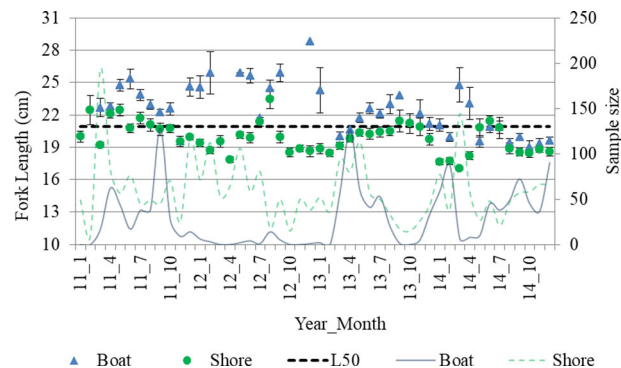

FIGURE 7 Mean fork length (cm) of *Lethrinus atkinsoni* landed by shore- and boat-based fishing efforts per month and year. Data were collected from the Saipan-based nighttime commercial spear fishery in the Commonwealth of the Northern Mariana Islands. LM_{50} = length at female maturity.

resulted in E estimates of 0.12 (CR) and 0.07 (CC), indicating very low levels of exploitation.

3.5 | Location and gear effects on catches

Supplementary fishery-dependent data importantly informed our evaluation. Over 95% of *L. atkinsoni* sampled in the NCSF during 2011–14 were caught on Saipan, and 91% of those fish were recorded as being caught in Saipan Lagoon. The mean measured monthly lengths of *L. atkinsoni* varied between shore- and boat-based fishing methods, with boat-based mean lengths tending to be greater than shore-based lengths (Figure 7). There were seasonal patterns in the mean size of *L. atkinsoni* captured from both the boat- and shore-based fishing methods, with the smallest monthly mean sizes of *L. atkinsoni* being landed during the November–March time period when mean wind speeds are greater (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018). Increased leeward aspect shore-based fishing effort, overwhelmingly from Saipan Lagoon, resulted in smaller individuals being landed and sampled.

Including landings from the 1990s scuba-spear fishery, the species has been landed only from Saipan, Tinian and Aguijan. Mean sizes from the three islands and island aspects, where available, are depicted in Figure 8, with data from the 1990s scuba-spear fishery accounting for about 10% of the total sample size. The largest mean body sizes were found to be from Tinian and Aguijan, with the smallest from Saipan's west aspect and lagoon. Of the females histologically staged, 56% were identified as immature. Of the 4235 individuals measured from the PIFSC CNMI BSP, 66% were under the estimated LM_{50}.

3.6 | Fishery-independent data sources

All MARAMP belt transect and stationary point count data collected on PIFSC cruises throughout the islands and at several diveable offshore banks and reefs of the CNMI during 2003–2017 lacked *L. atkinsoni*.
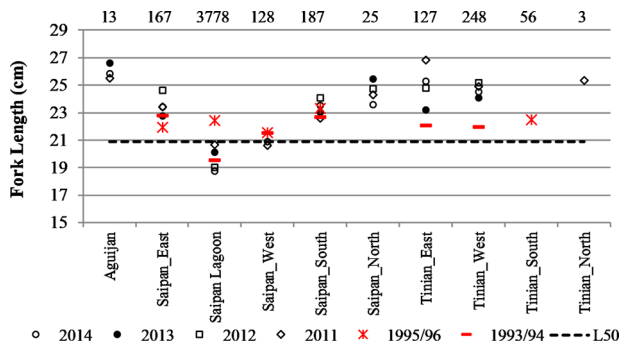
FIGURE 8 Comparison of mean fork length (cm) of *Lethrinus atkinsoni* by location for data collected by spear fishing using scuba/hookah during 1993–96, and the Saipan-based nighttime commercial free-dive spear fishery in the Commonwealth of the Northern Mariana Islands. LM_{50} = length at female maturity. Numbers at top of graph reflect sample size.

Although the MARAMP surveys did not include Saipan Lagoon, survey depths ranged from 5 to nearly 30 m. Survey data collected by the CNMI BECQ Marine Monitoring Team (2011–14) included survey efforts in Saipan Lagoon as well as from Saipan, Tinian, Aguijan and Rota to depths of 9 m. Two observations of *L. atkinsoni* from Rota Island were recorded at depths of about 9 m.

4 | DISCUSSION

4.1 | Life history

Spawning season was not clearly identified for *L. atkinsoni* from this study, despite sampling for 28 months over 3 consecutive years. This result contrasts with the studies in the GBR (Currey et al., 2013) and the Ryukyu Islands (Ebisawa, 1999), where identified spawning period peaks corresponded seasonally during the spring in both jurisdictions, with the factors prompting those respective peaks not evaluated.

The estimated 95% confidence limits for LM_{50} from this study, 20.6–21.3 cm FL, overlapped with the range of active maturity reported by Ebisawa (1999) from the Ryukyu Islands where the maturity of *L. atkinsoni* at Yaeyama was estimated to start at 19.0 cm and be completed by 21.9 cm FL, and at Okinawa beginning at 21.0 cm with completion by 24.9 cm FL. Conversely, the estimated 95% confidence limits of AM_{50} from this study, 3.1–3.6 years, were slightly greater than that estimated from those Ryukyu Islands, where A_{50} from both islands was estimated at 2–3 years. The paucity of males sampled from the fishery prohibited the estimation of sex-specific maturation; only a single 16.4 cm FL male was identified as immature and several mature males occurred in the 18–20 cm FL range. The majority of males sampled fell within the size range from 21 to 25 cm FL, and it can be reasoned that the LM_{50} of male *L. atkinsoni* from the populations in the Saipan NCSF may occur near that for females, which appears consistent with findings by Ebisawa (1999) and similar to that reported for *L. obsoletus* from the same fishery by Taylor et al. (2017).

The estimate of the maximum age of 18 years for *L. atkinsoni* sampled in the NCSF was similar to the range of ages estimated from the Ryukyu Islands, 18–24 years, but considerably different than the range of age estimates from the GBR provided by Currey et al. (2013) of 28–36 years. Comparisons of growth between the Ryukyu Islands and the GBR were evaluated using the different fits of the VBGF models in this study. The unconstrained model fit was similar to that used in the Ryukyu Islands, with the *K* value of 0.198 from Saipan within the range of values from the Ryukyu Islands, 0.186–0.260. The constrained fitted VB model from the GBR reflected much lower growth rates, 0.32 and 0.25, than the rate of 0.607 from Saipan, influenced by greater age-at-length. The lack of larger and older individuals of *L. atkinsoni* from the NCSF samples resulted in a poorer fit of those age bins to the constrained VBGF model, influencing the resulting L_{∞} estimate but capturing the species growth. Several studies have revealed spatial variation in the population biology of coral reef fish species (Lowe et al., 2022; Taylor, 2014; Taylor et al., 2018; Trip et al., 2008); although the difference in growth rate between Saipan landed fish and the GBR is not unexpected, the similarities between the CNMI and the Ryukyus suggest further investigation is warranted for the growth of coral reef fish between the two jurisdictions. The results from our study concluded that *L. atkinsoni* in the Northern Marianas exhibited a sexual pattern that was functionally gonochoristic, where characteristics of both early male and early female cell lines were present, with individuals subsequently developing as either mature females or males. Although brown bodies (possible atretic oocytes) were present in some mature males, no other characteristics were observed that would indicate prior female function.

4.2 | Fishery characteristics

Boat-based fishing captured, on average, larger individuals than shore-based fishing, indicating the species undergoes an ontogenetic habitat shift during its lifespan, which is further underscored by the monthly mean size of fish captured on Saipan where the smallest individuals were captured in the shore-based fishery from the west aspect of Saipan with the majority being at or below the female LM_{50}. No specimens of *L. atkinsoni* landed in the NCSF were found in sampled catches from Rota or the Northern Islands, whereas the yearly mean sizes of specimens from Tinian and Aguijan exceeded LM_{50}. The results from the Saipan NCSF corresponded with those sampled landings from the 1990s scuba-spear fishery, which also trended to smaller fish being landed from the west aspect of Saipan, including the lagoon. It should be noted that boat-based fishing events target a different species composition than shore-based, typically aimed at larger members of the Scaridae and Nasinae (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018), generally found in deeper water environments, in order to economically afford such excursions. Thus, the lack of smaller *L. atkinsoni* from boat-based fishing efforts may be an issue related to species size, in addition to the probable extent of preferred juvenile habitat in the CNMI which may limit the abundance of adults with increasing distance from Saipan Lagoon.

One issue regarding the spatial distribution of this species is that it appears to be relatively uncommon in the Marianas outside of Saipan Lagoon, as considerable fisheries-independent survey effort only documented two individuals, both from reef slope habitats on Rota Island. This stands in stark contrast to the findings from Saipan from the Saipan NCSF where *L. atkinsoni* was one of the top 15 species landed by weight and number during the study period. The apparent inability to visually survey this species may be a natural behavioural characteristic or a result of fishing pressure, although landings data suggest the species is not a target outside of Saipan Lagoon.

4.3 | Management implications and recommendations

Data collected from the Saipan-based NCSF indicated that the majority of fishing efforts during the period of the study took place within Saipan Lagoon and overwhelmingly by shore-based effort, with the majority of individuals sampled being under the size of female maturity. This bias for immature fish in catches, together with the highly skewed sex ratio in sampled landings, suggests two possibilities regarding the status of *L. atkinsoni*. First, although estimated exploitation rates suggest the species is not being overexploited, the paucity of fisheries-independent observations, the large percentage of individuals sampled in the markets that were smaller than the estimated LM_{50}, and the skewed sex ratio indicate that the species may in fact be nearing, or at, some level of conservation concern. Although the lack of functional hermaphroditism and the overlap in the size distribution of males and females should insulate the species from sex-specific overharvest, females nonetheless dominated catch demographics. Second, it might simply be that the fishery overwhelmingly targets the younger portion of the population that is landed on Saipan through shore-based fishing in Saipan Lagoon, whereas the larger adults that have ontogenetically shifted to outer slope habitats are not preferred as boat-based fishing efforts target a different species composition than shore-based fishing (Trianni, Gourley, et al., 2018; Trianni, Tenorio, et al., 2018). This spatial targeting would explain the larger percentage of sampled fish under LM_{50} as well as the skewed sex ratio is given that females predominate in the smaller size classes. The impact of harvest on those smaller and younger fish might be detrimental to population recruitment, although given that larger fish are occasionally caught outside of Saipan Lagoon, as well as at Tinian and Aguijan, there would seem to be sufficient numbers of large females in those areas to ensure reproduction and population replenishment. Additionally, the rapid early growth rate indicated by the constrained VBGF model suggests resilience to observed levels of fishing effort. Estimated exploitation rates indicate a moderately exploited population, which further supports resiliency.

Despite considerable effort, the rarity of fisheries-independent observations cannot be de-emphasized, and coupled with the fact that the species appears to be relatively common in NCSF catches as immature fish presents an interesting conundrum in not only evaluating the status of *L. atkinsoni*, but understanding its ecological role in the broader coral reef ecosystem in the southern islands of the

CNMI. Future fishery-independent research on *L. atkinsoni* should be directed towards elucidating its diel and ontogenetic movement patterns and related ecological role in resource partitioning among lethrinids and other feeding guild members. A stock assessment is advised, but only after a more spatially comprehensive sampling design for fishery-dependent specimen collection, supplemented as necessary by a fishery-independent collection of additional small and very large specimens, has been implemented. We stress the need for expanded support to secure the necessary collections to better understand reproductive histology and population age structure in time and space.

AUTHOR CONTRIBUTIONS

Michael S. Trianni: Conceptualization, methodology, validation, software, project administration, formal analysis, investigation, data curation, writing – original draft, writing – review and editing; **Edward E. DeMartini and Brett M**. Taylor: Conceptualization, methodology, data curation, writing – original draft, writing – review and editing, validation, formal analysis

CONFLICT OF INTEREST
The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT
Data file included in supplementary information. Fisheries data available as referenced from public domain resources.

ETHICS STATEMENT
All animals were handled post-mortem from commercial fishing activity and processed following NOAA Pacific Islands Fisheries Science Center protocols.

ORCID
Michael S. Trianni https://orcid.org/0000-0003-4758-427X

REFERENCES
Andrews, A.H., Kalish, J.M., Newman, S.J. & Johnston, J.M. (2011) Bomb radiocarbon dating of three important reef–fish species using Indo–Pacific Δ14C chronologies. *Marine and Freshwater Research*, 62(11), 1259–1269 https://doi.org/10.1071/MF11080

Bentley, N. & Stokes, K. (2009) Contrasting paradigms for fisheries management decision making: how well do they serve data-poor fisheries? *Marine and Coastal Fisheries*, 1, 391–401. https://doi.org/10.1577/C08-044.1

Berkson, J., Barbieri, L., Cadrin, S., Cass-Calay, S.L., Crone, P., Dorn, M. et al. (2011) *Calculating* acceptable biological catch for stocks that have reliable catch data only (only reliable catch stocks – ORCS). NOAA Technical Memorandum NMFS-SEFSC-616, 56 P

Beverton, R.J.H. & Holt, S.J. (1957) *On the dynamics of exploited fish populations*. London: Chapman and Hall

Brown-Peterson, N.J., Wyanski, D.M., Saborido-Rey, F., Macewicz, B.J. & Lowerre-Barbieri, S.K. (2011) A standardized terminology for describing reproductive development in fishes. *Marine and Coastal Fisheries*, 3, 52–70. http://doi.org/10.1080/19425120.2011.555724

Carpenter, K.E. & Niem, V.H. (2001) *FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 5. Bony fishes part 3 (Menidae to Pomacentridae), estuarine crocodiles, sea turtles, sea snakes and marine mammals*. Rome: FAO Library

Chapman, D.G. & Robson, D.S. (1960) The analysis of a catch curve. *Biometrics*, 16, 354–368. https://doi.org/10.2307/2527687

Chen, Y., Jackson, D. A. & Harvey, H. H. (1992). A comparison of von Bertalanffy and polynomial functions in modelling fish growth data. *Canadian Journal of Fisheries and Aquatic Sciences*, 49, 1228–1235. https://doi.org/10.1139/f92-138

Choat, J.H. & Robertson, D.R. (2002) *Age-based studies. Coral reef fishes: dynamics and diversity in a complex ecosystem*. London: Academic Press, pp. 57–80

Chrysafi, A. & Kuparinen, A. (2015) Assessing abundance of populations with limited data: lessons learned from data-poor fisheries stock assessment. *Environmental Reviews*, 24, 25–38. https://doi.org/10.1139/er-2015-0044

Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center (2017a) *Pacific reef assessment and monitoring program: rapid ecological assessments of fish large-area Stationary Point Count Surveys (SPC) in the pacific ocean from 2000-09-09 to 2007-06-08 (NCEI Accession 0162466)*. [Indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://accession.nodc.noaa.gov/0162466 [Accessed 6/28/2019].

Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center (2017b) *Pacific reef assessment and monitoring program: Stratified Random Surveys (StRS) of reef fish, including benthic estimate data of the U.S. pacific reefs from 2008-01-27 to 2012-09-13 (NCEI Accession 0162472)*. [Indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://accession.nodc.noaa.gov/0162472 [Accessed 6/28/2019].

Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center (2017c) *Pacific Reef Assessment and Monitoring Program: rapid Ecological Assessments of Fish Belt Transect Surveys (BLT) in the Pacific Ocean from 2000-09-09 to 2009-05-05 (NCEI Accession 0162462)*. [Indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://accession.nodc.noaa.gov/0162462 [Accessed 6/28/2019].

Currey, L.M., Williams, A.J., Mapstone, B.D., Davies, C.R., Carlos, G., Welch, D.J. et al. (2013) Comparative biology of tropical *Lethrinus* species (Lethrinidae): challenges for multi-species management. *Journal of Fish Biology*, 82, 764–788. https://doi.org/10.1111/jfb.3495

DeMartini, E.E., Langston, R.C. & Eble, J.A. (2014) Spawning seasonality and body sizes at sexual maturity in the bluespine unicornfish, *Naso unicornis* (Acanthuridae). *Ichthyological Research*, 61, 243–251. https://doi.org/10.1007/s10228-014-0393-z

Dick, E.J. & MaCall, A.D. (2011) Depletion-based stock reduction analysis: a catch based method for determining sustainable yields for data-poor fish stocks. *Fisheries Research*, 110, 331–341. https://doi.org/10.1016/j.fishres.2011.05.007

Dowling, N.A., Dichmont, C.M., Haddon, M., Smith, D.C., Smith, A.D.M. & Sainsbury, K. (2015) Guidelines for developing formal harvest strategies for data-poor species and fisheries. *Fisheries Research*, 171, 130–140. https://doi.org/10.1016/j.fishres.2014.09.013

Dunn, A., Francis, R.I.C.C. & Doonan, I.J. (2002) Comparison of the Chapman-Robson and regression estimators of Z from catch-curve data when non-sampling stochastic error is present. *Fisheries Research*, 59, 149–159. https://doi.org/10.1016/S0165-7836(01)00407-6

Ebisawa, A. (1999) Reproductive and sexual characteristics in the Pacific yellowtail emperor, *Lethrinus atkinsoni*, in waters off the Ryukyu Islands. *Ichthyological Research*, 46, 41–358. https://doi.org/10.1007/BF02673977

Ebisawa, A. (2006) Reproductive and sexual characteristics in five *Lethrinus* species in waters off the Ryukyu Islands. *Ichthyological Research*, 53, 269–280. https://doi.org/10.1007/s10228-006-0345-3

Ebisawa, A. & Ozawa, T. (2009) Life-history traits of eight *Lethrinus* species from two local populations in waters off the Ryukyu Islands. *Fisheries Science*, 75, 553–566. https://doi.org/10.1007/s12562-009-0061-9

Graham, T. (1994) *Biological analysis of the nearshore reef fish fishery of Saipan and Tinian*. Commonwealth of the Northern Mariana Islands. Division of Fish and Wildlife Technical Report 94-02.

Grandcourt, E.M. (2002) Demographic characteristics of a selection of exploited reef fish from the Seychelles: preliminary study. *Marine and Freshwater Research*, 53, 123–130. https://doi.org/10.1071/MF0-1123

Grandcourt, E., Al Abdessalaam, T.Z., Francis, F. & Al Shamsi, A. (2010) Age-based life history parameters and status assessments of by-catch species (*Lethrinus borbonicus, Lethrinus microdon, Pomacanthus maculosus* and *Scolopsis taeniatus*) in the southern Arabian Gulf. *Journal of Applied Ichthyology*, 26, 381–389. https://doi.org/10.1111/j.1439-0426.2009.01380.x

Gulland, J.A. (1970) *The fish resources of the ocean*. FAO Fisheries Technical Paper No. 97. 453 p.

Gulland, J.A. (1971) Science and fishery management. *ICES Journal of Marine Science*, 33, 471–477. https://doi.org/10.1093/icesjms/33.3.471

Hoenig, J.M. (1983) Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin*, 82, 898–903.

Hordyk, A.R., Loneragan, N.R. & Prince, J.D. (2015) An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology. *Fisheries Research*, 171, 20–32. https://doi.org/10.1016/j.fishres.2014.12.018

Isermann, D.A. & Knight, C.T. (2005) A computer program for age–length keys incorporating age assignment to individual fish. *North American Journal of Fisheries Management*, 25, 1153–1160. https://doi.org/10.1577/M04-130.1

Johnson, A.E., Cinner, J.E., Hardt, M.J., Jacquet, J., McClanahan, T.R. & Sanchirico, J.N. (2013) Trends, current understanding and future research priorities for artisanal coral reef fisheries research. *Fish and Fisheries*, 14, 281–292. https://doi.org/10.1111/j.1467-2979.2012.00468.x

Johnston, L., Okano, R., Benavente, D., Johnson, S., Camacho, R., Houk, P. et al. (2015) *Commonwealth of the Northern Mariana Islands (CNMI) long-term coral reef monitoring from 2011-10-01 to 2014-09-30 (NCEI Accession 0129268)*. [Indicate subset used]. NOAA National Centers for Environmental Information. Dataset. https://accession.nodc.noaa.gov/0129268 [Accessed 4/6/2017]

Kittinger, J.N. (2013) Human dimensions of small-scale and traditional fisheries in the Asia-Pacific region. *Pacific Science*, 67, 315–325. https://doi.org/10.2984/67.3.1

Lowe, J.R., Russ, G.R., Bucol, A.A., Abesamis, R.A., Stockwell, B.L. & Choat, J.H. (2022) Patterns of biogeographic and regional life-history trait variation in four large-bodied tropical wrasses. *Marine Biology*, 169, 1–16.

McClanahan, T.R., Graham, N.A.J., MacNeil, M.A. & Cinner, J.E. (2015) Biomass-based targets and the management of multispecies coral reef fisheries. *Conservation Biology*, 29, 409–417. https://doi.org/10.1111/cobi.12430

Nadon, M.O. & Ault, J.S. (2016) A stepwise stochastic simulation approach to estimate life history parameters for data-poor fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 73, 1874–1884. https://doi.org/10.1139/cjfas-2015-0303

Nakamura, Y., Shibuno, T., Suzuki, N., Nakamori, J., Kanashiro, K. & Watanabe, Y. (2010) Interspecific variations in age and size at settlement of 8 emperor fishes (Lethrinidae) at the southern Ryukyu Islands, Japan. *Fisheries Science*, 76, 503–510. https://doi.org/10.1007/s12562-010-0225-7

Pilling, G.M., Apostolaki, P., Failler, P., Floros, C., Large, P.A., Morales-Nin, B. et al. (2009) Assessment and management of data-poor fisheries. *Advances in Fisheries Science*, 50, 280–305.

Robson, D.S. & Chapman, D.G. (1961) Catch curves and mortality rates. *Transactions of the American Fisheries Society*, 90, 181–189. https://doi.org/10.1577/1548-8659(1961)90[181:CCAMR]2.0.CO;2

Sadovy, Y.J. (1996) Reproduction of reef fishery species. In: *Reef fisheries*. Dordrecht: Springer, pp. 15–59.

Sadovy, Y. & Domeier, M.L. (2005) Perplexing problems of sexual patterns in the fish genus *Paralabrax* (Serranidae, Serraninae). *Journal of Zoology*, 267, 121–133. https://doi.org/10.1017/S0952836905007466

Sadovy de Mitcheson, Y., Liu, M., (2008) Functional hermaphroditism in teleosts. *Fish and Fisheries*, 9, 1–43. https://doi.org/10.1111/j.1467-2979.2007.00266.x

Sundberg, M., Humphreys, R., Lowe, M.K., Cruz, E., Gourley, J., Ochavillo, D. (2015) *Status of life history sampling conducted through the commercial fisheries bio-sampling programs in the Western Pacific Territories of American Samoa and Guam and in the Commonwealth of the Northern Mariana Islands.* NOAA, NMFS, PIFSC. Administrative Report H-2015. 56 p

Taylor, B.M. (2014) Drivers of protogynous sex change differ across spatial scales. *Proceedings of the Royal Society B: Biological Sciences*, 281, 20132423. https://doi.org/10.1098/rspb.2013.2423

Taylor, B.M. & McIlwain, J.L. (2010) Beyond abundance and biomass: effects of marine protected areas on the demography of a highly exploited reef fish. *Marine Ecology Progress Series*, 411, 243–258. https://doi.org/10.3354/meps08672

Taylor, B.M., Oyafuso, Z.S. & Trianni, M.S. (2017) Life history of the orange-striped emperor *Lethrinus obsoletus* from the Mariana Islands. *Ichthyological Research*, 64, 423–432. https://doi.org/10.1007/s10228-017-0573-8

Taylor, B.M., Brandl, S.J., Kapur, M., Robbins, W.D., Johnson, G., Huveneers, C. et al. (2018) Bottom-up processes mediated by social systems drive demographic traits of coral-reef fishes. *Ecology*, 99, 642–651. https://doi.org/10.1002/ecy.2127

Then, A.Y., Hoenig, J.M., Hall, N.G. & Hewitt, D.A. Handling editor: Ernesto J. (2015) Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, 72 82–92. https://doi.org/10.1093/icesjms/fsu136

Trianni, M.S. (2011) Biological characteristics of the spotcheek emperor, *Lethrinus rubrioperculatus*, in the Northern Mariana Islands. *Pacific Science*, 65, 345–363. https://doi.org/10.2984/65.3.345

Trianni, M.S., Gourley, J.E. & Ramon, M.S. (2018) Spatial, temporal, and biological characteristics of a nearshore coral reef fishery in the Northern Mariana Islands. *Marine and Coastal Fisheries*, 10, 283–297. https://doi.org/10.1002/mcf2.10024

Trianni, M.S., Tenorio, M.C., McKagan, S.C. & Dunn, W.O. (2018) Evaluation of a fishery resource response to a net-use restriction in Saipan Lagoon, Commonwealth of the Northern Mariana Islands. *Pacific Science*, 72, 291–307. https://doi.org/10.2984/72.3.1

Trip, E.L., Choat, J.H., Wilson, D.T. & Robertson, D.R. (2008) Inter-oceanic analysis of demographic variation in a widely distributed Indo-Pacific coral reef fish. *Marine Ecology Progress Series*, 373, 97–109. https://doi.org/10.3354/meps07755

Trianni, M.S. (2016). Life history characteristics and stock status of the thumbprint emperor (Lethrinus harak) in Saipan Lagoon. *Fishery Bulletin*, 114, 409–425.

Von Bertalanffy, L. (1938). A quantitative theory of organic growth (inquiries on growth laws. II). *Human biology*, 10, 181–213. https://www.jstor.org/stable/41447359

Young, P.C. & Martin, R.B. (1982) Evidence for protogynous hermaphroditism in some lethrinid fishes. *Journal of Fish Biology*, 21, 475–484. https://doi.org/10.1111/j.1095-8649.1982.tb02853.x

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.