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BRIEF COMMUNICATION

Growth and maturation of the redlip parrotfish *Scarus rubroviolaceus*

B. M. TAYLOR*†‡ AND C. PARDEE†‡

**Joint Institute for Marine and Atmospheric Research, University of Hawai'i, Honolulu, Hawai'i 96822 U.S.A. and †NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu, Hawai'I, 96818 U.S.A.*

Running headline: GROWTH AND MATURATION OF *S. RUBROVIOLACEUS*

‡Author to whom correspondence should be addressed. Tel.: +1 808 7255606; email: brett.taylor@noaa.gov

This study presents age-based life-history information for the red lip parrotfish *Scarus rubroviolaceus* based on a 5 year sampling programme from the commercial fishery of American Samoa. Females reached sexual maturity at 31.9 cm fork length (L_{F}) and 2.6 years and sex change occurred at 42.3 cm L_{F}, although not all females change sex through their ontogeny. The maximum observed age was 14 years and *c.* 65% of the fishery harvest was above the median L_{F} at sex change.

Key words: American Samoa; life history; maturation; otoliths; parrotfish; reproductive biology.

Parrotfishes (Labridae: tribe Scarinae) are a highly ubiquitous component of coral-reef faunal assemblages and bolster the functional diversity on reefs through processes of scraping and bio-eroding benthic substrata (Bellwood & Choat, 1990; Bellwood 1995*a*,*b*). They are also highly prevalent components of reef-associated commercial, artisanal and subsistence fisheries throughout the tropics, with the majority of species being actively targeted. Larger-bodied parrotfish species are particularly vulnerable to overexploitation (Jennings *et al.*, 1999; Hawkins & Roberts, 2003; Clua & Legendre, 2008; Mumby *et al.*; 2013 Taylor *et al.*, 2014), but a dearth of location-specific life-history information often hinders stock assessment of this group.

The redlip parrotfish *Scarus rubroviolaceus* Bleeker 1847 is a relatively large-bodied, dichromatic protogynous species that is broadly distributed from the Red Sea and eastern Africa across to the eastern Pacific Ocean (Fitzpatrick *et al.,* 2011). The species is common on fringing reefs characterized by high wave action (Taylor *et al.*, 2015) and represents a major food resource in many locations across its range. In the United States associated islands of the Pacific Ocean, *S. rubroviolaceus* is of prime importance to commercial fishers. It represents the highest landed scarid species by mass in Hawaii, the Commonwealth of the Northern Mariana Islands and American Samoa and is the third highest in Guam (Houk *et al.,* 2012; DeMartini & Howard, 2016; NOAA Commercial Fisheries Bio-Sampling Program, unpubl. data). Among these four locations, *S. rubroviolaceus* achieves the highest average density in American Samoa (CREP PIFSC, 2016), where the prevalence of low complexity fringing reef provides ideal habitat for the species across the Samoan Archipelago.

Preliminary estimates of growth and life span for *S. rubroviolaceus* from American Samoa were presented by Page (1998) to bolster regional management efforts. The present study expands on this work by deriving life-history information of value to fisheries management based on fishery-dependent collections spanning a 5 year period. In particular, estimates of growth, life span, length and age at female maturation and length at sex change are presented. The findings are discussed with regard to regional management of the species and variation in life-history trait values across bio-geographic regions based on comparison with other studies.

From October 2010 to September 2015, the coral-reef associated commercial fishery of Tutuila, American Samoa, was surveyed by Commercial Fisheries Bio-Sampling Program staff twice weekly (Sundberg *et al.,* 2015). During sampling times, all landed fishes were identified to the lowest taxonomic level, measured to the nearest 0.1 cm fork length (L_F) and weighed to the nearest g (total mass, M_T). The majority of the species and individuals targeted in American Samoa commercial markets come from night-time spear fishing. A sub-sample of the harvested *S. rubroviolaceus* was purchased opportunistically and later processed for life-history analysis. Opportunistic purchasing was performed using a random sampling design so that resultant length-frequency distributions reflected those of the fishery. From each purchased specimen, sagittal otolith pairs were extracted, cleaned and stored dry and gonads were extracted, macroscopically staged as male or female, weighed to the nearest 0.001 g (gonad mass, M_G) and stored in 10% buffered formalin solution.

Age was determined for specimens through interpretation of sectioned sagittal otoliths. One otolith from each pair was weighed to the nearest 0.0001 g and affixed to a glass slide using thermoplastic glue (Crystalbond 509, Aremco; www.aremco.com), with the primordium located just inside the edge of the slide and the sulcul ridge perpendicular to the slide edge. The otolith was ground to the slide edge using a 600 grit diamond lapping disc on a grinding wheel along the longitudinal axis. The otolith was then removed and re-affixed to a clean slide with the flat surface against the slide face and ground to produce a thin transverse section *c.* 200 µm thick, encompassing the core material. Finally, the exposed section was covered in thermoplastic glue to improve clarity of microstructures. Sections were examined twice and age in years was estimated by counting annuli (alternating translucent and opaque bands) along a consistent axis on the ventral side of the sulcul ridge, using transmitted light on a stereo microscope. When the two age estimates differed, a third blind read was conducted. Age in years was assigned when two age assignments agreed, which occurred for all specimens.

Sex-specific and combined growth patterns were modelled using the von Bertalanffy growth function (VBGF), represented by $L_t = L_\infty\,[1 - e^{-K(t-t_0)}]$, where L_t is the predicted L_F (cm) at age t (years), L_∞ is the mean asymptotic L_F, K is the coefficient used to describe the curvature of growth towards L_∞ and t_0 is the theoretical age at which L_F equals zero, as described by K. Fitted growth curves were constrained (y-intercept) to a common length at settlement taken as L_0 = 1.5 cm L_F (Bellwood & Choat, 1989).

Gonad material from specimens was histologically processed at the University of Hawaii School of Medicine to validate macroscopic sex assignments and determine stages of maturation.

Sections of gonad were embedded in paraffin wax, sectioned transversely at 6 μm and stained on microscope slides with haematoxylin and eosin. Histological preparations were viewed under compound and dissecting microscopes and the developmental stages were classified using the standardized terminology of Brown-Peterson *et al.* (2011).

Estimates of L_F and age at 50% female sexual maturity (L_{50} and t_{50}, respectively) and L_F at 50% sexual transition ($L\ _{50}$) from female to male were estimated based on histological features of gonad material. For L_{50}, proportional frequencies of immature and mature females across 2 cm size classes were fitted with a logistic curve: $p = \{1 + e[-\ln(19)\,(L - L_{50})(L_{95} - L_{50})^{-1}]\}^{-1}$, where p is the predicted proportion of mature females at a given length (L) and L_{50} and L_{95} are the L_F at 50% and 95% maturity, respectively. Curves were fitted by minimizing the binomial maximum likelihood and corresponding 95% C.L. for each parameter were derived by bootstrap resampling through 1000 iterations.

Spawning seasonality was investigated by plotting gonado-somatic index values [$I_G = M_G(M_T - M_G)^{-1}100$] of mature female specimens across the calendar year. I_G data from 2010 to 2015 were aggregated by calendar month as interannual sample numbers were too small to detect reproductive patterns. Potential peaks in mean I_G values were interpreted as increased reproductive activity. I_G values were also regressed against lunar day for all mature female data combined to examine patterns across the lunar month.

To examine geographic variability in age-based demography, estimates of life span (maximum age derived from otoliths of sampled specimens) and asymptotic L_F (L from VBGF constrained to *c.* 1.2 to 2.0 cm L_F *y*-intercept) were collated from American Samoa (present study), the northern Great Barrier Reef (Choat & Robertson, 2002; J. Choat, unpubl. data), Guam (Taylor & Choat, 2014), Hawaii (Howard, 2008; E. E. DeMartini, unpubl. data), Oman (Sabetian, 2010; J. Choat, unpubl. data), Seychelles (Grandcourt, 2002), Solomon Islands

(Sabetian, 2010), Taiwan (Sabetian, 2010; B. Taylor, unpubl. data) and Yap (B. Taylor, unpubl. data), spanning from 14.6° S to 22.6° N. Life span and asymptotic L_F were regressed against satellite-derived sea surface temperature (SST, °C) from each location (2004–2009 monthly average, Pathfinder database 5.2; https://www.nodc.noaa.gov/SatelliteData/pathfinder4km/) to examine responses of each variable across the range of SST.

In total, 4980 *S. rubroviolaceus* specimens were surveyed at the commercial market; 395 were purchased for life-history analysis and biological materials were extracted from 273. Of these 273, only 236 otolith pairs and 172 gonads were obtained for laboratory processing. Because of these discrepancies, true randomness in the catch could not be assumed and therefore age structure or mortality information are not presented from catch curves. Purchased specimens ranged from 17.9 to 54.5 cm L_F and 1 to 14 years of age. Males had a considerably greater mean L_F at age, whereas sampled females comprised the only individuals ($n = 3$) recorded above 7 years old (Fig. 1). The estimated L_∞ for females and males was 40.6 and 47.8 cm L_F, respectively, with a combined estimate of 42.7 cm L_F for the species in American Samoa. Female *S. rubroviolaceus* reached reproductive maturity at 31.9 cm L_F [L_{50}; Fig. 2(a)] and 2.6 years [t_{50}; Fig. 2(b)]. The species was found to change sex between *c.* 27 and 45 cm L_F, with a $L_{\ 50}$ estimate of 42.3 cm L_F [Fig. 2(c)]. A summary of growth, maturation and sex change model parameters with associated 95% C.L. is provided in Table I. The modal L_F class harvested by the American Samoa commercial fishery between 2010 and 2015 was 37 cm. In total, 65% of harvested individuals were above L_{50} and 15% were above $L_{\ 50}$ [Fig. 2(d)].

There was little evidence of strong seasonality in annual reproductive timing; however, I_G plots suggested that reproductive activity gradually increased in winter months and was lowest in summer months (Fig. 3). There was no relationship identified between lunar period and mean I_G value.

These results demonstrate that *S. rubroviolaceus* is a relatively longer-lived species compared with other parrotfishes and reaches its asymptotic length in *c.* 4–5 years. The maximum age of 14 years matches that previously reported by Page (1998) based on a limited fishery-independent sample from Tutuila. In the present study, only three individuals exceeded 7 years of age, probably reflecting truncation of ages as a result of fishery selection and pressure. Hence, actual life span of the species in American Samoa may be greater than represented. The species reached 50% female maturity at 75% of its estimated asymptotic L_F, which is similar to ratios from Hawaii (68%; Howard, 2008; DeMartini & Howard, 2016) and Guam (72%; Taylor & Choat, 2014) for the same species.

The parameter values and confidence regions presented here have direct utility to stock assessment. Because final sample distribution from market sampling for life-history analysis was non-random, resultant age-frequency distributions did not reflect those of the fishery. Hence, reliable estimates of age-based mortality were not derived. The sampling programme, however, did derive five consecutive years of high-resolution length-frequency data that were representative of the commercial fishery market, thus providing a robust framework that could be applied through length-based assessment models to calculate spawner potential ratio (Nadon *et al.* 2015; Prince *et al.*, 2015). Coupling the 2010–2015 data with similar market surveys conducted by Page (1998) in 1997–1998, suggests that both the mean and modal L_F of harvested *S. rubroviolaceus* has gradually decreased across the near-two decade period, although not at the level observed in Guam, where the estimated annual decline in mean L_F for *S. rubroviolaceus* was 3.4 times greater in magnitude (Taylor *et al.*, 2014). This decrease was not reflected in comparison with proportional harvest frequencies between the two time periods where *S. rubroviolaceus* has consistently represented *c.* 20% of the parrotfish harvest. This is surprising given that the 1990s surveys were dominated by scuba spear-caught individuals, a method that has since been banned (Green, 2003). Any sustained decline in mean length of a harvested species, however, warrants further investigation to ensure long-term sustainability (Jeffrey *et al.*, 2017).

Despite five consecutive years of market sampling, little resolution was achieved to determine annual patterns of spawning periodicity. An increase in mean I_G values during winter months (peak, July–August) suggests that reproductive activity may increase during this period, but it is clear that no stark peaks in reproduction occur temporally for this species. DeMartini & Howard (2016) demonstrated a pronounced peak in I_G values for the same species during late winter in Hawaii, where temporally distinct patterns of reproduction would be more likely with increased seasonality at greater latitude (Conover, 1992). Most scarines have prolonged spawning seasons with reproductive events co-ordinated with outgoing tidal currents, but little else is known regarding reproductive cycles of *S. rubroviolaceus* (Colin & Bell, 1991).

Although few detailed assessments of age-based demography have been published for *S. rubroviolaceus*, length-at-age estimates have been derived from across a wide geographic range. Existing data across nine distinct locations demonstrate considerable physiological responses in age-based demography to SST (Fig. 4). Estimates of both maximum observed age and asymptotic L_F decreased with increasing SST, which conforms to metabolic theory in ectotherms across temperature gradients (Robertson *et al.*, 2005; Trip *et al.*, 2014). This relationship was significant (linear regression model, $R^2 = 0.47$, $F_{1,8} = 6.14$, $P < 0.05$) for asymptotic length, but not for maximum age ($R^2 = 0.31$, $F_{1,8} = 3.13$, $P > 0.05$). Variability in observed maximum age from the expected is probably influenced by inconstant fishing pressure among locations and potentially insufficient sample sizes for estimating life span at some locations. Size-selective fishing pressure has a direct influence on observed (but not metabolic) lifespan in populations and locations that are heavily fished or under-sampled increase the likelihood of underestimating life span. Asymptotic L_F is more robust to these issues, but is also heavily influenced in marine fishes by ocean productivity, which facilitates resource quantity and quality. For instance, the location with the largest positive residual (*i.e.* larger than predicted based on regression with SST) in Fig. 4(b) was the sample from Oman, where seasonal monsoon upwelling generates ocean productivity values (Savidge *et al.*, 1990; measured as chlorophyll-*a* concentration) in the range of nine to 50 times higher than other locations presented here (data satellite-derived from the Aqua MODIS data base; https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA). Compared with length-at-age information, much fewer data exist regarding the reproductive biology of *S. rubroviolaceus* from across its range. Similar variability in schedules of maturation and sex change, however, can be expected as those seen for length-at-age and life span because life-history traits are physiologically linked (de Magalhães *et al.,* 2007).

In summary, this study provided a robust demographic baseline for informing management of the most highly targeted parrotfish species in American Samoa and identified signs of decreasing L_F over time in the fishery harvest. Further, it demonstrated that life-history traits vary widely across the geographic range of *S. rubroviolaceus* in relation to SST and potentially ocean productivity, a trend increasingly recognized for marine ectotherms. As a large-bodied and heavily targeted species throughout much of its range, further demographic research is warranted to tease apart the influence of environmental and anthropogenic factors on life span, body size and schedules of maturation.

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References

Bellwood, D. R. (1995*a*). Direct estimate of bio-erosion by two parrotfish species, *Chlorurus gibbus* and *C. sordidus*, on the Great Barrier Reef, Australia. *Marine Biology* **121**, 419–429. doi:10.1007/BF00349451

Bellwood, D. R. (1995*b*). Carbonate transport and within-reef patterns of bio-erosion and sediment release by parrotfishes (family Scaridae) on the Great Barrier Reef. *Marine Ecology Progress Series* **117**, 127–136.

Bellwood, D. R. & Choat, J. H. (1989). A description of the juvenile phase colour patterns of 24 parrotfish species (family Scaridae) from the Great Barrier Reef, Australia. *Records of the Australian Museum* **41,** 1–41.

Bellwood, D. R. & Choat, J. H. (1990). A functional analysis of grazing in parrotfishes (family Scaridae): the ecological implications. *Environmental Biology of Fishes* **28,** 189–214. doi:10.1007/BF00751035

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. doi:10.1080/19425120.2011.555724

Choat, J. H. & Robertson, D. R. (2002). Age-based studies. In *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem* (Sale, P. F., ed.), pp. 57–80. San Diego, CA: Academic Press.

Clua, E. & Legendre, P. (2008). Shifting dominance among scarid species on reefs representing a gradient of fishing pressure. *Aquatic Living Resources* **21,** 339–348. doi:10.1051/alr:2008036

Colin, P. L. & Bell, L. J. (1991). Aspects of the spawning of labrid and scarid fishes (Pisces:Labroidei) at Enewetak Atoll, Marshall Islands with notes on other families. *Environmental Biology of Fishes* **31**, 229–260. doi: 10.1007/BF00000690

Conover, D. O. (1992). Seasonality and the scheduling of life history at different latitudes. *Journal of Fish Biology* **41**, 161–178. doi:10.1111/j.1095-8649.1992.tb03876.x

de Magalhães, J. P., Costa, J. & Church, G. M. (2007). An analysis of the relationship between metabolism, developmental schedules and longevity using phylogenetic independent contrasts. *Journal of Gerontology: Biological Sciences A* **62**, 149–160. doi:10.1093/Gerona/62.2.149

DeMartini, E. E. & Howard, K. G. (2016). Comparisons of body sizes at sexual maturity and at sex change in the parrotfishes of Hawaii: input needed for management regulations and stock assessments. *Journal of Fish Biology* **88**, 523–541. doi:10.1111/jfb.12831

Fitzpatrick, J. M., Carlon, D. B., Lippe, C. & Robertson, D. R. (2011). The West Pacific diversity hotspot as a source or sink for new species? Population genetic insights from the Indo-Pacific parrotfish *Scarus rubroviolaceus*. *Molecular Ecology* **20**, 219–234. doi:10.1111/j.1365-294X.2010.04942.x

Grandcourt, E. (2002). Demographic characteristics of a selection of exploited reef fish from the Seychelles: preliminary study. *Marine and Freshwater Research* **53,** 122–130. doi:10.1071/MF01123

Green, A. (2003). American Samoa bans destructive scuba fishery: The role of monitoring in management. In *Monitoring Coral Reef Marine Protected Areas* (Wilkinson, C., Green, A., Almany, J. & Dionne, S., eds), pp. 38–39. Townsville: Australian Institute of Marine Science and the IUCN Marine Programme.

Hawkins, J. P. & Roberts, C. M. (2003). Effects of fishing on sex-changing Caribbean parrotfishes. *Biological Conservation* **115,** 213–226. doi:10.1016/S0006-3207(03)00119-8

Houk, P., Rhodes, K., Cuetos-Bueno, J., Lindfield, S., Fread, V. & McIlwain, J. L. (2012). Commercial coral-reef fisheries across Micronesia: a need for improving management. *Coral Reefs* **31,** 13–26. doi:10.1007/s00338-011-0826-3

Howard, K. (2008). Community structure, life history and movement patterns of parrotfishes: large protogynous fishery species. PhD Thesis. University of Hawaii, Honolulu, HI, U.S.A.

Jeffrey, K. M., Coté, I. M., Irvine, J. R. & Reynolds, J. D. (2017). Changes in body size of Canadian Pacific salmon over six decades. *Canadian Journal of Fisheries and Aquatic Sciences* **74**, 191–201. doi:10.1139/cjfas-2015-0600

Jennings, S., Reynolds, J. D. & Polunin, N. V. C. (1999). Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conservation Biology* **13,** 1466–1475. doi:10.1046/j.1523-1739.1999.98324.x

Mumby, P. J., Bejarano, S., Golbuu, Y., Steneck, R. S., Arnold, S. N., Woesik, R. & Friedlander, A. M. (2013). Empirical relationships among resilience indicators on Micronesian reefs. *Coral Reefs* **32**, 213–226. doi:10.1007/s00338-012-0966-0

Nadon, M. O., Ault, J. S., Williams, I. D., Smith, S. G. & DiNardo, G. T. (2015). Length-based assessment of coral reef fish populations in the Main and Northwestern Hawaiian Islands. *PLoS ONE* **10**, e0133960. doi:10.1371/journal.pone.0133960

Prince, J., Victor, S., Klouchad, V. & Hordyk, A. (2015). Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. *Fisheries Research* **171**, 42–58. doi:10.1016/j.fishres.2015.06.008

Robertson, D. R., Ackerman, J. L., Choat, J. H., Posada, J. M. & Pitt, J. (2005). Ocean surgeonfish *Acanthurus bahianus*. I. The geography of demography. *Marine Ecology Progress Series* **295**, 229–244. doi:10.3354/meps295229

Sabetian, A. (2010). Parrotfish fisheries and population dynamics: a case-study from Solomon Islands. PhD Thesis. James Cook University, Townsville, QLD, Australia.

Savidge, G., Lennon, J. & Matthews, J. (1990). A shore-based survey of upwelling along the coast of the Dhofar region, southern Oman. *Continental Shelf Research* **10**, 259–275. doi:10.1016/0278-4343(90)90022-E

Taylor, B. M. & Choat, J. H. (2014). Comparative demography of commercially important parrotfish species from Micronesia. *Journal of Fish Biology* **84**, 383–402. doi:10.1111/jfb.12294

Taylor, B. M., Houk, P. H., Russ, G. R. & Choat, J. H. (2014). Life histories predict vulnerability to overexploitation in parrotfishes. *Coral Reefs* **33**, 869–878. doi:10.1007/s00338-014-1187-5

Taylor, B. M., Lindfield, S. J. & Choat, J. H. (2015). Hierarchical and scale-dependent effects of fishing pressure and environment on the structure and size distributions of parrotfish communities. *Ecography* **38**, 520–530. doi:10.1111/ecog.01093

Trip, E. D. L., Clements, K. D., Raubenheimer, D. & Choat J. H. (2014). Temperature-related variation in growth rate, size, maturation and life span in a marine herbivorous fish over a latitudinal gradient. *Journal of Animal Ecology* **83**, 866–875. doi:10.1111/1365-2656.12183

Electronic references

CREP PIFSC (2016). National coral reef monitoring program: stratified random surveys (strs) of reef fish, including benthic estimate data of the U.S. Pacific reefs since 2007. Coral Reef Ecosystem Program; Pacific Islands Fisheries Science Center. NOAA National Centers for Environmental Information. Unpublished Dataset. Available at, https://inport.nmfs.noaa.gov/inport/item/24447 (last accessed 28-09-2016).

Page, M. (1998). The biology, community structure, growth and artisanal catch of parrotfishes of American Samoa. Department of Marine & Wildlife Resources, American Samoa. Available at: www.botany.hawaii.edu/basch/uhnpscesu/pdfs/sam/Page1998parrotfishesAS.pdf

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. Pacific Islands Fisheries Science Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96818-5007. PIFSC Administrative Report H-15-08. doi: 10.7289/V5XD0ZP5. Available at https://pifsc-www.irc.noaa.gov/library/pubs/admin/PIFSC_Admin_Rep_15-08.pdf