Age-Based Life History of the Mariana Islands' Deep-Water Snapper, *Pristipomoides filamentosus*

BY

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Abstract

The deep-water snapper *Pristipomoides filamentosus* is a commercially important bottomfish in the Mariana Islands and is a significant component of annual bottomfish catches from the Marianas. However, life-history parameters that inform management of this species are poorly resolved and unvalidated for populations of *P. filamentosus* in the Mariana Islands. I investigated the life-history of *P. filamentosus* from the Mariana Islands, commonly known as opakapaka and buninas, and applied bomb-radiocarbon (^{14}C) dating to validate traditional age estimates for this species. I determined the sex of male and female opakapaka histologically and used logistic regression analysis to investigate differences in length- and age-at-maturity between the sexes. The age of individual fish were estimated from counts of annuli from transverse sections of sagittal otoliths. I used a series of ^{14}C-validated otoliths to corroborate visual estimates of age from otoliths collected from the Mariana Islands. The von Bertalanffy growth function was used to investigate the functional relationship of age and length between male and female opakapaka and to explore regional differences from the northern and southern Mariana Islands. I also investigated the utility of otolith mass and otolith thickness for predicting ages using regression analyses. Length and age at maturity for males and females were estimated at 29.3 cm FL at 2.8 years and 41.2 cm FL at 5.0 years, respectively. Maximum visually estimated and validated age for this species in the Mariana Islands is 31 years and 25 years, respectively. Growth parameters between males and females did not differ significantly. However, growth parameters between fish from the northern and southern islands were significantly different. Estimates of fish age derived from counts of otolith annuli agreed with ^{14}C-validated ages otoliths, suggesting that visual methods are adequate for age estimation of opakapaka. Otolith mass and thickness were reliable predictors of age. Otolith mass differed between the sexes, but otolith thickness was not significantly different between males and females. This study finds that opakapaka from the Marianas have slow growth and long life spans. These results are comparable to results from other life-history studies of opakapaka in the Pacific. The information from this study can be readily used by fisheries management agencies to effectively manage this species when warranted.

Keywords: *Lutjanidae; Mariana Islands; bomb radiocarbon; otolith; age; life history; length-at-maturity; age-at-maturity; snapper*

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INTRODUCTION

Marine fisheries in the Pacific Island nations have strong social, cultural, and economic significance for the people of those islands (Board and National Research Council, 1999). Prior to western contact, fisheries provided much of the protein for those island communities (Amesbury et al., 1986; Amesbury, 2008). Even today, many of the people in the Pacific Islands rely on fishes as an important part of their diet (Needham and Funge-Smith, 2014).

The most common fisheries in the western Pacific are pelagic, coral-reef, and bottomfish fisheries (Gillett, 2011). Archeological evidence indicates that pelagic and coral-reef fisheries were important resources for prehistoric human populations of the Western Pacific. In contrast, deep-water bottomfish fishing is a new fishery especially in the Mariana Islands (Ikehara et al., 1970; Amesbury and Hunter-Anderson, 2008). Deep-water bottomfish fishing was introduced to the Mariana Islands in the 1960s in an attempt to expand fisheries to depths greater than 100 meters and to alleviate fishing pressure on shallow-water fisheries (Crossland and Grandperrin, 1980; Roberts, 2002; Stone, 2006). Although deep-water bottomfish fishing is a relatively new practice in the Marianas, it has become a very important fishery.

While commercial bottomfish landings in Guam have steadily increased since the mid-1980s, it wasn't until the mid-1990s when the fishery grew rapidly in the Commonwealth of the Northern Mariana Islands (CNMI) (Lowe et al., 2016). In the Marianas, approximately 79% of Guam-based fishermen (n = 139) and 91% of CNMI-based fishermen (n = 112) consider bottomfish as an important food source for their family (Hospital and Beavers, 2012, 2014). Historically, the bottomfish fishery has consisted of several species of groupers (Epinephelidae), jacks (Carangidae), emperors (Lethrinidae), and snappers (Lutjanidae), which occupy deep-water habitats between 100 m and 400 m (Amesbury et al., 1986; Ralston, 1988; Weng, 2013). For management purposes, the bottomfish fishery is divided into a shallow-water (<160 m) and a deep-water fishery (>160 m) (Yau et al., 2016).

The Western Pacific Fisheries Information Network (WPacFIN), in collaboration with Guam and CNMI fisheries managers, has been monitoring commercial fish landings since the 1980s (Houk et al., 2012). From 1982 to 2015, an annual average of 23.4 metric tons of bottomfish were landed in Guam and the CNMI (WPacFIN, 2017). Based on available data from WPacFIN from 1980 to 2018, deep-water groupers, jacks, and emperors comprise only a small portion of total landings when compared to deep-water snappers, which were ~25% and ~75% of the average estimated commercial weight sold in Guam and the CNMI, respectively. The main contributors to deep-water bottomfish landings in the Marianas are the snappers from the genera *Aphareus, Etelis,* and *Pristipomoides* (Amesbury et al., 1986; Newman et al., 2016). Deep-water snappers include large-bodied species that can attain lengths >90 cm, and are considered to be commercially valuable fishes (Ellis and DeMartini, 1995; Moffitt and Parrish, 1996; Fry et al., 2006; Oyafuso et al., 2017). However, many of these deep-water fishes are long-lived, have slow growth rates, and are slow to reach sexual maturity, making them potentially susceptible to overfishing (Haight et al., 1993; Cailliet and Andrews, 2008). To ensure the sustainability and successful management of this deep-water fishery, it is critical for fishery scientists to understand the entire life history of target species, including the lengths and ages at sexual maturity, the growth rates, and longevity.

Taxonomy and General Biology of Regional Deep-water Snappers

Deep-water snappers belong to the sub-family Etelinae, which consists of 5 genera and 20 species. *Aphareus furca* and *A. rutilans* are the only 2 species in this genus, while *Aprion virescens* and *Randallichthys filamentosus* are the lone species in these genera. *Etelis* is comprised of 5 species: *E. carbunculus, E. coruscans, E. oculatus, E. radiosus,* and *Etelis* sp. (a recently discovered and as yet undescribed species, K. R. Andrews et al., 2016). *Pristipomoides* is comprised of 11 species: *P. aquilonaris, P. argyrogrammicus, P. auricilla, P. filamentosus, P. flavipinnis, P. freemani, P. macrophthalmus, P. multidens, P. seiboldii, P. typus,* and *P. zonatus*. The eteline snappers are widely distributed within the Indo-Pacific; however, species richness declines with increasing distance from this region (Moffit, 1993). *Etelis oculatus, P. aquillonaris, P. freemani,* and *P. macrophthalmus* are currently only found coastally in the western Atlantic (Allen, 1985; Froese and Pauly, 2017). All Indo-Pacific eteline snappers have been recorded from the Marianas. Although rare to the fishery, *E. radiosus* and *R. filamentosus* have documented occurences in the Mariana Islands (Anderson and Allen, 2001; CNMI Division of Fish and Wildlife, 2014). The two most abundant snappers in the Marianas, based upon catch records, are *P. zonatus* and *P. auricilla* (Ralston and Williams, 1988).

Deep-water snappers are gonochoristic and iteroparous fishes, (i.e., they have separate sexes and spawn multiple times during their lifetime) (Martinez-Andrade, 2003). Most species spawn pelagically, and after fertilization, the larvae remain as pelagic, mid-water fishes until they reach ~6 cm (Leis and Lee, 1994). During their juvenile phase, deep-water snappers can be found at shallower depths and lower-relief habitats compared to larger congeners (DeMartini and Lau, 1999). Generally, adult deep-water snappers inhabit raised, ridge-like structures, which serve as predator refugia, and can be found in depths greater than 360 meters (Oyafuso et al., 2017). Despite similar life histories, the ecology and diet of deep-water snappers differ among taxa. Haight et al. (1993) reported that *Etelis carbunculus, E. coruscans,* and *Aprion virescens* are primarily piscivorous fishes, whereas *Pristipomoides filamentosus* and *P. sieboldii* feed on zooplankton (primarily salps). Information on predators of deep-water snappers is sparse; however, Anderson (1981) did find a juvenile *Etelis* sp. in the stomach of an indidivial *Euthynnus* sp. Predation by much larger demersal fishes is also likely. Gobert et al. (2005) reported a juvenile *E. oculatus* (8.5 cm TL), a Caribbean congener, in the stomach of a large beryciform fish caught at >200 m depth.

Information on the longevity of deep-water snappers is lacking for many species from the Mariana Islands. Much of what is known about the longevity of these fishes is based upon studies from other areas of the Pacific. In Australia, Newman and Dunk (2003) determined that the longevity of female and male *P. multidens* was similar at 27 and 30 years, respectively. Andrews et al. (2011a) estimated that *E. carbunculus* live at least 35 to 39 years, using otolith growth zone counting and age validated using bomb radiocarbon dating. Ralston and Williams (1988) estimated the early growth of several eteline snappers by extrapolating increment widths of daily growth increments of the otoliths. However, Ralston and Miyamoto (1983) suggested that extrapolating increment widths results in underestimates of the true age when applied to larger fish or fish with otoliths >6 mm. In the Mariana Islands, there are currently no data that conclusively establish the longevity of *P. filamentosus.*

Visual Estimates of Fish Age Using Otoliths

Accurate estimates of age are essential for understanding fish life history (Everhart and Youngs, 1981). The most widely used method to estimate the age of a fish is to count the growth rings of an otolith. Otoliths, or ear-stones, are calcified structures within the skull of a fish that are used to maintain their orientation and equilibrium in the water (Helfman et al., 2009). In teleost fishes, 3 pairs of otoliths are found in the otic capsule on either side of the head. Although the sizes of otoliths differ from species to species, the lapilli and the asterisci are most often the smallest pairs of the three. The largest and the most frequently used for determining an individual's age are the sagittae (Helfman et al., 2009). Otoliths may consist of different polymorphs of calcium carbonate ($CaCO_3$), such as calcite and vaterite, but are typically aragonite in teleost fishes (Campana, 1999). The carbonate layers are deposited daily, and are often used for determining the earliest growth of fishes. However, annual growth zones are also commonly observed and are used to estimate the age of fishes throughout their ontogeny. The use of otoliths to estimate fish age was first reported in Reibisch (1899), who investigated annual growth of European plaice (*Pleuronectes plessa*). Since then, otoliths have emerged as a standard method to estimate age among a variety of stocks (Jackson, 2007).

Growth zones are characterized as having a sequence of broad, translucent bands and narrow, opaque bands. Opaque bands are believed to be associated with slow growth, while translucent bands are associated with periods of rapid growth (Fowler, 2009). This banding pattern is seasonal and is closely related to sea-surface temperatures (Newman and Dunk, 2003). However, the exact timing of when the translucent bands and the opaque bands are laid down is complicated by environmental factors, such as temperature, and endogenous factors, such as reproduction (Fowler, 2009).

Traditional Approaches to Validating Fish Age

Estimates of fish age based upon counts of otolith annuli should be validated using independent methods of age determination for an accurate assessment of a fish's life history. There are a number of different approaches to validating the age of a fish. Mark-recapture of fish can establish specific dates in an individual's life by capturing a fish, measuring it in some manner (e.g., length and weight), tagging a fish using an external tag or a chemical tag such as oxytetracycline (OTC), releasing the fish for a specific time period, and then recapturing the fish to age. Oxytetracycline marking leaves a fluorescent mark in the otolith structure that can be viewed using fluorescence microscopy. Oxytetracycline is often used in hatcheries to mark freshwater fishes when they are very young juveniles, but has been proven to be applicable to older, marine fishes as well. For example, oxytetracycline marking was successfully administered during the fourth and fifth years of age for the Ballan Wrasse *Labrus bergylta* (Villegas-Ríos et al. 2013). Mark-recapture methods may be used to validate estimates of annual growth. However, the low number of recaptured marked fish in the wild may limit the method. Also, otolith increments in reared fish seldom resemble fish caught in the wild and it is often an unvalidated assumption that the age of a young fish is known, which can lead to over- or underestimation of age when the method is applied to an older fish at capture (Campana, 2001).

Radiochemical dating, which is based on the radioactive decay of naturally occurring isotopes incorporated into otoliths, is another valuable age-validation tool (Campana, 2001). Lead-radium dating, for example, is a technique that analyzes the decay of radium-226 (^{226}Ra) to lead-210 (^{210}Pb) in otoliths (Andrews et al., 1999a). Improvements to this method have been made to reduce the uncertainty of age estimates by directly measuring radium using thermal ionization mass spectrometry (TIMS) and ion-exchange, separation techniques (Andrews et al., 1999b). Because of variable radium uptake in the otolith structure and the relatively large mass of otolith material that was initially necessary, the early lead-radium dating method provided only rough estimates of fish age (Andrews et al., 2009). With newer methods that allow for much smaller samples of carbonate and coring of only a limited number of rings, the variability of radium uptake in the otolith structure became negligible and radiometric age determination became more accurate (Andrews et al., 1999b). Therefore, the information provided by this method can serve to validate annual growth of ring counts or can be used to provide age estimates when no other method is found to be reliable or available (Andrews et al., 2009; Andrews et al., 2012).

Validating Fish Age Using Bomb-radiocarbon Dating

A more recent approach to radiochemical dating relies on a conserved record of the rapid increase of bomb-produced radiocarbon (^{14}C) resulting from atmospheric thermonuclear tests in the latter half of the 20th Century (Broeker and Peng, 1982; Kalish, 1993; Campana, 1999; Andrews et al., 2011). The massive increase of neutrons in these explosions interacts with atmospheric nitrogen (^{14}N) to produce ^{14}C (Libby, 1946, 1955).

Although radiocarbon is also formed through natural processes in the upper atmosphere, the levels of atmospheric ^{14}C formed during the peak period of surface and atmospheric thermonuclear testing doubled naturally occurring levels (Broeker and Peng, 1982). Because atmospheric ^{14}C diffuses into seawater via air-sea gas exchange, radiocarbon is available for uptake by marine organisms and can be incorporated into skeletal carbonate (Broeker and Peng, 1982). The formation of the ^{14}C signal in the marine environment is also attributed to the direct injection of ^{14}C in seawater by the vaporization of coral material in the nuclear fireball at the nuclear testing grounds (close-in fallout; A. H. Andrews et al., 2016a,c). The world's largest reserves of radiocarbon are found in the marine environment in the form of carbonates and bicarbonates incorporated into the skeletons of marine organisms; this absorption from sea water establishes a radiocarbon record in these marine organisms, such as corals (Broeker and Peng, 1982). Many coral species and some sclerosponges exhibit distinct patterns of annual growth, a feature that has made them attractive for evaluating temporal changes in radioisotopes in the environment (Druffel and Linick, 1978; Druffel, 2002; Grottoli et al., 2010). Corals such as *Porites lutea* provide fine-scale resolution of ^{14}C levels because annual growth is easily identifiable as bands of differing density using radiographic X-ray techniques on coral cores (Mitsuguchi et al., 2004; A. H. Andrews et al., 2016a). Samples of ^{14}C samples from corals are carefully extracted at and within each growth band to produce a bomb-radiocarbon time series (e.g., A. H. Andrews et al., 2016a; Fig. 1). The accuracy of the bomb radiocarbon time series and the annual growth bands of the coral skeleton are independently validated using strontium/calcium ratios (Sr/Ca) or oxygen isotopic composition ($\delta^{18}O$) measurements, both of which are proxies for ocean temperature that is correlated to annual changes in water temperature (Beck et al., 1992; Asami et al., 2004, 2005). Using known radiocarbon measurements from age-validated corals, the bomb-radiocarbon dating method can then be successfully applied to establish specific dates within fish otoliths because the source of the carbon for the otolith is the same as for the coral, via dissolved inorganic carbon in the sea water (DIC; Campana 1999).

The bomb-radiocarbon dating method has been applied to temperate, pelagic, and coral-reef species, such as the Silver Seabream (*Pagrus auratus*), Blue Marlin (*Makaira nigricans*), and the Bluespine Unicornfish (*Naso unicornis*) (Kalish 1993; A. H. Andrews et al., 2016b, Andrews et al., 2018a). Kalish (1993) was the first to apply radiocarbon measurements from otolith cores to validate the ages of fish by aligning the ^{14}C measurements of otoliths detected in the first year of growth and the ^{14}C measurements of age-validated coral skeletons. This independent method has been successfully applied in fisheries science to test the accuracy of fish ages estimated by growth zone counting. Bluespine Unicornfish (*Naso unicornis*), for example, was accurately shown to live more than 50 years using the bomb-radiocarbon dating method; however, age estimates from growth zone counting were imprecise for the oldest fishes (A. H. Andrews et al., 2016b). This kind of finding is common in that the alignment of measured ^{14}C values to the reference material (coral) can often reveal inconsistencies in age estimates, leading to refinement of the age reading protocol.

Pristipomoides filamentosus

A wealth of biological information for *Pristipomoides filamentosus* exists; however, synthesis and validation of life-history information for *P. filamentosus* in the

Mariana Islands is lacking with regard to reproduction, age and growth, and longevity. The Pink Snapper, *Pristipomoides filamentosus*, also known as buninas, pink opakapaka, or opakapaka in the Mariana Islands, is widely distributed throughout the Indo-Pacific region from Japan to the Great Barrier Reef and the Seychelles to the Hawaiian Islands (Randall et al., 1997). *Pristipomoides filamentosus* is the largest species in the genus, reaching lengths >750 mm (Parrish, 1987). In the Hawaiian Islands, opakapaka has historically made up the greatest proportion of the deep-water fishery complex with an average of 67% of the total annual catch by weight during 1949–2015 (Langseth et al., 2018). It is equally important in the Seychelles, comprising 50% of the total commercial catch for the bottomfish fishery (Hardman-Mountford et al., 1997). In the Mariana Islands, opakapaka is not as commonly caught as in to other regions, but it is harvested as part of a larger deep-water complex. In Guam and the CNMI, opakapaka ranked third at approximately 12% and 13%, respectively, of the deep bottomfish management unit species landings (Fig. 2).

Because of its economic importance in the Pacific, an examination of the life history of opakapaka in the Marianas is needed. The few age-based studies that have been conducted for this species have focused on stocks in the Hawaiian Islands (e.g. Ralston and Miyamoto, 1983; Radtke, 1987; Andrews et al., 2012) and the Seychelles (e.g., Hardman-Mountford et al., 1997). Applying information from one region to another is potentially problematic because of the variability of life-history traits, geography, or the environments of conspecifics (e.g., Ruttenberg et al., 2005; Andrews et al., 2012; Taylor and Choat, 2014). In Hawaii, *Etelis carbunculus* and *Pristipomoides sieboldii* reach median maturity at an estimated 27.9 cm FL and 29.0 cm FL, respectively (DeMartini and Lau 1999). When comparing species between regions, DeMartini (2017) found differences in sexual maturation of ehu (*Etelis carbunculus*) and kalekale (*Pristipomoides sieboldii*) in the Main Hawaiian Islands (MHI) versus the Northwestern Hawaiian Islands (NWHI). The median length at maturity for ehu and kalekale was 4 cm and 5 cm smaller for these species, respectively, in the MHI than in the NWHI (DeMartini, 2017). Because ehu and kalekale have a long history of exploitation in both the NWHI and the MHI, extraction may have affected size and age distributions; however, maturation rates may be related to oceanographic differences between the NWHI versus the MHI (i.e., temperature and productivity) (DeMartini, 2017). The distances involved from the MHI to the NWHI are much less than from the Hawaiian Islands to the Marianas, so one might therefore expect that oceanographic differences might also result in differences in the life-history parameters between *P. filamentosus* populations from the Hawaiian Islands and the Marianas. In Australia, Newman and Dunk (2003) found *Pristipomoides multidens* males to be significantly larger than females when comparing their mass-at-length, but found no differences in length-at-age between the sexes or their growth parameters. Similarly, Nanami (2011) found males of *P. argyrogrammicus* males in Okinawa to be significantly larger than females. However, the median length at maturity for *P. argyrogrammicus* could not be determined because the smallest and largest females (17.7 cm to 27.8 cm, respectively) sampled had developed oocytes (Nanami, 2011).

As an example of the geographic variation in age and length of opakapaka between Hawaii and the Marianas, Andrews et al. (2012) estimated the age of a 51 cm opakapaka in the Hawaiian Islands to be ~28 years old. However, in the Marianas, a fish of approximately the same length was estimated to be ~20 years old (Andrews et al., 2012). Although this estimate was based on a very limited sample size from the Marianas (*n* = 4), growth trajectories differed from the Hawaiian samples (Andrews et al., 2012), and were more similar to limited growth estimates for this species in Papua New Guinea (Fry et al., 2006). Therefore, there is a critical need to determine the life-history parameters of opakapaka stocks exclusively from the Mariana Islands.

Research Objectives

This study aims to estimate the age of *P. filamentosus* by counting growth zones of sectioned otoliths visually, to refine and validate the estimates from bomb ^{14}C dating, to develop age-validated growth parameters, and to determine the median length- and age-at-maturity ($L_{50,}$ A_{50}) for *P. filamentosus* in the Mariana Islands. This study will also investigate potential differences in growth and maturity characteristics of male and female opakapaka. To provide an age-validated basis for these life-history determinations, bomb-radiocarbon dating was used on a series of opakapaka otoliths. This important life-history information for *P. filamentosus* will be provided to fisheries managers for use in more accurate stock assessments and effective management strategies that promote sustainability of this species in the Mariana Islands.

METHODOLOGY

Location

The Mariana Islands are located in the western Pacific at a distance of approximately 100 km to the west of the Marianas Trench (Fig. 3). This archipelago consists of 15 islands that were formed 30–40 million years ago (Cloud et al., 1956;

Karig, 1971) and is approximately 684 kilometers long. The ten northern-most islands are volcanic islands, which are primarily uninhabited and undeveloped. The islands south of Farallon de Medinilla are primarily raised marine limestone islands over volcanic rocks and are typically larger and cover more surface area, including more extensive reef structure than in the north. The islands are unincorporated United States Territories and have two separate governments, the Commonwealth of the Northern Mariana Islands (CNMI) and the Government of Guam, the latter of which consists of the island of Guam (largest island in the archipelago) and Cocos (islet). Based on the 2010 U.S. Census, the CNMI population consists of ~54,000 residents with an exclusive economic zone (EEZ) of 758,121 km^2. The island of Guam has 158,000 residents with an EEZ of 213,415 km^2 (U.S. Census Bureau, 2015).

The bottomfish fishing fleet consists of vessels that are eight meters or less. Regulations for bottomfish fishing and gear restrictions in the Mariana Islands are similar for both governments (i.e., vessels greater than 12 meters in the CNMI and 15 meters in Guam are required to have a federal bottomfish fishing permit to fish commercially) (WPRFMC, 2017). The Western Pacific Regional Fishery Management Council (WPRFMC) manages the deep bottomfish fishery within the EEZ of both the CNMI and Guam.

Data Collection

In 2014, fisheries scientists collected 132 *Pristipomoides filamentosus* specimens from the Northern Mariana Islands during the National Oceanic and Atmospheric Administration (NOAA) Oscar Sette Cruise, where fish data (length, weight, etc.), as well as gonad and otolith samples were collected. *Pristipomoides filamentosus* were caught with bottomfish-fishing gear, measured to the nearest 0.1 cm fork length (FL), weighed to the nearest 0.1 g, and processed for life history information (i.e. otolith and gonad removal). Fishing gear consisted of several hundred meters of braided line, which was attached to a terminal rig with branching, monofilament lines connected to curved hooks. The terminal rig was connected to a 2-kilogram weight so that the rig reached the bottom quickly. Fisheries scientists on the cruise extracted and weighed the gonads and then fixed the gonads in 10% neutral-buffered formalin. Fisheries scientists also extracted the sagittal otoliths from each fish, cleaned the otoliths with water, air dried them, and stored them in individually labeled vials. Gonads and otoliths were archived at NOAA Pacific Islands Fisheries Science Center (PIFSC) in Honolulu, Hawaii and were accessed for this study.

To supplement the data collected in 2014, gonad and otolith samples of *P. filamentosus* were extracted from recreational and commercial catches from the Guam Fishermen's Cooperative Association, Guam's NOAA PIFSC Territorial Science Liaison, the CNMI Division of Fish and Wildlife (DFW), and independent fishermen. Archived samples from previous collections by the NOAA Townsend Cromwell Cruise (1982), the CNMI DFW (2011–2013), the Guam Biosampling Program (2012, 2014–2018), and the NOAA Oscar Sette Cruise (2018) were also included in this study.

Reproduction

Gonads of each fish were extracted and weighed to the nearest 0.1 g and fixed in 10% neutral-buffered formalin. The sex and maturity of each fish were determined histologically. Histological samples were prepared at the University of Guam, where the samples went through a series of dehydration and clearing steps using ethanol (EtOH), followed by xylene (Kiernan, 1990). Gonads were infiltrated with and embedded within paraffin wax (Paraplast Plus®), sectioned to 5–7 µm thickness using a microtome, and stained using hematoxylin and eosin. The ovaries and testes were examined at 100× and 400× magnification under a compound microscope (Olympus CX33), respectively, and gonads were classified following a protocol from Luers et al. (2017). Male testes were considered reproductively mature if flagellae or tailed spermatozoa were visible. Female ovaries were considered reproductively mature if oocytes contained vitellin (yolk protein) or post-ovulatory follicles, which are collapsed follicular cells (Longenecker and Langston, 2016). Using the information collected from the histological analyses, median length (L_{50}) and age at maturity (A_{50}) was determined for males and females by fitting the logistic equation $P = \frac{1}{1+ e^{a-bX_f}}$ where P is the proportion of reproductive males or females, X_f is the length class, a and b are the fitted model constraints that determine the logistic intercept and slope, e is an exponential constant (Euler's number), and L_{50} is $-(a/b)$. Similarly, the logistic equation $P = \frac{1}{1+ e^{a-bX_f}}$ where P is the proportion of reproductive males or females, X_f is the age class, a and b are the fitted model constraints, that determine the logistic intercept and slope, e is Euler's number, and A_{50} is $-(a/b)$. Gonadosomatic index (GSI) was estimated using the following equation:

$$GSI = \frac{gonad\ weight}{total\ fish\ weight - gonad\ weight} \times 100\%$$

Statistical analyses were computed using the *FSA* package in R (Ogle et al., 2019, R Core Team, 2019). To produce the L_{50} and A_{50} models, data without values (i.e., blanks or values that were not available [NA] due to missing gonads or otoliths) were removed from the analyses.

Otolith Preparation and Age Estimation

To estimate longevity, clean otoliths were weighed to the nearest 0.001 g. Otolith thickness was measured to the nearest 0.1 mm from the whole otolith. The left otolith for each fish was fixed to a paper tag using an adhesive (Cytoseal^{TM} 60), and left to harden for 3 to 5 days. If the left otolith was broken, then the right otolith was used. A transverse section through the nucleus, the earliest site of growth, was taken perpendicular to the *sulcus acusticus* using an Isomet low-speed saw equipped with two diamond-edged blades ~0.6 mm apart. The result was a 500-µm to 600-µm transverse section of the otolith. Sectioned otoliths were etched in 2% HCL for ~30 seconds, then washed in water, and air-dried. The dried sections were attached to a glass slide using Cytoseal™ 60 and polished using 600 to 1200-grit, carbide wet-dry sandpaper until the growth zones were visible under a dissecting microscope. These cross-sections were viewed and photographed using a stereomicroscope (Leica S8 APO). Each slide was viewed using transmitted light, or reflected light against a dark background, at an average magnification of 20× based on previous work with similar species. Counts of the growth zones were performed using the stereomicroscope and an image-processing program, Image J (ver. 1.51; Rasband, 1997–2016). Counts of the growth zones were documented on three separate occasions without knowledge of the previously recorded counts to eliminate any bias. If two of three counts of growth zones did not agree with each other, then the average of all three counts were recorded as the estimated age.

Growth Parameters

To characterize the growth of *P. filamentosus*, age and length data were modeled using the von Bertalanffy growth function (VBGF) (von Bertalanffy, 1938): $L_t = L_\infty [1 - e^{-k(t - t_0)}]$; where L_t is the fork length (FL) of a fish at age t, L_∞ is the mean asymptotic FL, k is the Brody growth rate coefficient that describes the rate at which fish grow towards L_∞, t is the age of the fish, e is Euler's number, and t_0 is the theoretical age at which FL = 0, as described by the growth rate. Non-linear least squares were used to select the best-fitting curve for the length-age data using the *FSA* package in the programming language R (Ogle et al., 2019; R Core Team, 2019). In order to run the models, data without values (i.e., blanks or NA values due to missing otoliths) were removed from the analyses. Parameters of the VGBF were determined iteratively using the *nls* function of the *nlstools* package in R (Baty et al., 2015). However, the *nlsLM* function from the *minpack.lm* package (Elzhov et al., 2016) was also used to address issues such as algorithm failures associated with poor starting values (Ogle, 2016). Differences in growth parameters between fish from the northern and southern samples were investigated. Northern samples were defined as the islands north of Saipan (i.e, the islands of Farallon de Medinilla to Uracas), and the southern islands were defined as Saipan, Tinian, Rota, and Guam (Fig. 3). To account for the limited data between regions and to allow for comparisons between the two regions, t_0 was constrained to zero. The VBGF parameters for males and females were also investigated for any differences between the sexes. To test for differences between the von Bertalanffy parameters for the northern and southern samples, the most complex model (i.e., where L_∞, k, and t_0 differ between the regions) and the simplest model (i.e., where none of the parameters differ between the regions) were compared using a likelihood ratio test (Ogle, 2016). The VGBF parameters for males and females were investigated for differences in the same manner as the northern and southern samples.

Age Proxies

This study also explored the utility of the relationship between fish age and otolith mass, as well as otolith thickness, as potential proxies for age of *P. filamentosus* from the Mariana Islands. The relationship between age and otolith mass was assessed using regression analysis (Taylor and McIlwain, 2010). Data were log-transformed to meet the assumptions of linear regression. Analysis of Covariance (ANCOVA) was used to compare the age-and-otolith-mass relationship between the sexes with age as the dependent variable, otolith mass as the covariate, and sex as the categorical variable (Taylor and McIlwain, 2010). ANCOVA was also used to compare the age-and-otolith-thickness relationship between the sexes. Regression tables were produced using the *stargazer* package in R (Hlavac, 2018; R Core Team, 2019).

Bomb-radiocarbon Dating & Age Validation

Bomb-radiocarbon dating of otoliths was conducted following procedures described in Andrews et al. (2012) and elsewhere (e.g. Kalish, 1995; Andrews et al., 2005; Ewing et al., 2007). Briefly, whole otoliths of 19 *P. filamentosus* individuals were fixed onto a glass slide (distal side up) using Cytoseal$^{\text{TM}}$ 60 and left to harden for several days. Carbonate samples from the sagittal otoliths were extracted by first exposing the earliest form of growth using 320-grit to 1000-grit sandpaper. Then approximately 3 mg of carbonate from each otolith were collected using a fine-tipped, micro-milling machine (ESI–New Wave Research Division, Fremont, California). The carbonate powder from each otolith was placed in a micro-centrifuge tube and was analyzed using the standard analysis routine for carbonates on an accelerator mass spectrometer (AMS) at the National Ocean Sciences Accelerator Mass Spectroscopy (NOSAMS) laboratory at Woods Hole Oceanographic Institution in Woods Hole, Massachusetts (https://www.whoi.edu/nosams/home).

The carbonate powder was converted to carbon dioxide by reaction *in vacuo* with 100% phosphoric acid. An aliquot of carbon dioxide was used to determine $\delta^{13}C$ for each sample and the remaining carbon dioxide were converted to graphite. Radiocarbon was determined in each graphitized sample by AMS. Radiocarbon values were reported as fraction modern ($F^{14}C$) after correction for fractionation using measured $\delta^{13}C$ (Reimer et al., 2004; Appendix A). The $F^{14}C$ is the measured deviation of the $^{14}C/^{12}C$ ratio from a "modern" sample (e.g., Andrews et al., 2012). The $F^{14}C$ values were used to calculate age-corrected $\Delta^{14}C$ values (Stuiver and Polach 1977).

Ages were estimated by comparing the $\Delta^{14}C$ values of *P. filamentosus* otoliths to the reference $\Delta^{14}C$ coral time-series from Guam (A. H. Andrews et al., 2016a). The bomb-radiocarbon dated otoliths were sectioned and aged using previously described methods. Simple linear correlations and a paired two-sample *t*-test were used to compare visual age estimates and bomb ^{14}C-derived ages using methods described in Cailliet et al. (2001). If the estimated age range determined from the reference time series agreed with the ages determined from the sections, then a successful age-reading protocol was demonstrated using bomb-radiocarbon dating and visually determined counts of growth zone.

RESULTS

A total of 280 *P. filamentosus* were collected between 2011–2019 from the CNMI and Guam with lengths ranging from 20.9–65.5 cm FL (Appendix B). Of the 280 samples collected, 217 were used for histology and age analysis. A total of 127 males were collected with lengths and masses ranging from 22.5–65.5 cm FL and 189.7–4500 g. A total of 83 females were collected with lengths and masses ranging from 20.9–64.9 cm FL and 163.9–4000 g. The largest fish observed was a 65.5 cm FL male, which weighed 4386 g.

The length-at-mass relationship was calculated separately for males and females. Prior to analyses, both length and mass were $\log_{10}$-transformed. The relationship between length and mass for males and females was not significantly different (Table 1; ANCOVA: $F_{1,200} = 0.\ 142$, $p = 0.707$). The mass of opakapaka can be estimated using the following equation: Mass = $-1.43 \times \text{Length}^{2.78}$ (Table 2). Size distribution for males and females within the Marianas did not differ (two-sample K-S test, $D = 0.0557$, $p = 0.999$; Fig. 4). The age distribution for males and females also showed no difference (two-sample K-S test, $D = 0.156$, $p = 0.234$; Fig. 5).

Reproduction

Of the 280 opakapaka collected, 254 were used to predict the length at median maturity. Because of the lack of immature fish from the northern islands, opakapaka from the northern and southern islands were combined for histology and age analyses (Fig. 6).

A total of 111 female and 143 male opakapaka were verified using histological analysis. Of the 111 females, 68 and 43 females were classified as mature and immature, respectively. Of the 143 males, 127 and 16 males were classified as mature and immature, respectively. The smallest mature female and male recorded were 29.3 cm (462.3 g) and 24.1 cm (254.0 g), respectively. The median length at maturity (L_{50}) for females was estimated as 41.2 cm FL (95% CI 38.7–43.8 cm; Fig. 7). The median length at maturity (L_{50}) for males was estimated as 27.6 cm FL (95% CI 25.4–29.4 cm). The slopes for the logit-transformed models do not differ between the sexes ($X^2 = 1.90$, $p = 0.168$). However, the main effect for the model (sex) is significantly different, which indicates a difference in the y-intercepts for the male and female logit-transformed models ($X^2 = 64.7$, $p < 0.0001$). Therefore, there is a significant difference in the median length-at-maturity between males and females.

The median age of maturity (A_{50}) for females was estimated as 5 years (95% CI 4.25–5.72 years; Fig. 8). The median age of maturity (A_{50}) for males was estimated as 2.8 years (95% CI 2.53–3.09 years). The slopes for the logit-transformed models do not differ between the sexes ($X^2 = 3.42$, $p = 0.0645$). The main effect for the model (sex) is significantly different, which indicates a difference in the y-intercepts for the male and female logit-transformed models ($X^2 = 27.2$, $p < 0.0001$;). Therefore, there is significant difference in the median age-at-maturity between males and females. Examination of mean GSI for both males and females showed peak GSI during the months of June and October (Fig. 9).

Age Estimation

To estimate the age of *P. filamentosus,* otoliths from 217 opakapaka were analyzed (90 females and 127 males). Growth curves for opakapaka differed between the northern and southern opakapaka samples (Likelihood ratio test: $X^2 = 26.37$, $df = 3$, $p < 0.0001$; Fig. 10). Asymptotic growth (L_∞) for the northern and southern samples did not differ significantly compared to L_∞ of the simplest model; however, K values did differ significantly (Likelihood ratio test: $X^2 = 4.873$ $p = 0.02729$). Northern samples had a smaller K value compared to the southern samples ($K = 0.2248$ *vs* $K = 0.1869$, respectively) (Table 3). That is, northern populations grew faster, but tended to grow toward a common asymptotic length with the southern samples after their first 9 years. The von Bertalanffy growth curves for males and females were not significantly different (Likelihood ratio test: $X^2 = 5.95$, $p = 0.114$). However, the mean ages of males (10.7 years) and females (8.7 years) differed significantly (Welch Two Sample *t*-test: $t = -2.4078$, $df = 213.51$, $p = 0.0169$). The VBGF parameters for both males and females were $L_\infty = 54.482$, $K = 0.201$, $t_0 = -0.935$ (Table 3). Growth for both sexes was generally rapid during the first 5 to 10 years, but began to slow towards L_∞ after that period (Fig. 11).

Age Proxy

Otolith thickness and otolith mass proved to be reliable predictors of age, which accounted for 89% and 87% of the variability in thickness or mass, respectively (Tables 4 and 5). The slope of the age-to-otolith thickness relationship did not differ significantly between the sexes (ANCOVA: $F_{1,200} = 0.110$, $p = 0.740$; Table 6; Fig. 13a). However, the age-to-otolith mass relationship did differ significantly between the sexes (ANCOVA: $F_{1,172} = 7.14$, $p = 0.008$; Table 7; Fig. 13b).

Age Estimation Versus Validated Ages

There was a significant correlation between the estimated age and bomb ^{14}C-validated ages of *P. filamentosus* ($r = 0.957$, $p < 0.0001$; Fig. 14). A paired two-sample *t*-test showed no significant difference between estimated age and validated age ($t = 0.33379$, $df = 18$, $p = 0.7424$).

DISCUSSION

Prior to this study, reproduction, age, and growth parameters of *Pristipomoides filamentosus* were generally lacking from the Mariana Islands. Using histological analyses, traditional age estimation techniques, and bomb radiocarbon dating, life history parameters of *P. filamentosus* have been obtained and are presented here in this study. The logistic regression models of the median length and age of reproductive maturity for opakapaka were found to be significantly different between males and females. Growth parameters between males and female opakapaka were not significantly different. Additionally, this study confirms that opakapaka from the Mariana Islands grow more slowly and attain a smaller L_∞ compared to opakapaka from the Hawaiian Islands. Bomb ^{14}C validated ages agreed with visually estimated ages of *P. filamentosus* from the Mariana Islands, which suggests that the visual age-reading protocol used in this study is adequate.

Reproduction

The estimated size at maturity for opakapaka in the Mariana Islands was similar to estimates of the L_{50} for opakapaka in the Pacific. In the Main Hawaiian Islands (MHI), Luers et al. (2017) found males to reach their L_{50} at 34.3 cm FL (95% CI: 33.3–35.3 cm) and females to reach their L_{50} at 40.7 cm FL (95% CI 40.3–41.2 cm). In Okinawa, Japan, Uehara et al. (2018) found males and females to reach their L_{50} at ca. 20.0 cm FL and 35.7 cm FL, respectively. This study estimated males and females to reach their L_{50} at 27.6 cm and 41.2 cm, respectively. When estimated size at maturity for both sexes was combined for the Marianas, the result was very similar to estimates for opakapaka from Papua New Guinea. Lokani et al. (1990) estimated the L_{50} for male and female *P. filamentosus* as 34.0 cm using GSI values. The present study estimated the combined L_{50} for both sexes as 32.6 cm using histological analysis. However, it is not clear how Lokani et al. (1990) derived the estimated L_{50} for *P. filamentosus* (Luers et al., 2017).

Based on the data from this study, peak spawning period appears to occur in the months of May–July, which is similar to fish spawning in the MHI (May–September) and Okinawa (March–October) (Luers et al., 2017; Uehara et al., 2018). The greatest observed gonadosomatic indices (GSI) for female and male opakapaka occurred in the months of June (n = 92) and October (n = 4). In June, 97.7% of females and 100% of males were mature, and in October, all fish were classified as mature.

The estimated age at maturity for fish in the present study was estimated as ca. 5 and 3 years for female and male opakapaka, respectively. Female opakapaka from the Mariana Islands appear to mature 1.5 years later than female opakapaka from the MHI (3.5 years; Luers et al., 2017). However, male opakapaka appear to mature at the same age in the present study as males from the MHI (2.8 years vs. 2.5 years respectively; Luers et al., 2017). In this study, the maturation schedules for length and age between males and females differ by 6.4 cm FL and 2 years, respectively. These differences have important implications to management, which may lead to over- or under-estimation of stock assessments especially when applying proxies for life history parameters from estimates outside of the region, such as Hawaii or the Seychelles.

The differences in maturation schedules have been demonstrated in other regional fishes. Confamilial species of *P. filamentosus,* such as *Etelis oculatus* from Puerto Rico, and *Etelis coruscans* and *Paracaesio caerulea* from Japan, also have sexually, differing maturity schedules with males consistently smaller in length compared to females (Rosario et al., 2006; Uehara et al., 2018). Female fishes from other taxa are known to mature much later compared to males, and this is a result of the high energetic constraints females endure (Wooten, 1985; Taylor et al., 2017). Competition in reproduction between males may also explain early maturity in males (i.e., sneak mating of smaller males rather than paired mating of larger mature males) (Parker, 1990; Uehara et al., 2018).

Age Estimation and Growth

In an effort to identify differences between the northern and southern regions of the Mariana Islands, the von Bertalanffy growth function (VBGF) parameters from the two regions were compared and were found to be significantly different. Visual comparisons of the growth functions from the two regions much slower growth of opakapaka from the southern islands compared to the northern islands. While there appears to be differences in growth between the northern and southern regions from the values determine, the data are not sufficient to confirm these results because individuals smaller than 37 cm from the northern islands were lacking. Nevertheless, given the available data, fish from the northern islands grow more rapidly in the first 3 to 9 years, then grow toward a value of L_∞ similar to their southern conspecifics. In a previous study by Ralston (1988), no differences in the condition (i.e., mass) of opakapaka were observed when comparing northern and southern samples, but differences between the northern samples and samples from offshore seamounts of the West Mariana Ridge (not included in this study) were observed. Differences in environmental conditions and nutrient availability in the northern and southern regions, if any, could possibly explain differences in growth between the northern and southern samples. Future sampling of smaller, immature fish from the northern islands is recommended to explore these differences further. Therefore, a unified curve combining data from the northern and southern samples and describing the relationship between age and length is likely the best model for this species across the region (Fig. 10).

The VGBF parameters between males and females were also compared and revealed no differences in length and age between sexes. This finding is similar to *P. multidens* found in northwestern Austrailia (Newman and Dunk, 2003). The maximum observed length and age in this study was 65.5 cm and 31 years, respectively. There was very little difference in the parameters of this study ($L_\infty = 54.5$, $K = 0.201$, $t_0 = -0.935$) compared to Ralston and Williams' opakapaka ($L_\infty = 58.4$, $K = 0.289$, $t_0 = -0.54$; 1988; Fig. 12). Ralston and Williams (1988) observed a maximum length and age of 64.0 cm and 5 years. Estimated ages were obtained, however, by numerical integration of daily growth increments and suffered from a low sample size ($n = 10$; Ralston and Williams, 1988). Regional comparison of the maximum observed length and age also show considerable differences between Hawaii and the Mariana Islands. In Hawaii, observed lengths were greater than 70 cm, with a maximum validated age exceeding 40 years (Andrews et al., 2012). Growth parameters for opakapaka from the Mariana Islands are considerably different compared to opakapaka from the Hawaiian Islands (L_∞: 54.5 cm *vs* 67.4 cm; K: 0.201 *vs* 0.252 year^{-1}, respectively; Fig. 12) (Andrews et al., 2012). These differences in growth parameters may be due to significant latitudinal changes, and are observed in other fish species such as *Naso unicornis* (Atkinson and Sibly, 1997; A. H. Andrews et al., 2016b). In Papua New Guinea (PNG), L_∞ for *P. filamentosus* was estimated to ~55.1 cm, which is very similar to fish in this study (Fry et al., 2006). However, age validation of visually estimated ages were inclusive for fish from PNG (Fry et al., 2006), and respective growth coefficients, K = 0.118 and t_0 = -4.0, suggest differing projected growth rates compared to these same parameters estimated in this study.

Age Proxy

The age-to-otolith thickness relationship for male and female opakapaka did not differ significantly and proved to be a good predictor of age in *P. filamentosus* from the Mariana Islands. However, the age-to-otolith mass relationship between males and females did differ significantly, therefore future use of otolith mass as a proxy for age will require prior knowledge of the sex of the fish. In a similar study, otolith thickness and weight were identified as the most important variables in predicting age when applied to *Etelis carbunculus, E. coruscans, E. marshi,* and *P. filamentosus* from the South Pacific Ocean; however, the differences between the sexes were not investigated

(Williams et al., 2015). A. H. Andrews et al. (2016b) found comparable results when otolith morphometrics were applied to an inshore reef fish, *Naso unicornis*. The age-to-otolith mass relationship for *N. unicornis* differed between males and females, but the age-to-otolith thickness relationship did not differ (A. H. Andrews et al., 2016b). Templeman and Squires (1956) also found differences in otolith mass between sexes for haddock *Melanogrammus aeglefinus* (L.) from the north Atlantic region. Although there was little difference between the otolith mass of male and female haddock at smaller sizes, the difference became increasingly significant for otoliths of larger and older, mature male and female fish in the same size range (Templeman and Squires, 1956). Although these otolith morphometrics proved to be good predictors of age, there was considerably more variation in these parameters as the age of the fish increases, consequently reducing the precision of predicted ages (Pilling et al., 2003). For this reason, estimating individual fish ages from their otolith weight or otolith thickness is not considered an accurate method to discriminate between age classes (e.g., Pilling et al., 2003; Williams et al., 2015). However, these age proxies can be used to discriminate outliers that may have been improperly assigned an age or to identify discrepancies in the fish data (e.g., fish length or weight). Age proxies also prove to be useful tools for fisheries managers when it is not possible to establish fish age from counting growth rings on the otolith. This may be especially true for *Pristipomoides filamentosus* from the Mariana Islands that are less than 20 years old; or less than ~60.0 cm FL or ~3050 g.

Age Estimation Versus Validated Ages

A comparison of the estimated ages and ^{14}C validated ages showed that these ages were statistically equivalent—demonstrating a valid age-reading protocol for *P. filamentosus* in the Mariana Islands. However, there is some imprecision in age estimation especially for ages between 10 and 15 years, but the central tendency of age reading is accurate with acceptable age estimates for this study (Fig. 14). Numerous studies have noted the difficulty in estimating age for this species (e.g., Ralston and Miyamoto, 1983; Fry et al., 2006; Andrews et al., 2012), however, significant agreement of age interpretations is achievable (Wakefield et al., 2016). As such, the need for ^{14}C-validated otoliths is evident and this study addresses the need for a validated age reading protocol for *P. filamentosus* in the Mariana Islands.

Based on the regional ^{14}C data available, in comparison to ^{14}C data attained from this fish, the validated age is at minimum 25 years at 61.6 cm FL (Paka-G01-GCDD-092, Appendix B). In Hawaii, the greatest ^{14}C validated age for *P. filamentosus* was at least 40 years at lengths greater than 70.0 cm FL (Andrews et al., 2012). Using traditional age-reading techniques, the maximum estimated age for opakapaka from the Mariana Islands is at least 31 years. Bomb-radiocarbon dating has emerged as a standard tool for validating fish age and was crucial to providing a basis for accurate ages for several species of fishes where longevity was previously underestimated, such as the pink snapper *Pristipomoides filamentosus* from the Hawaiian Islands, speckled hind *Epinephelus drummondhayi* from the Gulf of Mexico, and red steenbras *Petrus rupestris* from South Africa (Andrews et al., 2012; 2013; 2018b). In the case of *P. filamentosus* in the Marianas, bomb-^{14}C dating provided support for the development of an accurate age reading protocol that resulted in estimates of longevity and growth rates that were significantly different from the Hawaiian Islands population.

Conclusion

In summary, this study provides important information that describes critical life-history parameters for *Pristipomoides filamentosus* from the Mariana Islands. The length- and age-at-maturity was obtained using logistic regression models and this study calculated that the L_{50} and A_{50} for male and female opakapaka to the lengths and ages of 27.6 cm FL at ca. 3 years and 41.2 cm FL at 5 years, respectively. Using traditional age estimation techniques, the maximum age estimated in this study was 31 years. This study also applied bomb-radiocarbon dating to otoliths of opakapaka collected in the Mariana Islands and the maximum validated age recorded for this fish was 25 years. An analysis of von Bertalanffy growth functions for opakapaka collected in the islands north of Saipan suggested faster growth rates from the northern populations of opakapaka compared to samples collected in the southern islands. However, further investigation is required to provide definitive results for the two regions. The VBGF also revealed no differences between male and female opakapaka allowing a unified growth function to be estimated for the species ($L_\infty = 54.5$, $K = 0.201$, $t_0 = -0.935$). The results from this study confirm that this deep-water, bottomfish snapper from the Mariana Islands is a long-lived, slow-growing, and late-maturing fish.

The information obtained in this study can be applied in future stock assessments without the need to apply life-history parameters from different locations or conspecifics. To determine whether or not the differences in growth and reproduction observed here across the Mariana Islands are biologically significant or will significantly affect management decisions, further specimen and data collection in the northern region is necessary. Otoliths that were ^{14}C age validated were critical to the successful development and refinement of an age-reading protocol for this study, as well as other studies applying ^{14}C measurements to fish otoliths (e.g. Kalish, 1995; Andrews et al., 2012, 2016b, 2018, and others). Using this technique for other deep-water bottomfish fishes from the Mariana Islands will be important for fisheries managers to better understand the life-history characteristics of fishes from this region, ultimately providing valid life-history parameters for use in future management.

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FIGURES & TABLES

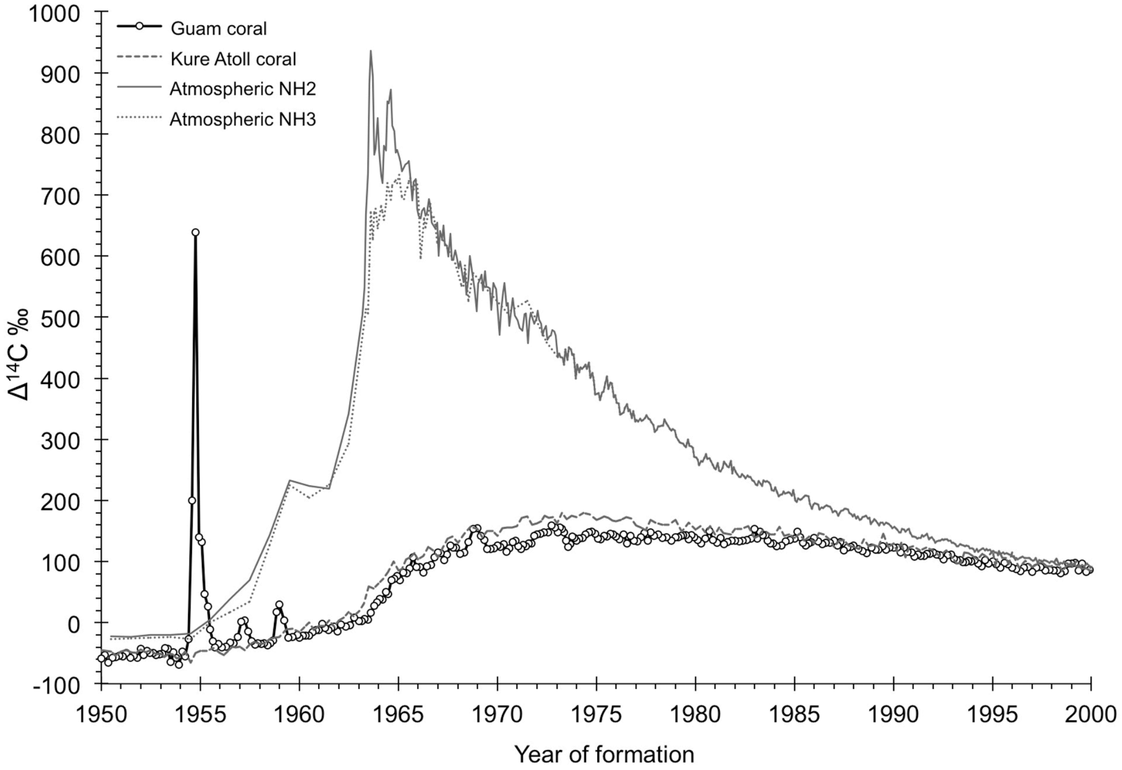

Figure 1: Plot of the coral $\Delta^{14}C$ records from Guam and Kure Atoll with atmospheric records from the two applicable Northern Hemisphere zones (2 and 3) for the location (Hua et al. 2013). The applicable reference series for the *Pristipomoides filamentosus* aged in this study was the declining side of the Guam coral ^{14}C record. Figure image provided by AH Andrews from Andrews et al. (2016a)

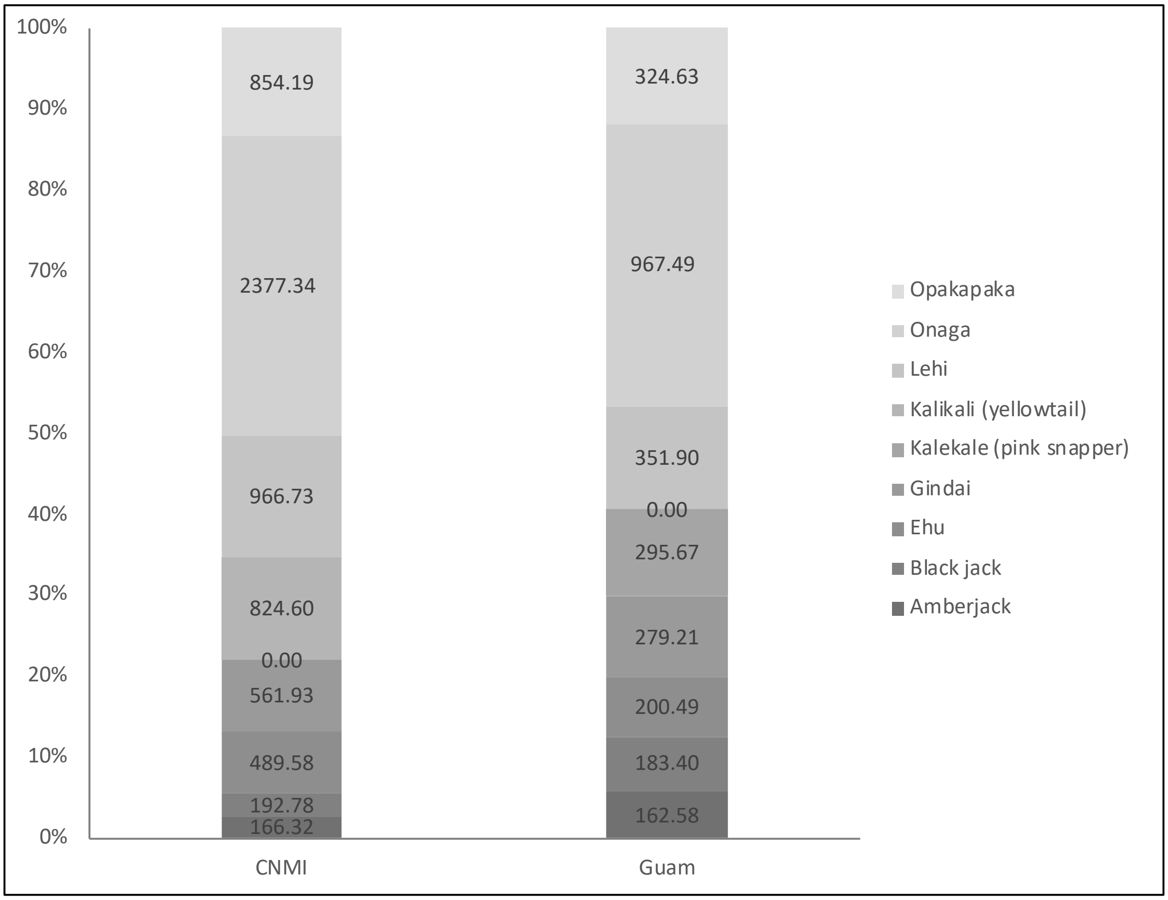

Figure 2: Average catch of deep bottomfish management unit species (BMUS) from Guam and the Commonwealth of the Northern Mariana Islands (CNMI) in kilograms from 1981–2015. Note that opakapaka (*Pristipomoides filamentosus*) were responsible for the 3rd greatest biomass of the catch of bottomfish species in the CNMI and Guam. Data source: https://www.pifsc.noaa.gov/wpacfin/. (Last accessed: August 26, 2017).

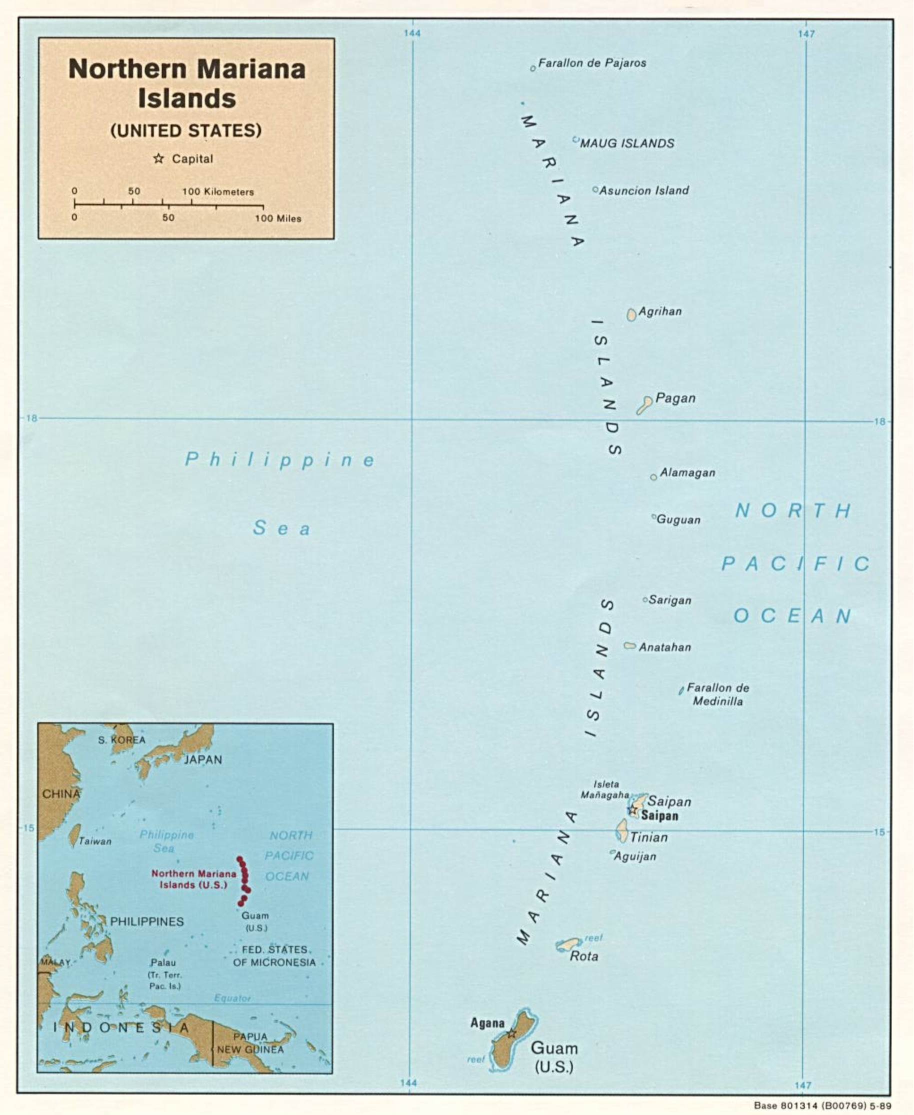

Figure 3: Map of the Northern Mariana Islands and Guam showing their location in the central western Pacific and the extent of the island chain (double arc). Source: http://legacy.lib.utexas.edu/maps/islands_oceans_poles/nomarianaislands.jpg (Last accessed: September 27, 2019).

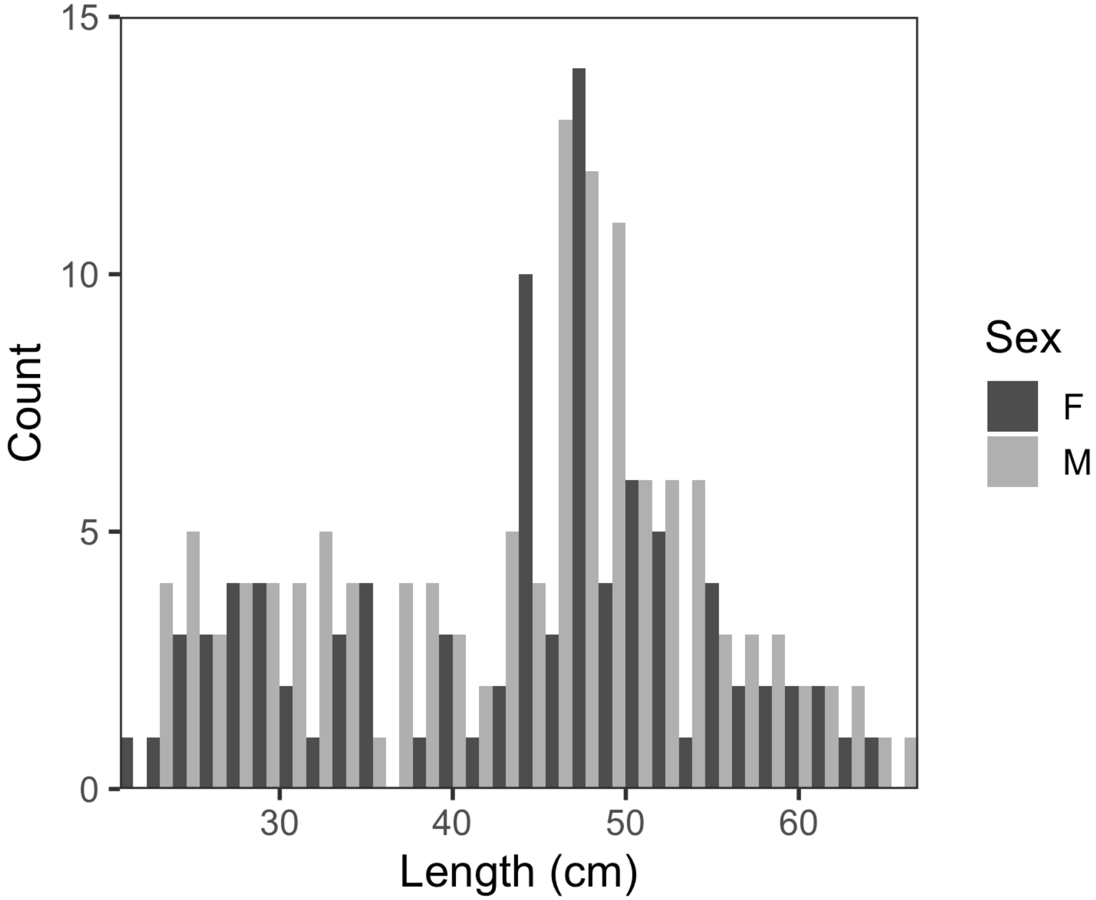

Figure 4: Length-frequency distributions for male and female *Pristipomoides filamentosus* in the Mariana Islands (*n* = 217). Size distribution for males and females within the Marianas did not differ.

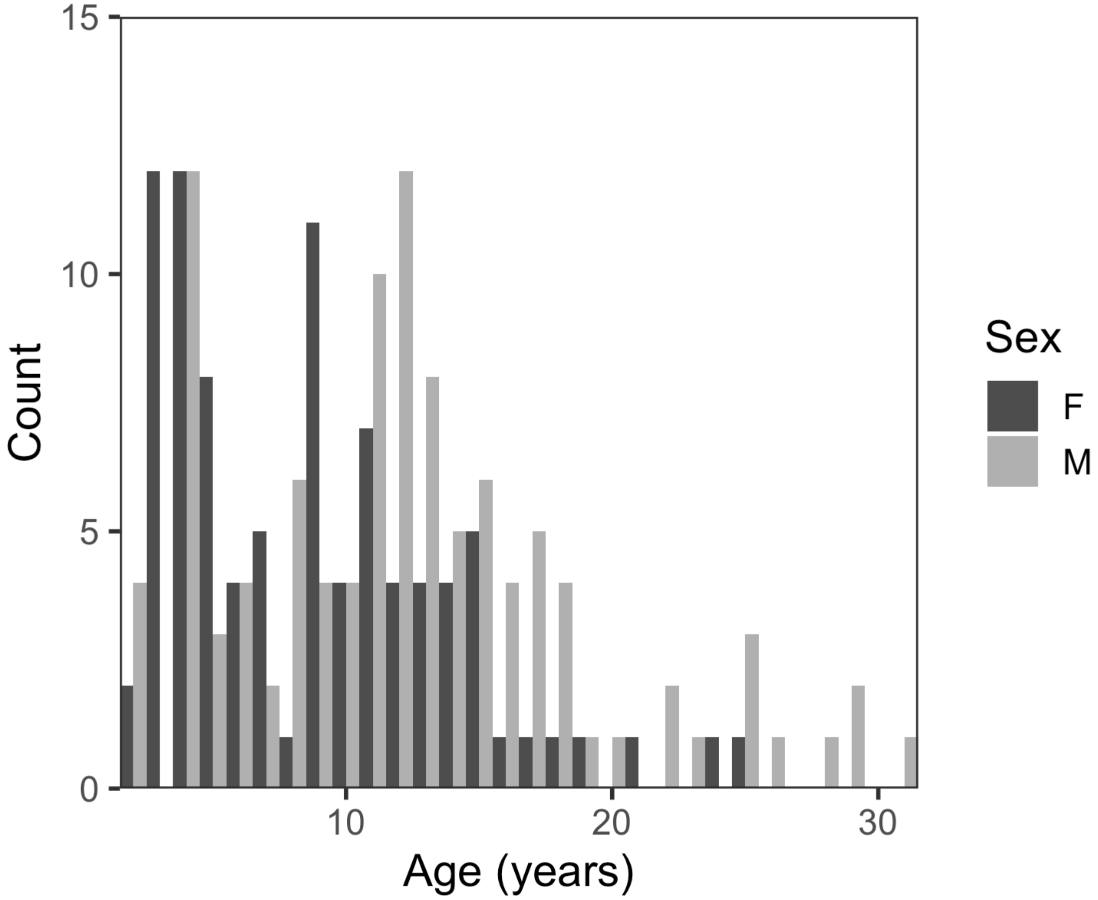

Figure 5: Age-frequency distributions for male and female *Pristipomoides filamentosus* in the Mariana Islands (*n* = 217). Age distributions for males and females did not show any significant differences.

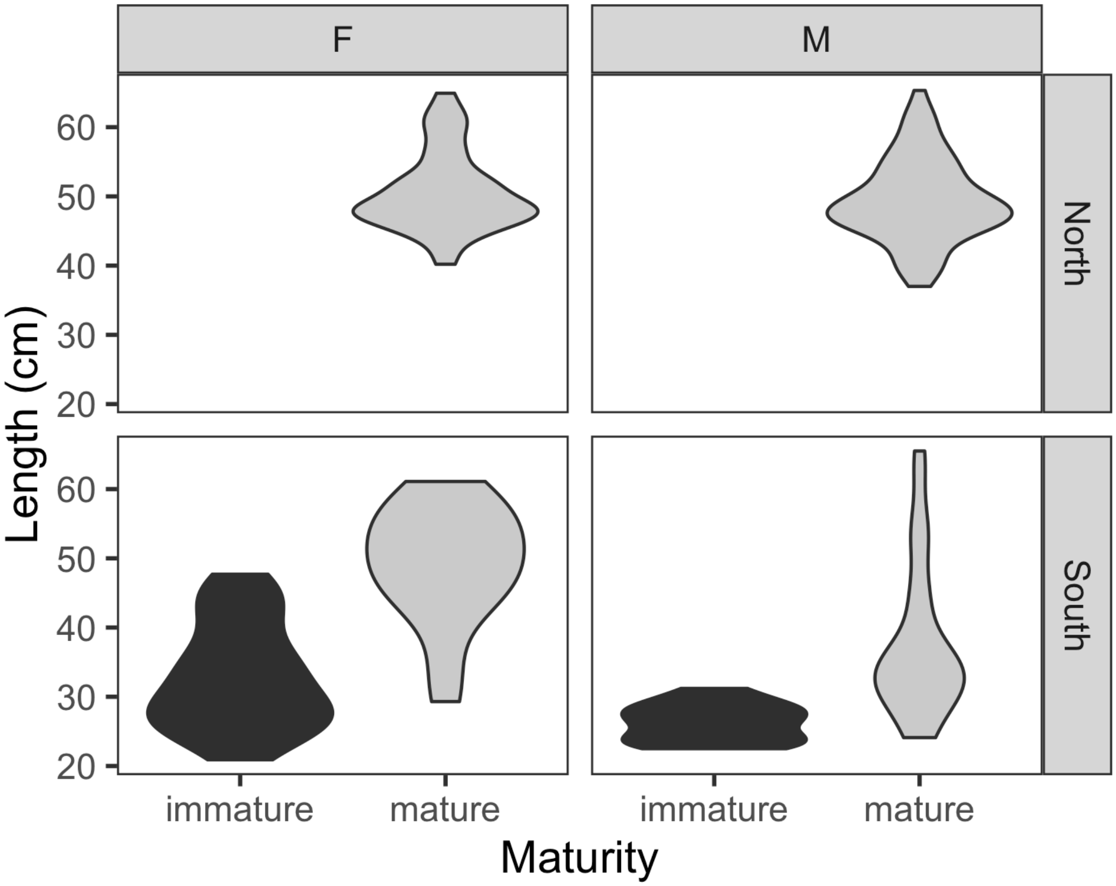

Figure 6: Violin plot of mature and immature opakapaka from the northern and southern Mariana Islands (*n* = 254). Northern samples were defined as the islands north of Saipan (i.e, the islands of Farallon de Medinilla to Uracas), and the southern islands were defined as Saipan, Tinian, Rota, and Guam. Immature opakapaka and samples with lengths >40 cm FL from the northern islands were lacking.

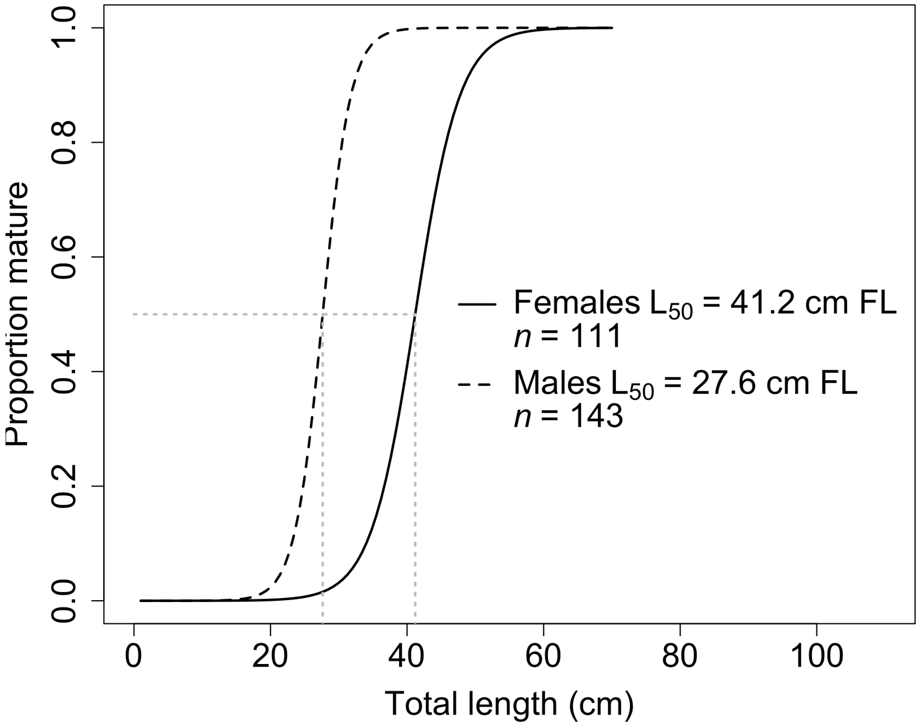

Figure 7: Fitted logistic regression of female and male opakapaka, where the proportion of mature opakapaka, $P = \frac{1}{1+ e^{a-bX_f}}$. The length at 50% maturity (L_{50}) is intersected and represented by grey dotted lines.

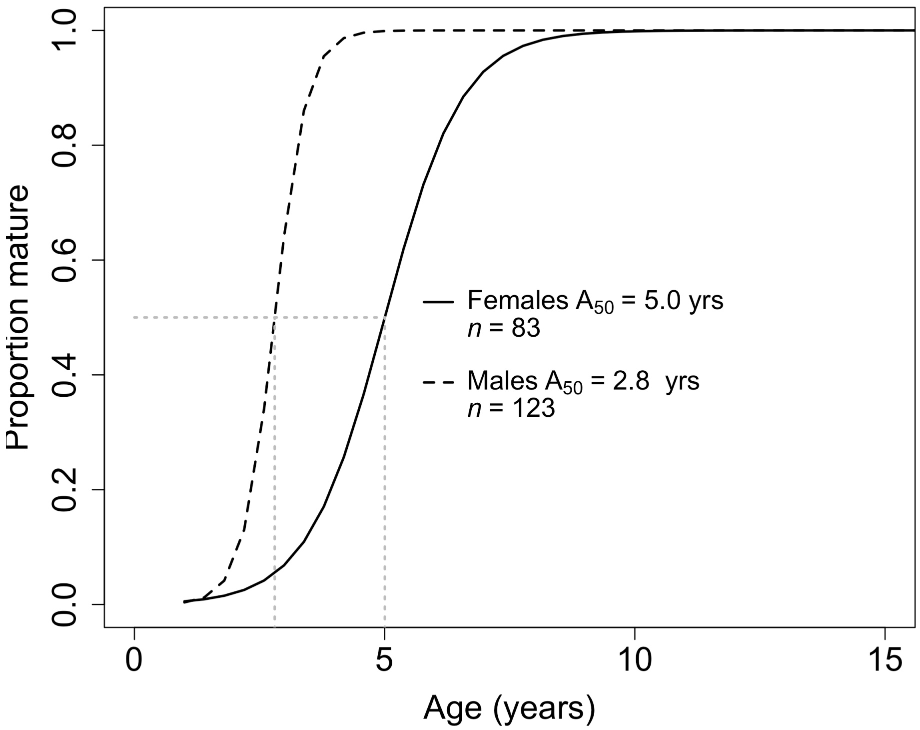

Figure 8: Fitted logistic regression of female and male opakapaka, where the proportion of mature opakapaka, $\boldsymbol{P} = \frac{\mathbf{1}}{\mathbf{1}+\, e^{a-bX_f}}$. The age at 50% maturity (A_{50}) is intersected and represented by grey dotted lines.

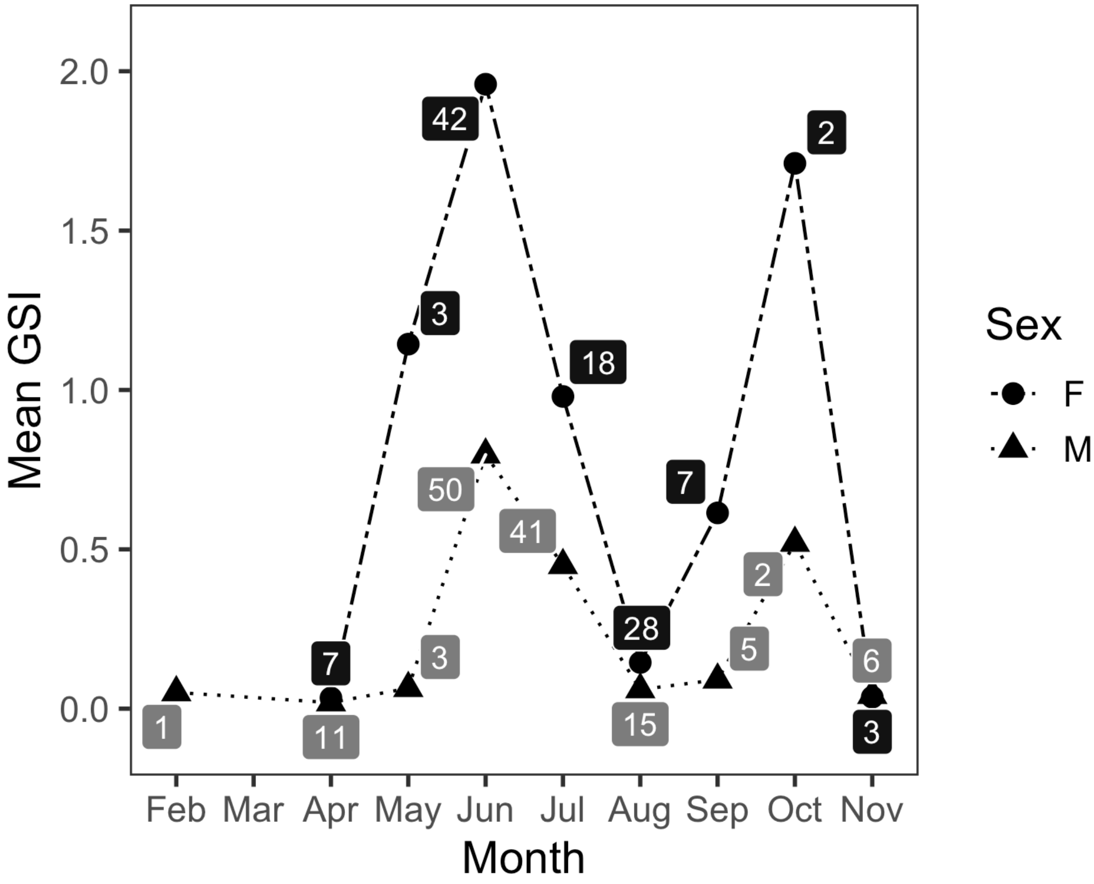

Figure 9: Mean gonadosomatic indices (GSI) for female and male opakapaka during the months of February to November (2012, 2014–2018). Mean GSI peaks occur in June and October. Numbers represent total sample size of female (black) and male (grey) opakapaka that were either mature or immature for each month collected.

Table 1: ANCOVA table for log-transformed values of fish mass and length. There were no significant differences in lengths and weights between male and female *Pristipomoides filamentosus* from the Mariana Islands.

Response: Log_{10} (mass)

	df	Sum Squares	Mean Squares	F value	Pr (>F)	
Log_{10} (length)	1	22.7955	22.7955	21869.0144	<0.001	***
Sex	1	0.0002	0.0002	0.2263	0.6348	
Log_{10} (length): sex	1	0.0001	0.0001	0.1416	0.7071	
Residuals	200	0.2085	0.001			

Note: *** $p < 0.01$

Table 2: Regression results for log-transformed values of fish length and fish weight for *Pristipomoides filamentosus* from the Mariana Islands.

	Dependent variable:	
	Log_{10} (mass)	Standard error
Log_{10} (length)	2.784^{***}	0.019
Constant	-1.432^{***}	0.030
Observations	204	
R^2	0.991	
Adjusted R^2	0.991	
Residual Std. Error	0.032 ($df = 202$)	
F $\text{Statistic}_{1,202}$	$22{,}047.150^{***}$	
Note:		$^{***}p < 0.01$

Table 3: Growth parameters derived from the von Bertalanffy growth function (VBGF) of *Pristipomoides filamentosus* from the Mariana Islands. Bootstrapped replicates n = 999. Northern samples were defined as the islands north of Saipan (i.e, the islands of Farallon de Medinilla to Uracas), and the southern islands were defined as Saipan, Tinian, Rota, and Guam. Note that t_0 was constrained to zero for the northern and southern samples.

	VBGF Parameters	Parameter Estimates	Bootstrap Confidence Intervals	
			95% LCI	95% UCI
Male & Females	L_∞	54.482	52.429	57.331
	K	0.201	0.148	0.265
	t_0	-0.935	-2.225	-0.034
Females	L_∞	58.094	53.881	65.283
	K	0.167	0.102	0.250
	t_0	-1.362	-3.604	0.064
Males	L_∞	53.653	51.305	57.250
	K	0.196	0.137	0.281
	t_0	-1.085	-2.639	0.059
Northern samples	L_∞	54.489	50.184	65.833
	K	0.225	0.283	0.453
Southern samples	L_∞	54.634	52.297	61.049
	K	0. 187	0.197	0.265

Table 4: Regression results for log-transformed values of otolith thickness and age for *Pristipomoides filamentosus* from the Mariana Islands.

	Dependent variable:	
	Log_{10} (age)	Standard error
Log_{10} (otolith thickness)	2.445***	0.065
Constant	0.381***	0.016
Observations	176	
R2	0.891	
Adjusted R2	0.89	
Residual Standard Error	0.097 (*df* = 174)	
F $\text{Statistic}_{1,174}$	1,417.561***	
Note:	*** $p < 0.01$	

Table 5: Regression results for log-transformed values of otolith mass and age for *Pristipomoides filamentosus* from the Mariana Islands.

	Dependent variable:	
	Log_{10} (age)	Standard error
Log_{10} (otolith mass)	0.995^{***}	0.048
sexM	0.157^{***}	0.052
Log_{10}(otolith mass):sexM	0.162^{***}	0.061
Constant	1.704^{***}	0.041
Observations	204	
R^2	0.876	
Adjusted R^2	0.874	
Residual Standard Error	0.104 (*df* = 200)	
F $\text{Statistic}_{3,200}$	470.094^{***}	
Note:		$^{***}p < 0.01$

Table 6: ANOVA table for log-transformed values of otolith thickness and age for *Pristipomoides filamentosus* from the Mariana Islands.

Response: Log_{10} (age)	*df*	Sum Squares	Mean Squares	F value	Pr (>F)	
Log_{10} (otolith thickness)	1	13.3094	13.3094	1403.766	<0.001	***
Sex	1	0.0019	0.0019	0.1965	0.6581	
Log_{10} (otolith thickness): sex	1	0.001	0.001	0.1102	0.7403	
Residuals	172	1.6308	0.0095			

Note: *** p <0.01

Table 7: ANOVA table for log-transformed values of otolith mass and age for *Pristipomoides filamentosus* from the Mariana Islands.

Response: Log_{10} (age)

	df	Sum Squares	Mean Squares	F value	Pr(>F)	
Log_{10} (otolith mass)	1	15.1293	15.1293	1400.5819	<0.001	***
sex	1	0.0277	0.0277	2.5613	0.111088	
Log_{10} (otolith mass): sex	1	0.0771	0.0771	7.1387	0.008166	**
Residuals	200	2.1604	0.0108			

Note: ** p <0.05, *** p <0.01

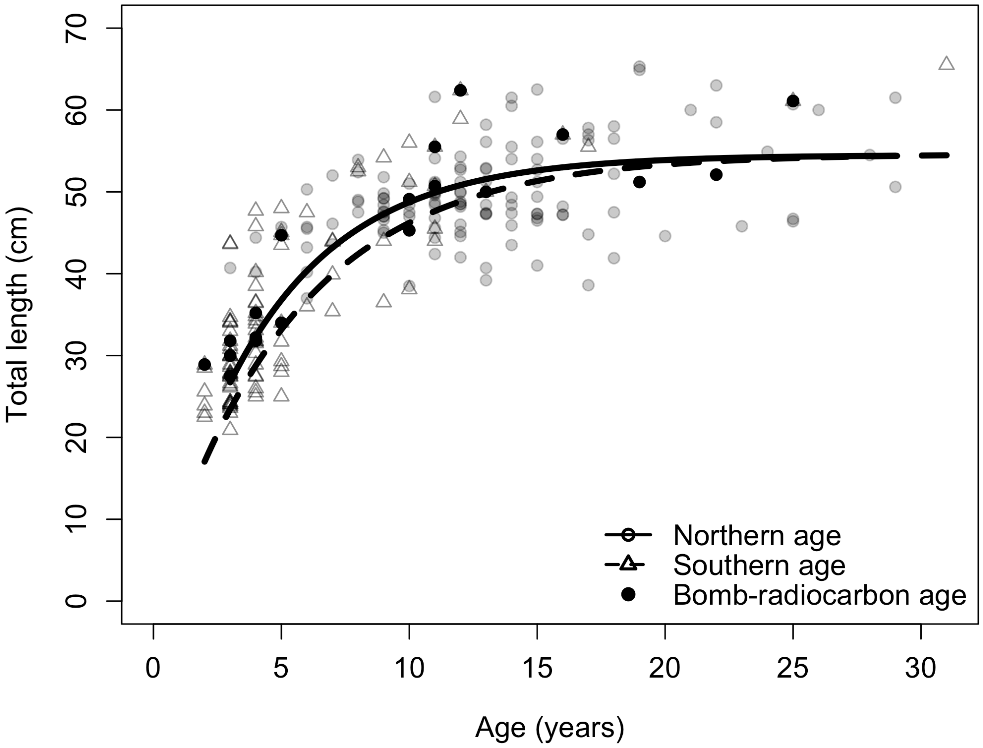

Figure 10: Length at age and von Bertalanffy growth curve for northern and southern *Pristipomoides filamentosus* from the Mariana Islands with t_0 constrained to zero. Northern samples were defined as the islands north of Saipan (i.e, the islands of Farallon de Medinilla to Uracas), and the southern islands were defined as Saipan, Tinian, Rota, and Guam. von Bertalanffy growth function (VBGF) parameter estimates for northern samples were $L_\infty = 54.5$ and $K = 0.225$. VBGF parameter estimates for southern samples were $L_\infty = 54.5$ and $K = 0.187$. There were no differences for L_∞; however, K values between the northern and southern samples differed.

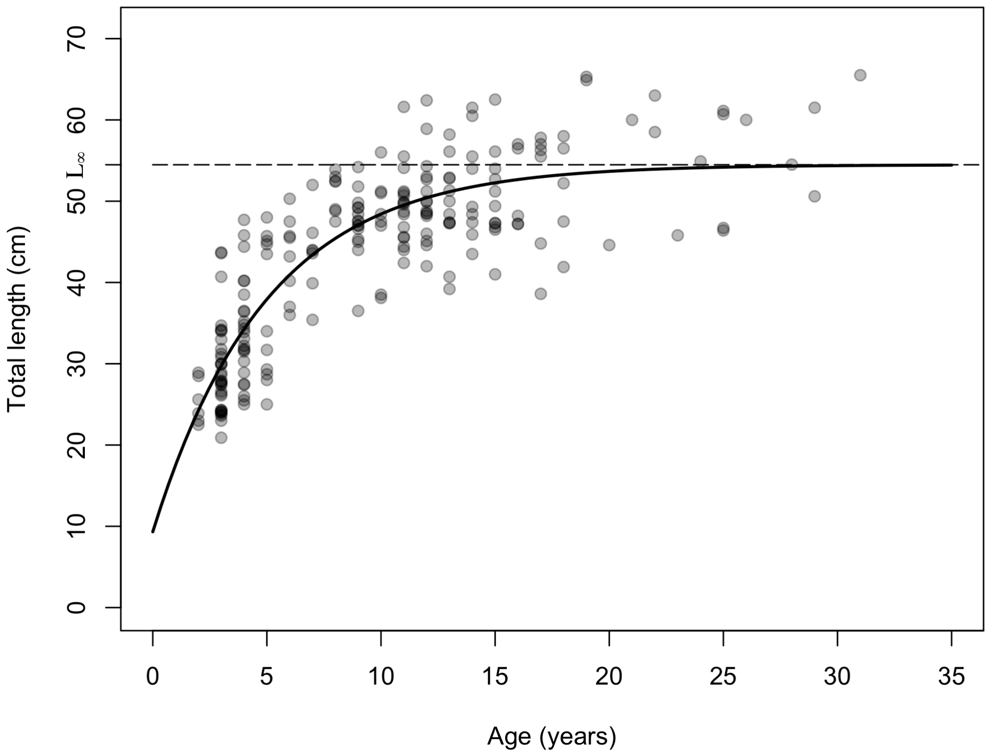

Figure 11: Length at age and von Bertalanffy growth curve for Pristipomoides filamentosus from the Mariana Islands. von Bertalanffy growth function parameter estimates were $L_\infty = 54.5$, $K = 0.201$, and $t_0 = –0.935$.

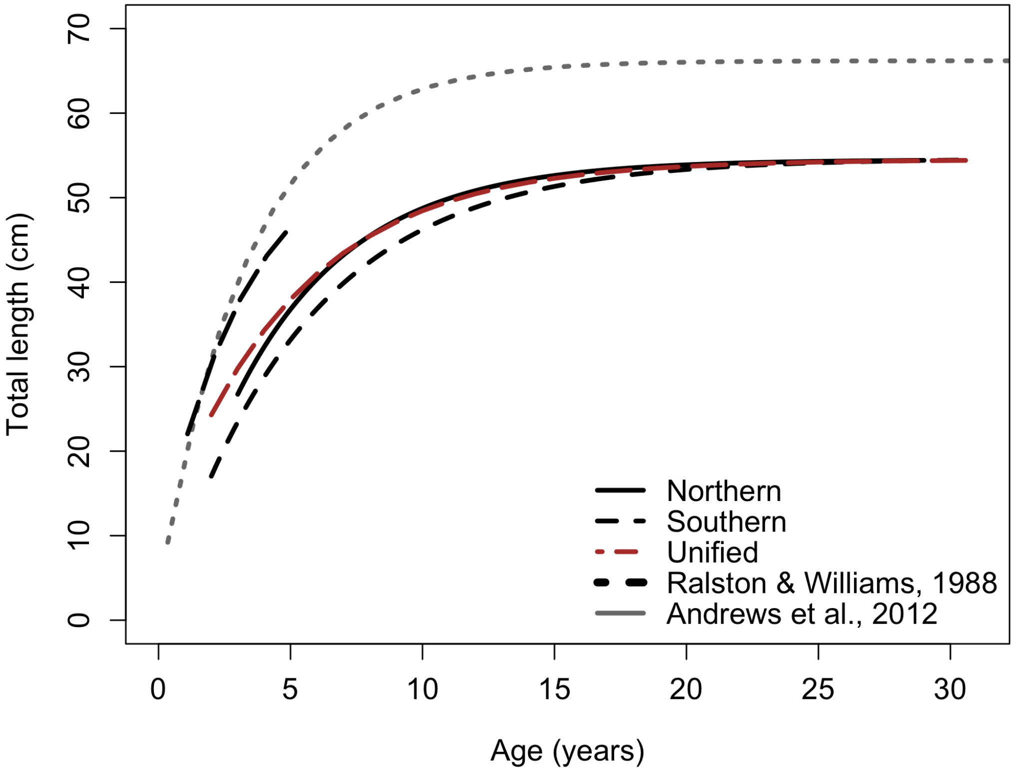

Figure 12: von Bertalanffy growth curves for northern and southern samples as well as a unified curve for *Pristipomoides filamentosus* from the Mariana Islands. Northern samples were defined as the islands north of Saipan (i.e, the islands of Farallon de Medinilla to Uracas), and the southern islands were defined as Saipan, Tinian, Rota, and Guam. Growth curves from Ralston and Williams (1988) and Andrews et al. (2012) are also included to compare temporal and spatial growth of *P. filamentosus.*

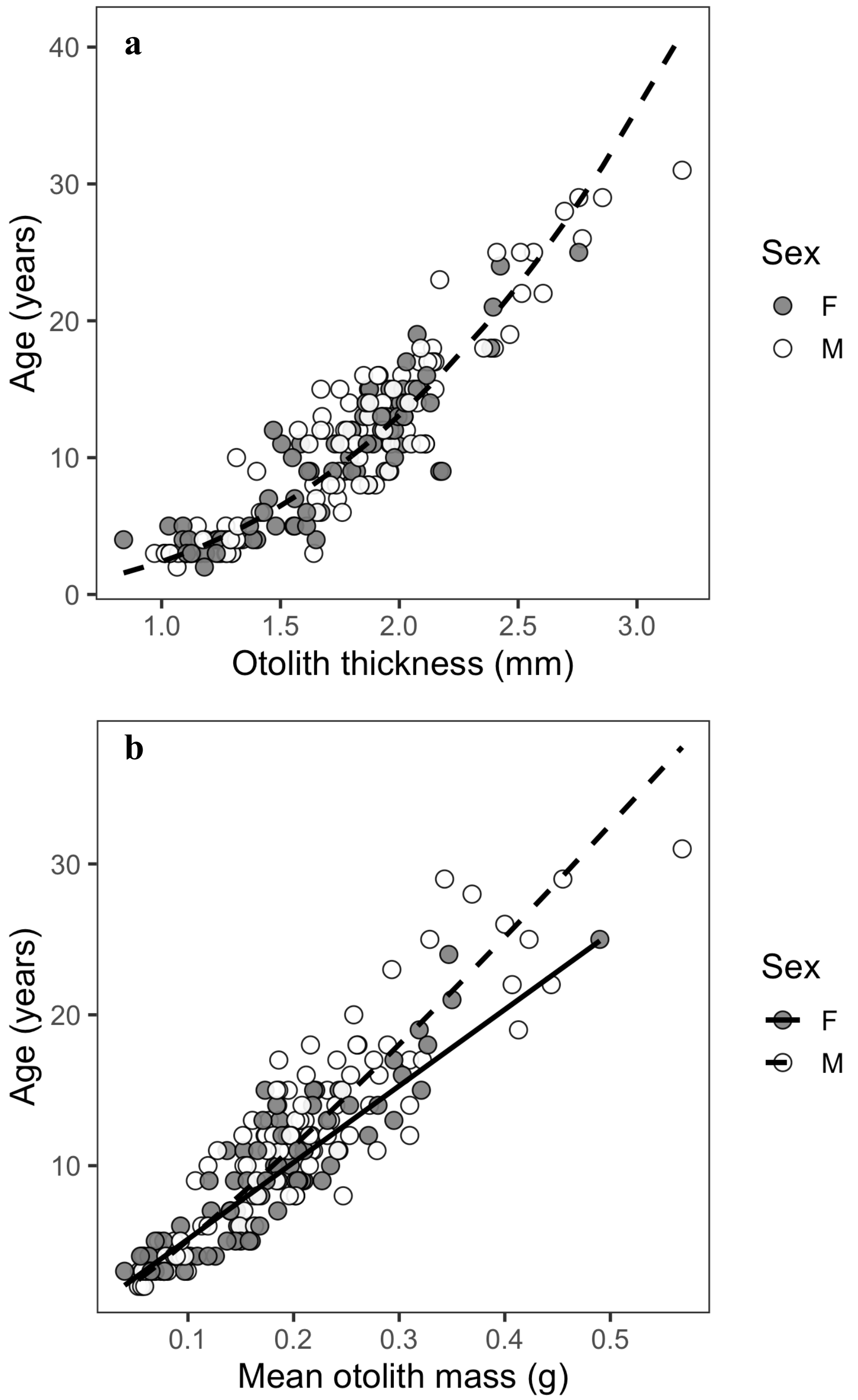

Figure 13: The relationship of age versus otolith thickness and otolith mass for *Pristipomoides filamentosus* from the Mariana Islands. **(a)** The prediction model for age-to-otolith thickness can be explained by the equation Age = 0.38 × Otolith thickness$^{2.45}$. (n = 176) **(b)** The relationship between otolith mass and age between male and female opakapaka can be predicted with the equation Age$_{\text{male}}$ = 1.86 × Otolith mass$^{1.57}$ (n = 84) and Age$_{\text{female}}$ = 1.70 × Otolith mass$^{0.99}$ (n = 120).

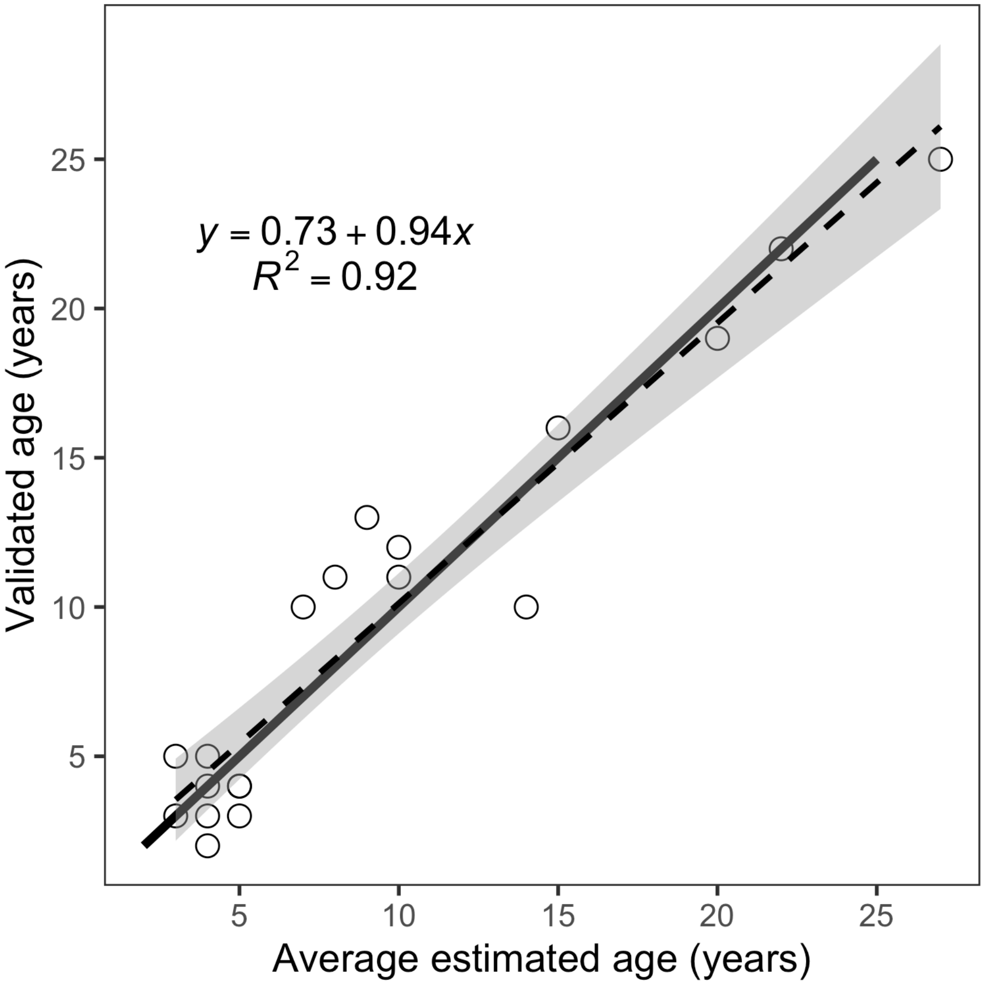

Figure 14: Comparison of average estimated age versus ^{14}C-validated age for Pristipomoides filamentosus (r = 0.957, n = 19, p < 0.0001). The solid line represents the best-fit line between age estimates (slope of 1). The broken line was a regression of the compared ages. Shaded area represents the 95% confidence interval.

APPENDICES

Appendix A. *Pristipomoides filamentosus* sample and measurement data from otoliths collected in the Mariana Islands on the NOAA Townsend Cromwell in 1982 and by the Guam Biosampling Program in 2012, 2014, and 2015

Original sample #, lab #	Collection year	Fish length (cm FL)	Otolith wt. (g)	∂^{13}C (‰)	Fraction modern (Fm)	Δ^{14}C (‰)	NOSAMS number
Paka-G01, GVDP-0092	2012.7	61.6	0.4900	-5.04	1.1344	127.5	OS-118510
Paka-G02, GVDP-0109	2014.7	62.4	0.3100	-5.62	1.0700	63.5	OS-118545
Paka-G03, GVDP-076	2014.6	57.0	0.2990	-5.61	1.0906	84.0	OS-118546
Paka-G04, GVDP-104	2014.7	27.5	0.0690	-5.53	1.0559	49.5	OS-130523
Paka-G06, GVDP-118	2014.8	28.9	0.0785	-5.70	1.0535	47.2	OS-130499
Paka-G07, GVDP-103	2014.7	30.0	0.0775	-5.51	1.0574	51.0	OS-130525
Paka-G08, GVDP-105	2014.7	31.8	0.0650	-5.23	1.0571	50.7	OS-130526
Paka-G09, GVDP-110	2014.7	31.8	0.0930	-5.83	1.0552	48.8	OS-130527
Paka-G10, GECC-962	2014.6	32.2	0.0970	-5.35	1.0538	47.4	OS-130528
Paka-G11, GECC-979	2014.7	34.0	0.0930	-5.62	1.0539	47.6	OS-130498
Paka-G12, GVDP-372	2015.8	35.2	0.0890	-5.37	1.0443	38.0	OS-130501
Paka-G14, GVDP-075	2014.6	44.7	0.1365	-5.52	1.0590	52.6	OS-130530
Paka-G15, GECC-1134	2015.6	50.0	0.2315	-5.51	1.0848	78.2	OS-130546
Paka-G16, GVDP-102	2014.7	50.7	0.2035	-5.74	1.0726	66.2	OS-130531
Paka-G17, GVDP-119	2014.8	55.5	0.2415	-5.40	1.0744	67.9	OS-130532
Paka 42, TC82-02-1279	1982.4	52.1	0.3360	-4.90	0.9766	-24.3	OS-84030
Paka 45, TC82-02-602	1982.4	51.2	0.3130	-4.90	1.0134	11.9	OS-84040
Paka 47, TC82-02-23	1982.3	49.1	0.1890	-4.90	1.1398	138.1	OS-84023
Paka 48, TC82-02-599	1982.4	45.3	0.2090	-4.82	1.1457	144.2	OS-84034

Appendix B. *Pristipomoides filamentosus* data collected in the Mariana Islands in 1982 and 2011–2018.

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
PF001 (18)	CNMI DFW	5/8/12	Saipan	3	23.0	202.5	0.1	IMM	M	NA	0.0560
PF002 (32)	CNMI DFW	4/19/12	Saipan	2	23.0	209.4	0.0	IMM	M	NA	0.0530
PF003 (33)	CNMI DFW	4/19/12	Saipan	2	23.9	235.7	0.0	IMM	M	NA	0.0570
PF004 (31)	CNMI DFW	4/19/12	Saipan	3	23.8	242.5	0.1	IMM	F	NA	0.0580
PF005 (30)	CNMI DFW	4/19/12	Saipan	5	25.0	301.7	0.1	IMM	F	1.0	0.0570
PF006 (35)	CNMI DFW	4/19/12	Saipan	3	23.6	236.8	0.0	IMM	M	NA	0.0540
PF007 (27)	CNMI DFW	8/11/12	Saipan	5	31.7	574.4	0.1	MAT	M	1.2	0.0870
PF008 (36)	CNMI DFW	4/19/12	Saipan	2	28.5	391.5	0.1	IMM	F	NA	0.0760
PF009 (30)	CNMI DFW	8/11/12	Saipan	5	28.7	439.1	0.2	IMM	F	1.1	0.0770
PF010 (2)	CNMI DFW	6/23/11	Tinian	3	28.5	413.6	0.1	NA	NA	NA	0.0730
PF011 (29)	CNMI DFW	4/19/12	Saipan	4	25.5	283.7	0.1	IMM	F	0.8	0.0570
PF012 (39)	CNMI DFW	8/30/12	Saipan	3	26.6	330.0	0.0	IMM	F	NA	0.0570
PF013 (26)	CNMI DFW	8/11/12	Saipan	3	28.9	471.1	0.2	IMM	M	NA	0.0740
PF014 (28)	CNMI DFW	8/11/12	Saipan	3	30.0	515.6	0.2	IMM	M	NA	0.0780
PF015 (22)	CNMI DFW	6/30/11	Saipan	4	35.4	860.0	1.3	NA	NA	NA	0.1020
PF016 (34)	CNMI DFW	4/19/12	Saipan	3	24.0	246.3	0.0	IMM	M	NA	0.0600
PF017 (40)	CNMI DFW	8/30/12	Saipan	3	20.9	163.9	0.1	IMM	F	NA	0.0400
PF018 (19)	CNMI DFW	5/8/12	Saipan	2	22.5	189.7	0.0	IMM	M	NA	0.0560
PF019 (5)	CNMI DFW	8/8/12	Saipan	NA	23.4	231.8	0.1	IMM	F	NA	NA
PF020 (37)	CNMI DFW	4/19/12	Saipan	4	27.4	381.5	0.2	IMM	F	NA	0.0670
PF021 (29)	CNMI DFW	8/11/12	Saipan	5	29.3	462.3	0.1	MAT	F	NA	0.0690
PF022 (31)	CNMI DFW	8/11/12	Saipan	NA	29.9	480.9	0.3	IMM	F	1.1	0.0680
PF023 (32)	CNMI DFW	8/11/12	Saipan	6	36.0	849.0	0.8	IMM	F	NA	0.0930
PF024 (16)	CNMI DFW	1/15/13	Saipan	3	40.5	1174.0	0.4	NA	NA	NA	0.1270
PF025 (15)	CNMI DFW	1/15/13	Saipan	7	43.0	1351.0	0.5	NA	NA	NA	0.1360
PF026 (3)	CNMI DFW	6/20/12	Saipan	7	43.9	1489.0	14.9	MAT	F	NA	0.1460
PF027 (4)	CNMI DFW	6/20/12	Saipan	9	44.0	1514.5	4.0	MAT	F	NA	0.1200
PF028 (5)	CNMI DFW	6/20/12	Saipan	7	44.0	1411.5	17.9	MAT	F	NA	0.1400

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
PF029 (SE-14-04-1497)	SE-14-04	7/10/14	Pagan	17	44.8	1580.0	7.0	MAT	M	NA	0.2410
PF030 (SE-14-04-1500)	SE-14-04	7/10/14	Pagan	10	38.5	900.0	10.0	MAT	M	NA	0.1530
PF031 (SE-14-04-1777)	SE-14-04	7/12/14	Guguan	10	47.5	1600.0	17.0	MAT	F	NA	0.1970
PF032 (SE-14-04-1778)	SE-14-04	7/12/14	Guguan	10	47.0	1620.0	4.0	MAT	M	NA	0.1560
PF033 (SE-14-04-1783)	SE-14-04	7/12/14	Guguan	13	47.3	1700.0	5.0	MAT	M	NA	0.2070
PF034 (SE-14-04-1836)	SE-14-04	7/13/14	Guguan	9	47.5	1720.0	19.0	MAT	F	NA	0.1440
PF035 (SE-14-04-1838)	SE-14-04	7/13/14	Guguan	7	52.0	2100.0	16.0	MAT	F	NA	0.1850
PF036 (SE-14-04-2121)	SE-14-04	7/15/14	Sarigan	13	52.9	2460.0	7.0	MAT	M	NA	0.2340
PF037 (SE-14-04-2142)	SE-14-04	7/15/14	Sarigan	6	40.2	1100.0	8.0	MAT	M	NA	0.1130
PF038 (SE-14-04-2141)	SE-14-04	7/15/14	Sarigan	26	54.6	2500.0	14.0	NA	NA	NA	0.3710
PF039 (SE-14-04-0349)	SE-14-04	6/24/14	Maug	7	43.6	1300.0	5.0	MAT	M	1.7	0.1410
PF040 (SE-14-04-0290)	SE-14-04	6/23/14	Uracas	9	51.8	2260.0	40.0	MAT	F	2.2	0.2100
PF041 (SE-14-04-0099)	SE-14-04	6/22/14	Uracas	9	45.3	2000.0	28.0	MAT	F	2.2	0.1860
PF042 (SE-14-04-0287)	SE-14-04	6/23/14	Uracas	11	48.7	1900.0	29.0	MAT	F	2.0	0.2060
PF043 (SE-14-04-0348)	SE-14-04	6/24/14	Maug	11	48.4	1880.0	10.0	MAT	M	2.1	0.1950
PF044 (SE-14-04-0292)	SE-14-04	6/23/14	Uracas	10	48.4	1720.0	27.0	MAT	F	1.8	0.1850
PF045 (SE-14-04-0296)	SE-14-04	6/23/14	Uracas	9	49.2	1840.0	19.0	MAT	M	2.0	0.1840
PF046 (SE-14-04-0291)	SE-14-04	6/23/14	Uracas	6	50.3	2000.0	25.0	MAT	F	1.7	0.1560
PF047 (SE-14-04-0308)	SE-14-04	6/24/14	Maug	8	47.5	1680.0	4.0	MAT	M	1.6	0.1630
PF048 (SE-14-04-0330)	SE-14-04	6/24/14	Maug	15	46.8	1620.0	13.0	MAT	M	2.0	0.2320
PF049 (SE-14-04-0289)	SE-14-04	6/23/14	Uracas	12	49.9	1640.0	17.0	MAT	M	1.8	0.2170
PF050 (SE-14-04-0324)	SE-14-04	6/24/14	Maug	18	58.0	3000.0	14.0	MAT	M	2.1	0.2610
PF051 (SE-14-04-0597)	SE-14-04	6/25/14	Maug	14	45.9	1400.0	8.0	MAT	M	1.8	0.1850
PF052 (SE-14-04-1779)	SE-14-04	7/12/14	Guguan	12	50.0	1900.0	6.0	MAT	M	1.8	0.1730
PF053 (SE-14-04-0091)	SE-14-04	6/22/14	Uracas	15	47.3	1500.0	60.0	MAT	F	2.0	0.2210
PF054 (SE-14-04-2122)	SE-14-04	7/15/14	Sarigan	26	60.0	3500.0	14.0	MAT	M	2.8	0.4000
PF055 (SE-14-04-1837)	SE-14-04	7/13/14	Guguan	3	40.7	1000.0	1.0	MAT	M	1.6	0.1180
PF056 (SE-14-04-1784)	SE-14-04	7/12/14	Guguan	11	46.8	1680.0	11.0	MAT	M	2.1	0.1770
PF057 (PRFI-05-110417)	NOAA Guam	11/4/17	Guam	3	31.2	542.0	0.1	IMM	M	1.2	0.0770
PF058 (SE-14-04-0092)	SE-14-04	6/22/14	Uracas	11	51.0	2000.0	20.0	MAT	M	2.0	0.2190

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
PF059 (SE-14-04-0100)	SE-14-04	6/22/14	Uracas	15	52.7	2250.0	80.0	MAT	F	1.9	0.2430
PF060 (SE-14-04-0107)	SE-14-04	6/22/14	Uracas	14	55.5	2500.0	17.0	MAT	M	2.1	0.2720
PF061 (SE-14-04-0240)	SE-14-04	6/23/14	Uracas	17	57.0	NA	26.0	MAT	M	2.2	0.3100
PF062 (SE-14-04-0241)	SE-14-04	6/23/14	Uracas	14	54.0	2000.0	18.0	MAT	M	1.9	0.2400
PF063 (SE-14-04-0286)	SE-14-04	6/23/14	Uracas	28	54.5	3500.0	20.0	MAT	M	2.7	0.3690
PF064 (SE-14-04-0323)	SE-14-04	6/24/14	Maug	17	57.8	2500.0	19.0	MAT	M	2.1	0.3220
PF065 (SE-14-04-1781)	SE-14-04	7/12/14	Guguan	13	56.1	3000.0	9.0	MAT	M	2.0	0.2350
PF066 (SE-14-04-2231)	SE-14-04	7/16/14	Sarigan	18	52.2	2140.0	9.0	MAT	M	2.4	0.2890
PF067 (SE-14-04-0095)	SE-14-04	6/22/14	Uracas	19	65.3	4500.0	36.0	MAT	M	2.5	0.4130
PF068 (SE-14-04-0089)	SE-14-04	6/22/14	Uracas	19	64.9	4000.0	70.0	MAT	F	2.1	0.3190
PF069 (SE-14-04-0242)	SE-14-04	6/23/14	Uracas	22	63.0	3500.0	35.0	MAT	M	2.5	0.4070
PF070 (SE-14-04-0097)	SE-14-04	6/22/14	Uracas	11	61.6	3000.0	100.0	MAT	F	2.0	0.2430
PF071 (SE-14-04-0149)	SE-14-04	6/22/14	Uracas	29	61.5	2500.0	31.0	MAT	M	2.9	0.4550
PF072 (SE-14-04-1076)	SE-14-04	6/30/14	Asuncion	25	60.7	3800.0	28.0	MAT	M	2.6	0.4230
PF073 (SE-14-04-0478)	SE-14-04	6/25/14	Maug	21	60.0	3000.0	74.0	MAT	F	2.4	0.3500
PF074 (SE-14-04-1495)	SE-14-04	7/10/14	Pagan	6	37.0	900.0	7.0	MAT	M	1.4	0.1190
PF075 (SE-14-04-1502)	SE-14-04	7/10/14	Pagan	17	38.6	920.0	7.0	MAT	M	2.1	0.1860
PF076 (SE-14-04-2116)	SE-14-04	7/15/14	Sarigan	22	58.5	3000.0	13.0	MAT	M	2.6	0.4440
PF077 (SE-14-04-0086)	SE-14-04	6/22/14	Uracas	12	53.0	2250.0	20.0	MAT	M	2.0	0.2320
PF078 (SE-14-04-0147)	SE-14-04	6/22/14	Uracas	9	49.2	1500.0	39.0	MAT	F	1.9	0.2080
PF079 (SE-14-04-0151)	SE-14-04	6/22/14	Uracas	12	42.0	1000.0	42.0	MAT	F	1.5	0.1320
PF080 (SE-14-04-0213)	SE-14-04	6/23/14	Uracas	16	56.5	3500.0	26.0	MAT	M	2.0	0.2810
PF081 (SE-14-04-0482)	SE-14-04	6/25/14	Maug	18	56.5	2900.0	49.0	MAT	F	2.4	0.3270
PF082 (SE-14-04-0599)	SE-14-04	6/25/14	Maug	15	56.1	2500.0	38.0	MAT	F	2.0	0.2190
PF083 (SE-14-04-0601)	SE-14-04	6/25/14	Maug	11	44.4	1400.0	4.0	MAT	M	1.8	0.1870
PF085 (SE-14-04-1490)	SE-14-04	7/10/14	Pagan	13	40.7	1100.0	3.0	MAT	M	1.9	0.1770
PF086 (SE-14-04-2115)	SE-14-04	7/15/14	Sarigan	17	56.3	2500.0	10.0	MAT	M	2.1	0.2760
PF087 (SE-14-04-1504)	SE-14-04	7/10/14	Pagan	13	39.2	1040.0	3.0	MAT	M	2.0	0.2110
PF088 (SE-14-04-1505)	SE-14-04	7/10/14	Pagan	23	45.8	1500.0	5.0	MAT	M	2.2	0.2930
PF089 (SE-14-04-1498)	SE-14-04	7/10/14	Pagan	15	41.0	1180.0	7.0	MAT	M	2.1	0.1950

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
PF090 (SE-14-04-1499)	SE-14-04	7/10/14	Pagan	18	41.9	1200.0	7.0	MAT	M	2.4	0.2600
PF091 (SE-14-04-1785)	SE-14-04	7/12/14	Guguan	15	54.0	2500.0	7.0	MAT	M	2.2	0.2460
PF092 (SE-14-04-2120)	SE-14-04	7/15/14	Sarigan	24	54.9	2500.0	72.0	MAT	F	2.4	0.3470
PF093 (SE-14-04-0088)	SE-14-04	6/22/14	Uracas	15	46.5	1500.0	14.0	MAT	M	1.7	0.1860
PF094 (SE-14-04-0093)	SE-14-04	6/22/14	Uracas	12	48.8	1750.0	11.0	MAT	M	1.7	0.1740
PF095 (SE-14-04-0101)	SE-14-04	6/22/14	Uracas	9	47.0	1500.0	36.0	MAT	F	1.8	0.2020
PF096 (SE-14-04-0102)	SE-14-04	6/22/14	Uracas	11	49.9	2000.0	33.0	MAT	M	2.0	0.2170
PF097 (SE-14-04-0103)	SE-14-04	6/22/14	Uracas	15	47.3	1500.0	44.0	MAT	F	1.9	0.1730
PF098 (SE-14-04-0104)	SE-14-04	6/22/14	Uracas	13	48.4	1750.0	12.0	MAT	M	1.9	0.2060
PF099 (SE-14-04-0105)	SE-14-04	6/22/14	Uracas	12	46.0	1500.0	15.0	MAT	M	1.6	0.1520
PF100 (SE-14-04-0106)	SE-14-04	6/22/14	Uracas	9	45.0	1500.0	24.0	MAT	F	1.6	0.1560
PF101 (SE-14-04-0148)	SE-14-04	6/22/14	Uracas	13	47.3	1500.0	60.0	MAT	F	1.9	0.1870
PF102 (SE-14-04-0150)	SE-14-04	6/22/14	Uracas	13	51.3	2000.0	21.0	MAT	M	1.7	0.2020
PF103 (SE-14-04-0152)	SE-14-04	6/22/14	Uracas	9	49.8	2000.0	19.0	MAT	M	2.0	0.2040
PF104 (SE-14-04-0153)	SE-14-04	6/22/14	Uracas	16	47.2	1500.0	21.0	MAT	M	1.9	0.2120
PF105 (SE-14-04-0154)	SE-14-04	6/22/14	Uracas	8	49.0	1750.0	16.0	MAT	M	1.9	0.2020
PF106 (SE-14-04-0156)	SE-14-04	6/22/14	Uracas	9	47.0	1750.0	26.0	MAT	M	1.7	0.1650
PF107 (SE-14-04-0157)	SE-14-04	6/22/14	Uracas	9	47.6	1500.0	54.0	MAT	F	1.8	0.2050
PF108 (SE-14-04-0158)	SE-14-04	6/22/14	Uracas	14	49.3	2000.0	38.0	MAT	F	2.0	0.2180
PF109 (SE-14-04-0160)	SE-14-04	6/22/14	Uracas	13	47.4	1500.0	21.0	MAT	M	1.9	0.1610
PF110 (SE-14-04-0474)	SE-14-04	6/25/14	Maug	14	48.4	1960.0	17.0	MAT	F	2.1	0.2530
PF111 (SE-14-04-0596)	SE-14-04	6/25/14	Maug	14	47.4	1520.0	22.0	MAT	F	1.9	0.1840
PF112 (SE-14-04-0598)	SE-14-04	6/25/14	Maug	18	47.5	1530.0	8.0	MAT	M	2.1	0.2160
PF113 (SE-14-04-0600)	SE-14-04	6/25/14	Maug	9	48.4	1530.0	22.0	MAT	F	1.8	0.2040
PF114 (SE-14-04-0603)	SE-14-04	6/25/14	Maug	11	49.8	1560.0	7.0	MAT	M	2.1	0.2100
PF115 (SE-14-04-0604)	SE-14-04	6/25/14	Maug	15	49.4	1526.0	11.0	MAT	M	2.0	0.1840
PF116 (SE-14-04-0666)	SE-14-04	6/26/14	Maug	10	40.0	1060.0	16.0	NA	NA	2.0	0.2470
PF117 (SE-14-04-0155)	SE-14-04	6/22/14	Uracas	12	48.5	1500.0	18.0	MAT	M	1.8	0.1930
PF118 (SE-14-04-1496)	SE-14-04	7/10/14	Pagan	25	46.7	1020.0	8.0	MAT	M	2.4	0.2500
PF119 (SE-14-04-1787)	SE-14-04	7/12/14	Guguan	12	45.1	1600.0	6.0	MAT	M	NA	0.1810

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
PF120 (SE-14-04-1834)	SE-14-04	7/13/14	Guguan	6	43.2	1340.0	3.0	IMM	F	NA	0.1470
PF121 (SE-14-04-1835)	SE-14-04	7/13/14	Guguan	14	47.4	1620.0	8.0	NA	NA	2.2	0.1940
PF122 (SE-14-04-1965)	SE-14-04	7/13/14	Guguan	9	46.6	1500.0	20.0	MAT	F	1.6	0.1740
PF123 (SE-14-04-0098)	SE-14-04	6/22/14	Uracas	12	51.2	2000.0	48.0	MAT	F	1.8	0.1940
PF124 (SE-14-04-0293)	SE-14-04	6/23/14	Uracas	8	48.8	1900.0	12.0	MAT	M	1.7	0.2020
PF125 (SE-14-04-0294)	SE-14-04	6/23/14	Uracas	10	51.0	2300.0	15.0	MAT	M	1.8	0.2150
PF126 (SE-14-04-0295)	SE-14-04	6/23/14	Uracas	12	48.5	1700.0	17.0	MAT	M	1.8	0.1980
PF127 (SE-14-04-0321)	SE-14-04	6/24/14	Maug	12	52.7	3000.0	12.0	MAT	M	2.0	0.2530
PF128 (SE-14-04-0329)	SE-14-04	6/24/14	Maug	7	46.1	1500.0	8.0	MAT	M	1.7	0.1530
PF129 (SE-14-04-0545)	SE-14-04	6/25/14	Maug	11	45.6	1580.0	9.0	MAT	M	1.8	0.1750
PF130 (SE-14-04-0602)	SE-14-04	6/25/14	Maug	12	44.6	1480.0	19.0	MAT	F	2.0	0.1890
PF131 (SE-14-04-0697)	SE-14-04	6/26/14	Maug	11	51.2	2000.0	29.0	MAT	F	1.9	0.2100
PF132 (SE-14-04-1491)	SE-14-04	7/10/14	Pagan	16	47.2	1800.0	11.0	MAT	M	1.9	0.2540
PF133 (SE-14-04-1503)	SE-14-04	7/10/14	Pagan	20	44.6	1460.0	10.0	MAT	M	NA	0.2570
PF134 (SE-14-04-1506)	SE-14-04	7/10/14	Pagan	29	50.6	2020.0	7.0	MAT	M	2.8	0.3430
PF135 (SE-14-04-1780)	SE-14-04	7/12/14	Guguan	12	48.2	1740.0	6.0	MAT	M	NA	0.1970
PF136 (SE-14-04-0090)	SE-14-04	6/22/14	Uracas	8	52.4	2500.0	54.0	MAT	F	1.9	0.1690
PF137 (SE-14-04-0094)	SE-14-04	6/22/14	Uracas	13	52.8	2500.0	45.0	MAT	F	2.0	0.1710
PF138 (SE-14-04-0326)	SE-14-04	6/24/14	Maug	6	45.7	1400.0	16.0	MAT	M	1.8	0.1490
PF139 (SE-14-04-0365)	SE-14-04	6/24/14	Maug	15	53.2	3000.0	26.0	NA	NA	2.0	0.3110
PF140 (SE-14-04-0606)	SE-14-04	6/25/14	Maug	11	42.4	1200.0	NA	MAT	M	1.6	0.1280
PF141 (SE-14-04-1782)	SE-14-04	7/12/14	Guguan	6	45.5	1500.0	4.0	MAT	M	1.7	0.1630
PF142 (SE-14-04-2123)	SE-14-04	7/15/14	Sarigan	8	53.9	2500.0	8.0	MAT	M	1.9	0.2470
PF143 (GUPRFI 52518-01)	Marc Artero	5/24/18	Guam	3	34.1	750.0	0.7	IMM	F	1.1	0.0660
PF144 (GUPRFI 52518-02)	Marc Artero	5/24/18	Guam	6	47.5	1750.0	25.2	MAT	F	1.4	0.1680
PF145 (GFCV-004)	NOAA Guam	7/16/18	Guam	8	53.0	2477.0	3.5	MAT	M	1.8	0.1960
PF147 (GVDP-780)	NOAA Guam	4/11/18	Guam	3	28.6	422.0	0.1	IMM	M	1.1	0.0660
PF148 (GVDP-781)	NOAA Guam	4/11/18	Guam	4	33.1	649.0	0.2	MAT	M	1.3	0.0870
PF149 (GVDP-782)	NOAA Guam	4/11/18	Guam	4	27.5	362.0	0.1	IMM	F	1.2	0.0630
PF150 (GVDP-783)	NOAA Guam	4/11/18	Guam	5	29.0	439.0	0.1	NA	NA	1.3	0.0770

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PF151 (GVDP-784)	NOAA Guam	4/11/18	Guam	4	31.7	589.0	0.2	MAT	M	1.3	0.0860
PF152 (GVDP-785)	NOAA Guam	4/11/18	Guam	3	29.9	477.0	0.1	MAT	M	1.3	0.0770
PF153 (GECC-1543)	NOAA Guam	4/11/18	Guam	2	25.1	280.0	NA	NA	NA	1.1	0.0540
PF154 (GECC-1544)	NOAA Guam	4/11/18	Guam	2	26.0	303.0	NA	NA	NA	1.1	0.0520
PF155 (GECC-1545)	NOAA Guam	4/11/18	Guam	3	34.0	673.0	0.3	IMM	F	1.3	0.0770
PF156 (GECC-1546)	NOAA Guam	4/11/18	Guam	3	33.0	699.0	0.2	MAT	M	1.2	0.0810
PF157 (GECC-1547)	NOAA Guam	4/11/18	Guam	4	33.9	752.0	0.2	MAT	M	1.3	0.0930
PF158 (GECC-1548)	NOAA Guam	4/11/18	Guam	4	30.3	501.0	0.1	MAT	M	1.3	0.0790
PF159 (SE-14-04-0159)	SE-14-04	6/22/14	Uracas	11	49.6	2000.0	37.0	MAT	F	1.7	0.1660
PF160 (SE-14-04-0325)	SE-14-04	6/24/14	Maug	15	51.2	2000.0	14.0	MAT	M	1.8	NA
PF161 (SE-14-04-1489)	SE-14-04	7/10/14	Pagan	16	48.2	1720.0	6.0	MAT	M	1.9	NA
PF162 (SE-14-04-1492)	SE-14-04	7/10/14	Pagan	14	43.5	1400.0	8.0	MAT	M	1.9	0.2080
PF164 (PRFI-01-110417)	NOAA Guam	11/4/17	Guam	3	27.7	412.0	0.1	IMM	F	1.1	0.0610
PF165 (PRFI-02-110417)	NOAA Guam	11/4/17	Guam	3	24.3	272.0	0.1	IMM	F	1.0	0.0570
PF166 (PRFI-03-110417)	NOAA Guam	11/4/17	Guam	3	26.3	339.0	0.1	IMM	M	1.1	0.0680
PF167 (PRFI-04-110417)	NOAA Guam	11/4/17	Guam	3	27.8	408.0	0.1	IMM	M	1.0	0.0630
PF168 (PRFI-06-110417)	NOAA Guam	11/4/17	Guam	2	27.1	368.0	NA	NA	NA	1.1	0.0590
PF169 (PRFI-07-110417)	NOAA Guam	11/4/17	Guam	2	25.6	295.0	0.1	IMM	M	1.1	0.0590
PF170 (PRFI-08-110417)	NOAA Guam	11/4/17	Guam	3	27.4	403.0	NA	IMM	M	1.0	0.0600
PF171 (PRFI-09-110417)	NOAA Guam	11/4/17	Guam	3	27.9	421.0	NA	IMM	M	1.0	0.0650
PF172 (PRFI-10-110417)	NOAA Guam	11/4/17	Guam	3	26.1	316.0	NA	IMM	M	1.1	0.0630
PF173 (PRFI-11-110417)	NOAA Guam	11/4/17	Guam	2	27.5	383.0	NA	NA	NA	1.1	0.0380
PF174 (PRFI-12-110417)	NOAA Guam	11/4/17	Guam	3	24.1	261.0	NA	MAT	M	1.1	0.0600
PF175 (PRFI-13-110417)	NOAA Guam	11/4/17	Guam	3	24.1	254.0	NA	MAT	M	1.0	0.0570
PF176 (GECC-1456)	NOAA Guam	7/13/17	Guam	5	43.5	1394.0	4.8	IMM	F	1.6	0.1500
PF177 (GECC-1481)	NOAA Guam	7/25/17	Guam	31	65.5	4386.0	12.8	MAT	M	3.2	0.5680
PF178 (GECC-1487)	NOAA Guam	8/6/17	Guam	4	38.5	1020.0	1.1	IMM	F	1.4	0.1260
PF179 (GECC-1488)	NOAA Guam	8/6/17	Guam	4	34.8	777.0	0.6	IMM	F	1.2	0.0900
PF180 (GECC-1489)	NOAA Guam	8/6/17	Guam	4	36.5	832.0	0.3	MAT	M	1.3	0.0950
PF181 (GECC-1490)	NOAA Guam	8/6/17	Guam	3	30.8	537.0	0.2	MAT	M	1.1	0.0770

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PF182 (GECC-1491)	NOAA Guam	8/6/17	Guam	4	26.0	323.0	0.2	IMM	F	1.1	0.0550
PF183 (GECC-1492)	NOAA Guam	8/6/17	Guam	3	24.4	271.0	NA	NA	NA	1.1	0.0580
PF184 (GECC-1504)	NOAA Guam	8/11/17	Guam	10	56.0	2873.0	19.2	MAT	F	2.0	0.2350
PF185 (GECC-1505)	NOAA Guam	8/11/17	Guam	4	47.7	1790.0	3.9	IMM	F	1.7	0.1650
PF186 (GVDP-511)	NOAA Guam	8/9/16	Guam	5	45.1	1622.0	2.0	IMM	F	1.5	0.1450
PF187 (GVDP-512)	NOAA Guam	8/9/16	Guam	5	48.0	1936.0	5.8	MAT	F	1.6	0.1600
PF188 (GVDP-542)	NOAA Guam	10/9/16	Guam	7	35.4	757.0	17.6	MAT	F	1.6	0.1400
PF189 (GVDP-802)	NOAA Guam	5/22/18	Guam	9	54.2	2852.0	52.4	MAT	F	1.7	0.2270
PF190 (PRFI-081218-01)	NOAA Guam	8/12/18	Guam	4	31.5	570.0	0.4	IMM	F	1.1	0.0870
PF191 (PRFI-081218-02)	NOAA Guam	8/12/18	Guam	3	34.2	744.0	0.3	MAT	M	1.3	0.0995
PF192 (PRFI-081218-03)	NOAA Guam	8/12/18	Guam	4	34.3	727.0	0.5	IMM	F	1.2	0.1020
PF193 (PRFI-081218-04)	NOAA Guam	8/12/18	Guam	3	34.7	790.0	0.4	IMM	F	1.2	0.0968
PF194 (PRFI-081218-05)	NOAA Guam	8/12/18	Guam	4	45.8	1764.0	1.0	MAT	M	NA	0.1530
PF195 (PRFI-09618-01)	NOAA Guam	9/6/18	Guam	4	40.2	1117.0	1.5	IMM	F	1.3	0.1090
PF196 (PRFI-09618-02)	NOAA Guam	9/6/18	Guam	3	43.7	1523.0	1.1	MAT	M	1.3	0.1290
PF197 (PRFI-09618-03)	NOAA Guam	9/6/18	Guam	3	43.6	1597.0	1.5	MAT	M	1.3	0.1350
PF198 (PRFI-09618-04)	NOAA Guam	9/6/18	Guam	17	55.5	3274.0	68.0	MAT	F	2.0	0.2950
PF199 (PRFI-101018-01)	Marc Artero	10/10/18	Rota	12	58.9	3356.0	34.6	MAT	F	1.9	0.2710
PF200 (PRFI-101018-02)	Marc Artero	10/10/18	Rota	8	52.5	2620.0	26.0	MAT	M	1.7	0.1660
PF201 (SE-18-02-1535)	SE-18-02	6/15/18	Uracas	5	45.7	1500.0	20.0	MAT	F	1.6	0.1580
PF202 (SE-18-02-1538)	SE-18-02	6/15/18	Uracas	4	40.2	1000.0	20.0	MAT	F	1.3	0.1190
PF203 (SE-18-02-1539)	SE-18-02	6/15/18	Uracas	25	46.4	2500.0	15.0	MAT	M	2.5	0.3290
PF204 (SE-18-02-1541)	SE-18-02	6/15/18	Uracas	6	NA	2250.0	60.0	MAT	F	1.6	0.1980
PF205 (SE-18-02-1545)	SE-18-02	6/15/18	Uracas	15	62.5	4000.0	70.0	MAT	F	2.1	0.3210
PF206 (SE-18-02-1547)	SE-18-02	6/15/18	Uracas	12	54.3	2750.0	10.0	MAT	M	1.9	0.2150
PF207 (SE-18-02-1551)	SE-18-02	6/15/18	Uracas	13	58.2	3250.0	60.0	MAT	F	2.0	0.2950
PF208 (SE-18-02-1552)	SE-18-02	6/15/18	Uracas	14	60.5	3500.0	65.0	MAT	F	2.0	0.2800
PF209 (SE-18-02-1553)	SE-18-02	6/15/18	Uracas	4	44.4	1500.0	20.0	MAT	F	1.4	0.1380
PF210 (SE-18-02-1554)	SE-18-02	6/15/18	Uracas	14	61.5	3750.0	20.0	MAT	M	2.0	0.3100
PF211 (SE-18-02-1961)	SE-18-02	6/28/18	Pagan	11	54.1	2500.0	10.0	MAT	M	2.1	0.2790

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SE-14-04-0096	SE-14-04	6/22/14	Uracas	NA	46.8	2500.0	24.0	MAT	M	NA	NA
SE-14-04-0239	SE-14-04	6/23/14	Uracas	NA	54.1	NA	47.0	MAT	F	NA	NA
SE-14-04-0288	SE-14-04	6/23/14	Uracas	NA	50.6	2120.0	14.0	MAT	M	NA	0.1790
SE-14-04-0328	SE-14-04	6/24/14	Maug	NA	47.6	1800.0	17.0	MAT	F	NA	NA
SE-14-04-0479	SE-14-04	6/25/14	Maug	NA	51.7	2450.0	36.0	MAT	F	NA	NA
SE-14-04-0605	SE-14-04	6/25/14	Maug	NA	54.9	3000.0	44.0	MAT	F	NA	NA
SE-14-04-1493	SE-14-04	7/10/14	Pagan	NA	50.0	1900.0	22.0	MAT	F	NA	0.3760
SE-14-04-1494	SE-14-04	7/10/14	Pagan	NA	46.7	1500.0	8.0	MAT	M	NA	0.2510
SE-14-04-1501	SE-14-04	7/10/14	Pagan	NA	39.5	1000.0	10.0	MAT	M	NA	NA
SE-14-04-1776	SE-14-04	7/12/14	Guguan	NA	59.8	3500.0	40.0	MAT	F	NA	0.2330
SE-14-04-1786	SE-14-04	7/12/14	Guguan	NA	50.8	1980.0	5.0	MAT	M	NA	0.2010
SE-14-04-2232	SE-14-04	7/16/14	Sarigan	NA	54.5	2480.0	20.0	MAT	F	NA	NA
SE-18-02-1546	SE-18-02	6/15/18	Uracas	NA	46.9	1500.0	10.0	MAT	M	NA	NA
GUPRFI 52518-03	Marc Artero	5/24/18	Guam	NA	46.7	1750.0	2.6	MAT	M	NA	NA
GCDD-055	NOAA Guam	8/2/12	Guam	NA	29.5	432.0	0.9	MAT	M	1.6	0.1140
GECC-1276	NOAA Guam	8/27/16	Guam	4	28.0	396.0	NA	NA	NA	1.0	0.0670
GECC-1277	NOAA Guam	8/27/16	Guam	11	44.0	1622.0	2.0	IMM	F	1.6	0.1370
GECC-1278	NOAA Guam	8/27/16	Guam	10	38.1	1041.0	0.7	MAT	M	1.3	0.1190
GECC-1279	NOAA Guam	8/27/16	Guam	5	26.2	313.0	NA	NA	NA	1.2	0.0580
GECC-1280	NOAA Guam	8/27/16	Guam	4	23.7	239.0	NA	NA	NA	1.2	0.0480
GECC-1281	NOAA Guam	8/27/16	Guam	4	25.0	278.0	NA	MAT	M	1.2	0.0580
GECC-1282	NOAA Guam	8/27/16	Guam	4	27.0	344.0	NA	NA	NA	1.2	0.0670
GECC-1283	NOAA Guam	8/27/16	Guam	9	36.5	869.0	0.6	MAT	M	1.4	0.1070
GECC-1284	NOAA Guam	8/27/16	Guam	11	45.5	1617.0	1.7	IMM	F	1.5	0.1530
GECC-1285	NOAA Guam	8/27/16	Guam	7	39.9	1117.0	2.2	IMM	F	1.5	0.1220
GVDP-444	NOAA Guam	6/20/16	Guam	3	24.3	270.0	0.1	IMM	F	1.2	0.0560
GVDP-457	NOAA Guam	7/3/16	Guam	NA	32.7	624.0	1.8	MAT	M	2.1	0.1760
GVDP-458	NOAA Guam	7/3/16	Guam	5	28.0	357.0	1.8	MAT	M	1.3	0.0720
GVDP-459	NOAA Guam	7/3/16	Guam	10	51.2	2234.0	22.1	MAT	F	1.6	0.1820
GVDP-460	NOAA Guam	7/3/16	Guam	NA	31.5	532.0	2.4	MAT	M	1.8	0.1390

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
GVDP-461	NOAA Guam	7/3/16	Guam	NA	35.2	727.0	11.5	MAT	F	1.8	0.1580
GVDP-502	NOAA Guam	7/23/16	Guam	NA	55.0	2724.0	19.0	MAT	F	NA	NA
GVDP-675	NOAA Guam	2/19/17	Guam	NA	32.5	590.0	0.3	MAT	M	NA	NA
GVDP-730	NOAA Guam	7/27/17	Guam	NA	33.0	672.0	0.5	IMM	F	NA	NA
GVDP-731	NOAA Guam	7/27/17	Guam	NA	50.5	2151.0	22.5	MAT	F	NA	NA
GVDP-732	NOAA Guam	7/27/17	Guam	NA	54.4	2503.0	26.3	MAT	F	NA	NA
GVDP-734	NOAA Guam	7/31/17	Guam	NA	45.9	1691.0	1.7	IMM	F	NA	NA
GVDP-735	NOAA Guam	7/31/17	Guam	NA	56.5	3002.0	6.1	MAT	M	NA	NA
GVDP-736	NOAA Guam	8/3/17	Guam	NA	31.8	605.0	0.4	NA	NA	NA	NA
GVDP-741	NOAA Guam	8/5/17	Guam	NA	32.3	638.0	0.3	IMM	F	NA	NA
GVDP-742	NOAA Guam	8/5/17	Guam	NA	34.7	791.0	0.8	MAT	M	NA	NA
GVDP-743	NOAA Guam	8/5/17	Guam	NA	32.1	617.0	0.2	MAT	M	NA	NA
GVDP-744	NOAA Guam	8/5/17	Guam	NA	32.0	614.0	0.4	IMM	F	NA	NA
GVDP-745	NOAA Guam	8/5/17	Guam	NA	32.2	628.0	0.4	IMM	F	NA	NA
GVDP-746	NOAA Guam	8/5/17	Guam	NA	50.1	2300.0	9.7	MAT	F	NA	NA
GVDP-747	NOAA Guam	8/6/17	Guam	NA	28.3	404.0	0.1	MAT	M	NA	NA
GVDP-748	NOAA Guam	8/6/17	Guam	NA	22.6	219.0	NA	NA	NA	NA	NA
GVDP-749	NOAA Guam	8/6/17	Guam	NA	32.2	614.0	0.3	MAT	M	NA	NA
GVDP-750	NOAA Guam	8/6/17	Guam	NA	35.0	734.0	0.4	IMM	F	NA	NA
GVDP-751	NOAA Guam	8/6/17	Guam	NA	37.7	944.0	0.7	IMM	F	NA	NA
GVDP-752	NOAA Guam	8/6/17	Guam	NA	24.9	293.0	NA	NA	NA	NA	NA
[α] Paka-G01-GCDD-092	NOAA Guam	9/3/12	Guam	25	61.1	3676.0	15.6	MAT	F	2.8	0.4900
[α] Paka-G02-GVDP-109	NOAA Guam	9/23/14	Guam	12	62.4	4025.0	8.0	MAT	M	1.7	0.3100
[α] Paka-G03-GVDP-076	NOAA Guam	8/22/14	Guam	16	57.0	2494.0	14.5	MAT	F	2.1	0.3030
[α] Paka-G04-GVDP-104	NOAA Guam	9/23/14	Guam	3	27.5	391.0	0.2	IMM	F	1.1	0.0690
Paka-G05-GVDP-117	NOAA Guam	11/4/14	Guam	4	28.9	406.0	0.1	MAT	M	1.2	0.0760
[α] Paka-G06-GVDP-118	NOAA Guam	11/4/14	Guam	2	28.9	423.0	0.2	IMM	F	1.2	0.0790
[α] Paka-G07-GVDP-103	NOAA Guam	9/23/14	Guam	3	30.0	467.0	0.3	IMM	F	1.1	0.0780
[α] Paka-G08-GVDP-105	NOAA Guam	9/23/14	Guam	3	31.8	576.0	0.1	IMM	F	1.2	0.0650
[α] Paka-G09-GVDP-110	NOAA Guam	9/23/14	Guam	4	31.8	576.0	0.3	MAT	M	1.3	0.0930

Sample ID # (original tag #)	Source	Collection date	Location	Age (yr)	Fish lgth (cm FL)	Fish wt (g)	Gonad wt (g)	Maturity	Sex	Oto thknss (mm)	Oto wt (g)
[α] Paka-G10-GECC-962	NOAA Guam	8/24/14	Guam	4	32.2	602.0	0.5	MAT	M	1.3	0.0970
[α] Paka-G11-GECC-979	NOAA Guam	9/19/14	Guam	5	34.0	770.0	NA	MAT	M	1.3	0.0930
[α] Paka-G12-GVDP-372	NOAA Guam	10/12/15	Guam	4	35.2	807.0	0.3	MAT	M	1.2	0.0890
Paka-G13-GVDP-106	NOAA Guam	9/23/14	Guam	4	36.4	835.0	0.3	MAT	M	1.3	0.0990
[α] Paka-G14-GVDP-075	NOAA Guam	8/24/14	Guam	5	44.7	1544.0	3.3	IMM	F	1.4	0.1370
[α] Paka-G15-GECC-1134	NOAA Guam	7/28/15	Guam	13	50.0	2320.0	24.0	MAT	F	1.9	0.2320
[α] Paka-G16-GVDP-102	NOAA Guam	9/23/14	Guam	11	50.7	2268.0	33.2	MAT	F	1.9	0.2040
[α] Paka-G17-GVDP-119	NOAA Guam	11/4/14	Guam	11	55.5	2841.0	3.5	MAT	M	1.8	0.2420
[α,ϕ] Paka 42 (TC82-02-1279)	Andrews et al., 2012	5/29/82	NA	22	52.1	2420.0	NA	NA	NA	NA	0.3360
[α,ϕ] Paka 45 (TC82-02-602)	Andrews et al., 2012	5/17/82	NA	19	51.2	2270.0	NA	NA	NA	NA	0.3130
[α,ϕ] Paka 47 (TC82-02-23)	Andrews et al., 2012	4/20/82	NA	10	49.1	2200.0	NA	NA	NA	NA	0.1890
[α,ϕ] Paka 48 (TC82-02-599)	Andrews et al., 2012	5/17/82	NA	10	45.3	1590.0	NA	NA	NA	NA	0.2090

α = Age validated

ϕ = Published in Andrews et al. (2012) and collected by the NOAA Townsend Cromwell

NA = Not available

MAT/IMM = Mature/ Immature

M/F = Male/Female fish

SE = NOAA Oscar Elton Sette

Oto thknss = mean otolith thicknes

Oto wt = mean otolith mass