## Life History and Length-Derived Parameters

### MHI Coral Reef Ecosystem Components – Coral Reef Ecosystem Species Life History

#### Age, Growth, and Reproductive Maturity

**Description:** Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely cut, thin sections of sagittal otoliths. Validated age determination is based on several methods including an environmental signal (bomb radiocarbon 14C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally based aged coral core reference series for which the rise, peak, and decline of 14C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the 14C otolith core values back in time from its capture date to where it intersects with the known age 14C coral reference series. Fish growth is estimated by fitting the length-at-age data to a von Bertalanffy growth function. This function typically uses three coefficients (*L∞, k,*and *t0*),which together characterize the shape of the length-at-age growth relationship.

Length-at-reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved, cut into five micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity (*L****50***). For species that undergo sex reversal (primarily female to male in the tropical Pacific region) - such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes - standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a three or four-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal (*L∆50*).

Age at 50% maturity (*A50*) and age at 50% sex reversal (*A∆50*) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding *L****50***and *L∆50* values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of *A50* and *A∆50* are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (*A50*) and sex reversal (*A∆50*).

**Data Category:** Biological

**Timeframe:** N/A

**Jurisdiction:** MHI and NWHI

**Spatial Scale:** Archipelagic

**Data Source:** Sources of data are directly derived from research cruises sampling and market samples purchased from local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the “Reference” column in Table 57 for specific details on data sources by species.

**Parameter definitions:**

***Tmax*** **(maximum age)** – The maximum observed age revealed from an otolith-based age determination study. *Tmax* values can be derived from ages determined by annuli counts of sagittal otolith sections and/or bomb radiocarbon (14C) analysis of otolith core material. Units are years.

***L∞*(asymptotic length)** – One of three coefficients of the von Bertalanffy growth function (VBGF) that measures the mean maximum length at which the growth curve plateaus and no longer increases in length with increasing age. This coefficient reflects the estimated mean maximum length and not the observed maximum length. Units are centimeters.

***k* (growth coefficient)** – One of three coefficients of the VBGF that measures the shape and steepness by which the initial portion of the growth function approaches its mean maximum length (*L∞*).

***t0*** **(hypothetical age at length zero)** – One of three coefficients of the VBGF whose measure is highly influenced by the other two VBGF coefficients (*k* and *L∞*) and typically assumes a negative value when specimens representing early growth phases) are not available for age determination. This parameter can be fixed at 0. Units are years.

***M* (natural mortality)** – This is a measure of the mortality rate for a fish stock and is considered to be directly related to stock productivity (i.e., high *M* indicates high productivity and low *M* indicates low stock productivity). *M* can be derived through use of various equations that link *M* to *Tmax* and the VBGF coefficients (*k* and *L∞*) or by calculating the value of the slope from a regression fit to a declining catch curve (regression of the natural logarithm of abundance versus age class) derived from fishing an unfished or lightly fished population.

***A50* (age at 50% maturity)** – Age at which 50% of the sampled stock under study has attained reproductive maturity. This parameter is best determined based on studies that concurrently determine both age (otolith-based age data) and reproductive maturity status (logistic function fitted to percent mature by age class with maturity determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating *A50* is to use an existing *L50* estimate to find the corresponding age (*A50*) from an existing VBGF curve. Units are years.

***A∆50* (age of sex switching)** – Age at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal. This parameter is best determined based on studies that concurrently determines both age (otolith-based age data) and reproductive sex reversal status (logistic function fitted to percent sex reversal by age class with sex reversal determined via microscopic analyses of gonad histology preparations). A more approximate means of estimating *A∆50* is to use an existing *L∆50* estimate to find the corresponding age (*A∆50*) from the VBGF curve. Units are years.

***L50*** **(length at which 50% of a fish population are capable of spawning)** – Length at which 50% of the females of a sampled stock under study has attained reproductive maturity; this is the length associated with *A50* estimates. This parameter is derived using a logistic function to fit the percent mature data by length class with maturity status best determined via microscopic analyses of gonad histology preparations. *L50* information is typically more available than *A50* since *L50* estimates do not require knowledge of age and growth. Units are centimeters.

***L∆50* (length of sex switching)** – Length at which 50% of the immature and adult females of the sampled stock under study is undergoing or has attained sex reversal; this is the length associated with *A∆50* estimates. This parameter is derived using a logistic function to fit the percent sex reversal data by length class with sex reversal status best determined via microscopic analyses of gonad histology preparations. *L∆50* information is typically more available than *A∆50* since *L∆50* estimates do not require knowledge of age and growth. Units are centimeters.

**Rationale:** These nine life history parameters provide basic biological information at the species level to evaluate the productivity of a stock - an indication of the capacity of a stock to recover once it has been depleted. Currently, the assessment of coral reef ecosystem resources in Hawaii are data limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these resources and also provide important biological inputs for future stock assessment efforts and enhance our understanding of the species-likely role and status as a component of the overall ecosystem. Furthermore, knowledge of life histories across species at the taxonomic level of families or among different species that are ecologically or functionally similar can provide important information on the diversity of life histories and the extent to which species can be grouped (based on similar life histories) for future multi-species assessments.

**Table 43. Available age, growth, and reproductive maturity information for coral reef ecosystem species in the Hawaiian Archipelago**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Age, growth, and reproductive maturity parameters** | | | | | | | | **Reference** |
| ***Tmax*** | ***L∞*** | ***k*** | ***t0*** | ***A50*** | ***A∆50*** | ***L50*** | ***L∆50*** |
| *Acanthurus triostegus* |  |  |  |  |  |  |  |  |  |
| *Calotomus carolinus* | 4d |  |  |  | 1.3d | 3.2 d | 24d | 37d | DeMartini et al. (2017), DeMartini and Howard (2016) |
| *Caranx melampygus* |  |  |  |  |  |  |  |  |  |
| *Cellana* spp. |  |  |  |  |  |  |  |  |  |
| *Chlorurus perspicillatus* | 19d | 53.2d | 0.23d | -1.48d | 3.1d | 7 d | 34d | 46d | DeMartini et al. (2017), DeMartini and Howard (2016) |
| *Chlorurus spilurus* | 11d | 34.4d | 0.40d | -0.13d | 1.5d | 4 d | 17d | 27d | DeMartini et al. (2017), DeMartini and Howard (2016) |
| *Kyphosus bigibbus* |  |  |  |  |  |  |  |  |  |
| lobster |  |  |  |  |  |  |  |  |  |
| *Lutjanus kasmira* |  |  |  |  |  |  |  |  |  |
| *Naso annulatus* |  |  |  |  |  |  |  |  |  |
| *Octopus cyanea* |  |  |  |  |  |  |  |  |  |
| *Panulirus marginatus* |  | 104.33-147.75d | 0.05-0.58d |  |  |  | 40.5d |  | O’Malley (2009), DeMartini et al. (2005), |
| *Parupeneus porphyus* |  |  |  |  |  |  |  |  |  |
| Scaridae |  |  |  |  |  |  |  |  |  |
| *Scarus psittacus* | 6d | 32.7d | 0.49d | -0.01d | 1d | 2.4 d | 14d | 23d | DeMartini et al. (2017), DeMartini and Howard (2016) |
| *Scarus rubroviolaceus* | 19d | 53.5d | 0.41d | 0.12d | 2.5d | 5 d | 35d | 47d | DeMartini et al. (2017), DeMartini and Howard (2016) |
| *Scyllarides squammosus* |  | A | A |  |  |  | 51.1 |  | O’Malley (2009), DeMartini et al. (2005), |
| *Naso unicornis* | 54d | 47.8d | 0.44d | -0.12d |  |  | f=35.5d m= 30.1d |  | Andrews et al. (2016) DeMartini et al. (2018) |

Notes:

A signifies that there are Schnute growth estimates but not VBGF parameters.

a signifies estimate pending further evaluation in an initiated and ongoing study.

b signifies a preliminary estimate taken from ongoing analyses.

c signifies an estimate documented in an unpublished report or draft manuscript.

d signifies an estimate documented in a finalized report or published journal article (including in press).

Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters *Tmax*, *t0*, *A50*, and *A∆50* are in units of years; *L∞*, *L50*, and *L∆50* are in units of mm fork length (FL); *k* in units of year-1; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable.

### MHI Bottomfish Ecosystem – Management Unit Species Life History

#### Age, Growth, and Reproductive Maturity

**Description:** Age determination is based on counts of yearly growth marks (annuli) and/or daily growth increments (DGIs) internally visible within transversely cut, thin sections of sagittal otoliths. Validated age determination is based on several methods including an environmental signal (bomb radiocarbon 14C) produced during previous atmospheric thermonuclear testing in the Pacific and incorporated into the core regions of sagittal otolith and other aragonite-based calcified structures such as hermatypic corals. This technique relies on developing a regionally based aged coral core reference series for which the rise, peak, and decline of 14C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the 14C otolith core values back in time from its capture date to where it intersects with the known age 14C coral reference series. Fish growth is estimated by fitting the length-at-age data to a von Bertalanffy growth function. This function typically uses three coefficients (*L∞, k,*and *t0*),which together characterize the shape of the length-at-age growth relationship.

Length-at-reproductive maturity is based on the histological analyses of small tissue samples of gonad material that are typically collected along with otoliths when a fish is processed for life history studies. The gonad tissue sample is preserved, cut into five micron sections, stained, and sealed onto a glass slide for subsequent examination. Based on standard cell structure features and developmental stages within ovaries and testes, the gender, developmental stage, and maturity status (immature or mature) is determined via microscopic evaluation. The percent of mature samples for a given length interval are assembled for each sex and these data are fitted to a three- or four-parameter logistic function to determine the best fit of these data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish have achieved reproductive maturity (*L****50***). For species that undergo sex reversal (primarily female to male in the tropical Pacific region) - such as groupers and deeper-water emperors among the bottomfishes, and for parrotfish, shallow-water emperors, and wrasses among the coral reef fishes - standard histological criteria are used to determine gender and reproductive developmental stages that indicate the transitioning or completed transition from one sex to another. These data are similarly analyzed using a three or four-parameter logistic function to determine the best fit of the data based on statistical analyses. The mid-point of this fitted function provides an estimate of the length at which 50% of fish of a particular species have or are undergoing sex reversal (*L∆50*).

Age at 50% maturity (*A50*) and age at 50% sex reversal (*A∆50*) is typically derived by referencing the von Bertalanffy growth function for that species and using the corresponding *L****50***and *L∆50* values to obtain the corresponding age value from this growth function. In studies where both age & growth and reproductive maturity are concurrently determined, estimates of *A50* and *A∆50* are derived directly by fitting the percent of mature samples for each age (one-year) interval to a three- or four-parameter logistic function using statistical analyses. The mid-point of this fitted logistic function provides a direct estimate of the age at which 50% of fish of a particular species have achieved reproductive maturity (*A50*) and sex reversal (*A∆50*).

**Data Category:** Biological

**Timeframe:** N/A

**Jurisdiction:** MHI and NWHI

**Spatial Scale:** Archipelagic

**Data Source:** Sources of data are directly derived from research cruises sampling and market samples purchased from local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program. Refer to the “Reference” column in Table 58 for specific details on data sources by species.

**Parameter Definitions:** Identical to Section 2.2.2.1.

Table 44. Available age, growth, and reproductive maturity information for MUS in the Hawaiian Archipelago

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Age, growth, and reproductive maturity parameters** | | | | | | | | | **Reference** |
| ***Tmax*** | ***L∞*** | ***k*** | ***t0*** | ***M*** | ***A50*** | ***A∆50*** | ***L50*** | ***L∆50*** |
| *Aphareus rutilans* |  |  |  |  |  |  | NA |  | NA |  |
| *Aprion virescens* | 27c | 72.71c | 0.33c |  | 0.24c |  | NA | 42.5-47.5d | NA | Everson et al. (1989); O’Malley et al. (in prep.) |
| *Etelis carbunculus* | 22c | 50.3c | 0.07c |  |  |  | NA | 23.4d | NA | Nichols et al. (in prep); DeMartini et al. (2017) |
| *Etelis coruscans* | a | a | a | a |  | a | NA | 66.3d | NA | LHP (in prep); Everson et al. (1989); |
| *Hyporthodus quernus* | 76d | 0.078d | 95.8d |  |  |  |  | 58.0d | 89.5d | Andrews et al. (2019); DeMartini et al. (2017) |
| *Pristipomoides filamentosus* | 42d | 67.5d | 0.24d | -0.29d |  |  | NA | f=40.7d  m=43.3d | NA | Andrews et al. (2012); Leurs et al. (2017) |
| *Pristipomoides sieboldii* |  |  |  |  |  |  | NA | 23.8d | NA | DeMartini et al. (2017) |
| *Pristpomoides zonatus* |  |  |  |  |  |  | NA |  | NA |  |

Notes:

a signifies estimate pending further evaluation in an initiated and ongoing study.

b signifies a preliminary estimate taken from ongoing analyses.

c signifies an estimate documented in an unpublished report or draft manuscript.

d signifies an estimate documented in a finalized report or published journal article (including in press).

Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters *Tmax*, *t0*, *A50*, and *A∆50* are in units of years; *L∞*, *L50*, and *L∆50* are in units of mm fork length (FL); *k* in units of year-1; X=parameter estimate too preliminary or Y=published age and growth parameter estimates based on DGI numerical integration technique and likely to be inaccurate; NA=not applicable.

**Literature Cited**

Andrews A.H., E.E. DeMartini, J. Brodziak, R.S. Nichols, R.L. Humphreys. 2012. A long-lived life history for a tropical, deepwater snapper (*Pristipomoides filamentosus*): bomb radiocarbon and lead-radium dating as extensions of daily increment analyses in otoliths. Canadian Journal of Fisheries and Aquatic Sciences 69: 1850-1869. https://doi.org/10.1139/f2012-109.

Andrews, A.H., E.E. DeMartini, J.A. Eble, B.M. Taylor, D.C. Lou, R.L. Humphreys. 2016. Age and growth of bluespine unicornfish (*Naso unicornis*): a half-century life-span for a keystone browser, with a novel approach to bomb radiocarbon dating in the Hawaiian Islands. Canadian Journal of Fisheries and Aquatic Sciences. https://doi.org/10.1139/cjfas-2016-0019.

Andrews, A.H., E.E. DeMartini, J. Brodziak, R. S. Nichols, R. L. Jr Humphreys. 2019. Growth and longevity of Hawaiian grouper (*Hyporthodus quernus*) — input for management and conservation of a large, slow‐growing grouper. Canadian Journal of Fisheries and Aquatic Sciences, 76, 1874– 1884. https://doi.org/10.1139/cjfas-2018-0170

DeMartini EE, McCracken ML, Moffitt RB, Wetherall JA. 2005. Relative pleopod length as an indicator of size at sexual maturity in slipper (*Scyllarides squammosus*) and spiny Hawaiian (*Panulirus marginatus*) lobsters. Fishery Bulletin 103(1): 23-33

DeMartini, E.E., A.R. Everson, R.S. Nichols. 2010. Estimates of body sizes at maturation and at sex change, and the spawning seasonality and sex ratio of the endemic Hawaiian grouper (*Hyporthodus quernus*, F. Epinephelidae) Fishery Bulletin 109: 123-134.

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

DeMartini E.E. 2016. Body size at sexual maturity in the eteline snappers *Etelis carbunculus* and *Pristipomoides sieboldii*: subregional comparisons between the main and north-western Hawaiian Islands. Marine and Freshwater Research 68, 1178-1186.

DeMartini E.E., K.G. Howard. 2016. Comparisons of body sizes at sexual maturity and at sex change in the parrotfishes of Hawaii: input needed for management regulations and stock assessments. Journal of Fish Biology. https://doi.org/10.1111/jfb.12831.

DeMartini E.E., A.H. Andrews, K.G. Howard, B.M. Taylor, D. Lou, M.K. Donovan. 2017. Comparative growth, age at maturity and sex change, and longevity of Hawaiian parrotfishes with bomb radiocarbon validation. Canadian Journal of Fisheries and Aquatic Sciences 75(4): 580-589. https://doi.org/10.1139/cjfas-2016-0523.

Everson, A.R., H.A. Williams and B.M. Ito. 1989. Maturation and reproduction in two Hawaiian Eteline snappers, uku, *Aprion virescens*, and Onaga, *Etelis coruscans*. Fisheries Bulletin 87:877-888.

Luers, M., A., E.E DeMartini, R.L. Humphreys. 2017. Seasonality, sex ratio, spawning frequency and sexual maturity of the opakapaka *Pristipomoides filamentosus* (Perciformes: Lutjanidae) from the Main Hawaiian Islands: fundamental input to size-at-retention regulations. Marine and Freshwater Research 69, 325-335.

O’Malley, J.M. 2009. Spatial and temporal variability in growth of Hawaiian spiny lobsters in the Northwestern Hawaiian Islands. Marine and Coastal Fisheries 1:325–342

O'Malley, J.M. 2011. Spatiotemporal variation in the population ecology of scaly slipper lobsters *Scyllarides squammosus* in the Northwestern Hawaiian Islands. Marine Biology 158(8): 1887-1902.