2.2 LIFE HISTORY AND LENGTH DERIVED PARAMETERS

The annual stock assessment and fishery evaluation (SAFE) report will serve as the repository of available life history information for the Western Pacific region. Life history data particularly age, growth, reproduction, and mortality information inform stock assessments on fish productivity and population dynamics. Some assessments, particularly for data poor stocks, utilize information from other areas that introduces biases and increase uncertainties in the population estimates. An archipelago specific life history parameter ensures accuracy in the input parameters used in the assessment.

The NMFS PIFSC Bio-Sampling Program allows for the collection of life history samples like otoliths and gonads from priority species in the bottomfish and coral reef fisheries. A significant number of samples are also collected during research cruises. These life history samples, once processed and examined, will contribute to the body of scientific information for the two data-poor fisheries in the region (coral reef fish and bottomfish). The life history information available from the region will be monitored by the Fishery Ecosystem Plan Team and will be tracked through this section of the report.

This section will be divided into two fisheries: 1) prioritized coral reef ecosystem component species, and 2) management unit species (MUS). The prioritized coral reef species list was developed by the CNMI Department of Fish and Wildlife (DFW) and the Guam Division of Aquatic and Wildlife Resources (DAWR) in 2019. The MUS are the species that are listed in the federal ecosystem plan and are managed on a federal level. Within each fishery, the available life history information will be described under the age, growth, and reproductive maturity section. The section labelled fish length derived parameters summarizes available information derived from sampling the fish catch or the markets. Length-weight conversion coefficients provide area-specific values to convert length from fishery-dependent and fishery-independent data collection to weight or biomass.

2.2.1 CNMI Coral Reef Ecosystem Components Life History

2.2.1.1 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 ^{14}C) 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 ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. Fish growth is estimated by fitting the length-at-age data to a von Bertalanffy growth function (VBGF). This function typically uses three coefficients (L_∞, k, and t_0), 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 ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and age at 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the VBGF for that species and using the corresponding L_{50} and $L\Delta_{50}$ 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 A_{50} and $A\Delta_{50}$ 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 (A_{50}) and sex reversal ($A\Delta_{50}$).

Category: Biological

Timeframe: N/A

Jurisdiction: CNMI

Spatial Scale: Archipelagic

Data Source: Sources of data are directly derived from research cruises sampling and market samples collected by the CNMI contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC Life History Program (LHP). Refer to the "Reference" column in Table 1 for specific details on data sources by species.

Parameter definitions:

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

L_{∞} **(asymptotic length)** – One of three coefficients of the 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_∞).

***t_0* (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 T_{max} 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.

***A_{50}* (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 A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve. Units are years.

***$A\Delta_{50}$* (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 $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve. Units are years.

***L_{50}* (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 A_{50} 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. 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.

***$L\Delta_{50}$* (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 $A\Delta_{50}$ 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. $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ 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. These parameters are also used as direct inputs into stock assessments. Currently, the assessment of coral reef fish resources in CNMI is data limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these

resources and 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 1. Available age, growth, reproductive maturity, and natural mortality information for prioritized coral reef ecosystem component species in CNMI

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Acanthurus lineatus										
Lethrinus harak	f=9[d] m=9 [d]	f=37.2[d] m=27.3[d]	f=0.14[d] m=0.38[d]	f=-2.92[d] m=-1.11[d]		f=2.6[d] m=2.4[d]	f=0.43 m=0.44	f=19.6[d] m=18.7[d]		Trianni 2016
Mulloidichthys flavolineatus	f=5[c] M=4[c]	f=25.55[c] m=21.80[c]	f=1.24[c] m=1.69[c]					f=15.8[c] m=16.1[c]		Reed et al. 2020
Naso lituratus									NA	
Naso unicornis								238[b]	NA	
Scarus rubroviolaceus										
Scarus ghobban										
Siganus argenteus	7[d]	274[d]	0.9[d]	-0.3[d]	0.56[d]	1.3[d]	NA	218[d]	NA	Taylor et. al. 2016

[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 T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ 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. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

2.2.1.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery Bio-sampling Program started in 2010. This program has two components: first is the Field/Market Sampling Program, and the second is the Lab Sampling Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear, and area fished);
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially);
- Accurate species identification;
- Develop accurate local length-weight curves.

In CNMI, the Bio-sampling Program was focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. However, in 2020 the Program switched focus to the MUS. Sampling is conducted in partnership with the fish vendors and fishermen. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information. Specific for CNMI, the program collects Daily Vendor Logs for reef fish that includes basic catch and effort information.

Category: Biological

Timeframe: N/A

Jurisdiction: CNMI

Spatial Scale: Archipelagic

Data Source: NMFS Bio-sampling Program

Parameter definitions:

n – ***sample size*** is the total number of fish sampled for length for each species recorded in the Bio-Sampling Program database.

L_{max} – ***maximum fish length*** is the largest individual per species recorded in the Bio-Sampling Program database from the commercial spear fishery. This value is derived from measuring the length of individual samples for species occurring in the spear fishery. Units are centimeters.

$N_{L\text{-}W}$ – ***sample size for L-W regression*** is the number of samples used to generate the *a* and *b* coefficients.

a and b – ***length-weight coefficients*** are the coefficients derived from the regression line fitted to all length and weight measured by species in the commercial spear fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested.

Rationale: Length derived information is an important component of fisheries monitoring and data poor stock assessment approaches. Maximum length (L_{max}), is used to derive missing species- and location-specific life history information (Nadon et al., 2015; Nadon and Ault, 2016; Nadon, 2019). The length-weight coefficients (*a* and *b* values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length is typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length derived variables for the CNMI coral reef ecosystem component fisheries.

Table 2. Available length derived information for prioritized coral reef ecosystem component species in CNMI

Species	Length derived parameters					Reference
	n	L_{max}	$N_{L\text{-}W}$	***a***	***b***	
Acanthurus lineatus	20228	23.5	4927	0.03882	2.868	Matthews et al. 2019
Lethrinus harak	2697					
Mulloidichthys flavolineatus	12516	31.4	2798	0.0138	3.05	Matthews et al. 2019

Species	Length derived parameters					Reference
	n	L_{max}	$N_{L\text{-}W}$	***a***	***b***	
Naso lituratus	28507	30.1	3868	0.0163	3.103	Matthews et al. 2019
Naso unicornis	12481	53.6	4448	0.0269	2.908	Matthews et al. 2019
Scarus ghobban[1]	7612	38.1	1644	0.0129	3.12	Matthews et al. 2019
Scarus rubroviolaceus	4032	52.6	1830	0.0089	3.24	Matthews et al. 2019
Siganus argenteus	14614	34.1	3961	0.0129	3.112	Matthews et al. 2019

[1]did not have data to cover 30% of the total length range

2.2.2 CNMI Management Unit Species Life History

2.2.2.1 Age, Growth, and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or 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 ^{14}C) 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 ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. Fish growth is estimated by fitting the length-at-age data to a VBGF. This function typically uses three coefficients (L_∞, k, and t_0), 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 for the data based on statistical analyses. The mid-point of the 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 ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and age at 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the VBGF for that species and using the corresponding L_{50} and $L\Delta_{50}$ values to obtain the corresponding age value from this growth function. In studies where both age and growth and

reproductive maturity are concurrently determined, estimates of A_{50} and $A\Delta_{50}$ are derived directly by fitting the percent of mature samples for each age (i.e., 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 species have achieved reproductive maturity (A_{50}) and sex reversal ($A\Delta_{50}$).

Category: Biological

Timeframe: N/A

Jurisdiction: CNMI

Spatial Scale: Archipelagic

Data Source: Sources of data are directly derived from research cruises sampling and market samples collected by the CNMI contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC LHP. Refer to the "Reference" column in Table 3 for specific details on data sources by species.

Parameter definitions: Identical to Section 2.2.2.1

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 fish resources in CNMI is data limited. Knowledge of these life-history parameters support current efforts to characterize the resilience of these resources, 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 3. Available age, growth, reproductive maturity, and natural mortality information for MUS in CNMI

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Aphareus rutilans							NA		NA	
Caranx ignobilis										
Caranx lugubris										
Etelis carbunculus[1]							NA		NA	
Etelis coruscans							NA		NA	
Lethrinus rubrioperculatus	8[d]	31.5[d]	0.80[d]	-0.52[d]				23.2[d]	29.0[d]	Trianni 2011
Lutjanus kasmira							NA		NA	
Pristipomoides auricilla[2]	18[d]	32.5[d]	0.60[d]		0.18[d]		NA		NA	O'Malley et al. 2019
Pristipomoides filamentosus[2]	31	54.6[c]	0.19[c]			f=5.0[c] m=2.8[c]	NA	f=41.2[c] m=27.6[c]	NA	Villagomez 2019
Pristipomoides flavipinnis							NA		NA	

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Pristipomoides sieboldii							NA		NA	
Pristpomoides zonatus	X[a]	X[a]	X[a]	X[a]			NA		NA	LHP (in prep)
Variola louti										

[1] *E. carbunculus* is now known to be comprised of two distinct, non-interbreeding lineages (Andrews et al. 2016). Both species occur in the Mariana Archipelago and are likely both captured by fishermen but reported as one species.
[2] Estimates are for the southern portion of the Mariana Archipelago
[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 T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm 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. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

2.2.2.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery Bio-sampling Program started in 2010. This program has two components: first is the Field/Market Sampling Program and the second is the Lab Sampling Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear, and area fished);
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially);
- Accurate species identification;
- Develop accurate local length-weight curves.

In CNMI, the Bio-sampling Program was focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. However, in 2020 the Program switched focus to the MUS. Sampling is conducted in partnership with the fish vendors and fishermen. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information. Specific for CNMI, the program collects Daily Vendor Logs for reef fish that includes basic catch and effort information.

Category: Biological

Timeframe: N/A

Jurisdiction: CNMI

Spatial Scale: Island

Data Source: NMFS Bio-sampling Program

Parameter definitions: Identical to Section 2.2.1.2

Rationale: Length derived information is an important component of fisheries monitoring and data poor stock assessment approaches. Maximum length (L_{max}), is used to derive missing species- and location-specific life history information (Nadon et al., 2015; Nadon and Ault, 2016; Nadon, 2019). The length-weight coefficients (*a* and *b* values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length is typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length derived variables for the CNMI MUS fisheries.

Table 4. Available length derived information for MUS species in CNMI

Species	Length derived parameters					Reference
	n	L_{max}	$N_{L\text{-}W}$	***a***	***b***	
Aphareus rutilans	120					
Caranx ignobilis	6					
Caranx lugubris	132	82.5	130	0.0313	2.87	Matthews et al. 2019
Etelis carbunculus[1]	746	53.5	685	0.0150	3.0430	2010-2015 CNMI Bio-Sampling Database
Etelis coruscans	377	96.4	325	0.0716	2.6147	2010-2015 CNMI Bio-Sampling Database
Lethrinus rubrioperculatus	1438	38.0	1353	0.0185	2.9897	2010-2015 CNMI Bio-Sampling Database
Lutjanus kasmira	422	32.5	258	0.0087	3.2307	2010-2015 CNMI Bio-Sampling Database
Pristipomoides auricilla	471	39.5	465	0.0189	3.0060	2010-2015 CNMI Bio-Sampling Database
Pristipomoides filamentosus	123	58.5	123	0.0773	2.5914	2010-2015 CNMI Bio-Sampling Database
Pristipomoides flavipinnis	179	51.5	168	0.0133	3.0762	2010-2015 CNMI Bio-Sampling Database
Pristipomoides sieboldii	112					
Pristpomoides zonatus	404	45.4	371	0.0180	3.0411	2010-2015 CNMI Bio-Sampling Database
Variola louti	6					

[1] *E. carbunculus* is now known to be comprised of two distinct, non-interbreeding lineages (Andrews et al. 2016). Both species occur in the Mariana Archipelago and are likely both captured by fishermen but reported as one species.

2.2.3 Guam Coral Reef Ecosystem Components Life History

2.2.3.1 Age, Growth, and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or 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 ^{14}C) 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 ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. Fish growth is estimated by fitting the length-at-age data to a VBGF. This function typically uses three coefficients (L_∞, k, and t_0), 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 ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and age at 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the VBGF for that species and using the corresponding L_{50} and $L\Delta_{50}$ 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 A_{50} and $A\Delta_{50}$ 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 (A_{50}) and sex reversal ($A\Delta_{50}$).

Category: Biological

Timeframe: N/A

Jurisdiction: Guam

Spatial Scale: Archipelagic

Data Source: Sources of data are directly derived from research cruises sampling and market samples collected by the Guam contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC LHP. Refer to the "Reference" column in Table 5 for specific details on data sources by species.

Parameter definitions:

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

***L_∞* (asymptotic length)** – One of three coefficients of the 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_∞).

***t_0* (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 T_{max} 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.

***A_{50}* (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 A_{50} is to use an existing L_{50} estimate to find the corresponding age (A_{50}) from an existing VBGF curve. Units are years.

***$A\Delta_{50}$* (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 $A\Delta_{50}$ is to use an existing $L\Delta_{50}$ estimate to find the corresponding age ($A\Delta_{50}$) from the VBGF curve. Units are years.

***L_{50}* (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 A_{50} 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. 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.

***$L\Delta_{50}$* (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 $A\Delta_{50}$ 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. $L\Delta_{50}$ information is typically more available than $A\Delta_{50}$ since $L\Delta_{50}$ 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. These parameters are also used as direct inputs into stock assessments. Currently, the assessment of coral reef fish resources in Guam is data-limited. Knowledge of these life history parameters support current efforts to characterize the resilience of these resources and 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 5. Available age, growth, reproductive maturity, and natural mortality information for prioritized coral reef ecosystem component species in Guam

Species	Age, growth, and reproductive maturity parameters							Reference
	T_{max}	L_∞	k	t_0	A_{50}	L_{50}	$L\Delta_{50}$	
Caranx melampygus	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]	X[a]	LHP (in progress)
Chlorurus frontalis	11[d]	37.2[d]	0.71[d]	-0.058[d]	1.55[d]	24.0[d]	34.3[d]	Taylor and Choat 2014
Epinephelus fasciatus								
Lethrinus harak								
Lethrinus olivaceus								
Lutjanus fulvus								
Naso unicornis	23[d]	49.3[d]	0.22[d]	-0.048[d]	f=4.0[d] m=3.2[d]	f=29.2[d] m=27.1[d]		Taylor et al. 2014
Scarus rubroviolaceus	6[d]	37.6[d]	0.66[d]	-0.062[d]	1.91[d]	27.1[d]	32.9[d]	Taylor and Choat 2014
Siganus spinus								

[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 T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm 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. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

2.2.3.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery Bio-sampling Program started in 2009. This program has two components: first is the Field/Market Sampling Program, and the second is the Lab Sampling Program, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear, and area fished);
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially);
- Accurate species identification;
- Develop accurate local length-weight curves.

In Guam, the Bio-sampling Program was focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. However, in 2020 the Program switched focus to the MUS. Sampling is conducted in partnership with the fish vendors and fishermen. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information.

Category: Biological

Timeframe: N/A

Jurisdiction: Guam

Spatial Scale: Archipelagic

Data Source: NMFS Bio-sampling Program

Parameter definitions:

n – ***sample size*** is the total number of fish sampled for length for each species recorded in the Bio-Sampling Program database.

L_{max} – ***maximum fish length*** is the largest individual per species recorded in the Bio-Sampling Program database from the commercial spear fishery. This value is derived from measuring the length of individual samples for species occurring in the spear fishery. Units are centimeters.

$N_{L\text{-}W}$ – ***sample size for L-W regression*** is the number of samples used to generate the *a* and *b* coefficients.

a and b – ***length-weight coefficients*** are the coefficients derived from the regression line fitted to all length and weight measured by species in the commercial spear fishery. These values are used to convert length information to weight. Values are influenced by the life history characteristics of the species, geographic location, population status, and nature of the fisheries from which the species are harvested.

Rationale: Length derived information is an important component of fisheries monitoring and data poor stock assessment approaches. Maximum length (L_{max}), is used to derive missing species- and location-specific life history information (Nadon et al. 2015, Nadon and Ault 2016, Nadon 2019). The length-weight coefficients (*a* and *b* values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length is typically

recorded but weight is the factor being used for management. This section of the report presents the best available information for the length derived variables for the Guam coral reef fisheries.

Table 6. Available length derived information for prioritized coral reef ecosystem component species in Guam

Species	Length derived parameters					Reference
	n	L_{max}	$N_{L\text{-}W}$	***a***	***b***	
Caranx melampygus	1157	69.8	551	0.0228	2.95	Kamikawa et al. 2015
Chlorurus frontalis	534	48.5	238	0.0172	3.08	Kamikawa et al. 2015
Epinephelus fasciatus	4223	57.0	1701	0.0118	3.08	Kamikawa et al. 2015
Lethrinus harak	886	29.9	258	0.0281	2.89	Kamikawa et al. 2015
Lethrinus olivaceus	751	71.7	272	0.0200	2.93	Kamikawa et al. 2015
Lutjanus fulvus	426	29.6	91	0.0134	3.12	Kamikawa et al. 2015
Naso unicornis	20618	57.2	7790	0.0267	2.92	Kamikawa et al. 2015
Scarus rubroviolaceus	2563	47.8	1713	0.0114	3.18	Kamikawa et al. 2015
Siganus spinus	5475	27.0	890	0.0284	2.87	Kamikawa et al. 2015

2.2.4 Guam Management Unit Species Life History

2.2.4.1 Age, Growth, and Reproductive Maturity

Description: Age determination is based on counts of yearly growth marks (annuli) and/or 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 ^{14}C) 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 ^{14}C values is available over the known age series of the coral core. Estimates of fish age are determined by projecting the ^{14}C otolith core values back in time from its capture date to where it intersects with the known age ^{14}C coral reference series. Fish growth is estimated by fitting the length-at-age data to a VBGF. This function typically uses three coefficients (L_∞, k, and t_0), 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 ($L\Delta_{50}$).

Age at 50% maturity (A_{50}) and age at 50% sex reversal ($A\Delta_{50}$) is typically derived by referencing the VBGF for that species and using the corresponding L_{50} and $L\Delta_{50}$ 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 A_{50} and $A\Delta_{50}$ 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 (A_{50}) and sex reversal ($A\Delta_{50}$).

Category: Biological

Timeframe: N/A

Jurisdiction: Guam

Spatial Scale: Archipelagic

Data Source: Sources of data are directly derived from research cruises sampling and market samples collected by the Guam-contracted bio-sampling team which samples the catch of fishermen and local fish vendors. Laboratory analyses and data generated from these analyses reside with the PIFSC LHP. Refer to the "Reference" column in Table 7 for specific details on data sources by species.

Parameter definitions: Identical to Section 2.2.3.1

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 fish resources in Guam is 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 7. Available age, growth, reproductive maturity, and natural mortality information for MUS in Guam

Species	Age, growth, and reproductive maturity parameters									Reference
	T_{max}	L_∞	k	t_0	M	A_{50}	$A\Delta_{50}$	L_{50}	$L\Delta_{50}$	
Aphareus rutilans							NA		NA	
Caranx ignobilis							NA		NA	
Caranx lugubris							NA		NA	
Etelis carbunculus[1]							NA		NA	
Etelis coruscans							NA		NA	
Lethrinus rubrioperculatus							NA		NA	
Lutjanus kasmira							NA		NA	
Pristipomoides auricilla[2]	18[d]	32.5[d]	0.60[d]		0.18[d]		NA		NA	O'Malley et al. 2019
Pristipomoides filamentosus[2]	31	54.6[c]	0.19[c]			f=5.0[c] m=2.8[c]	NA	f=41.2[3] m=27.6[3]	NA	Villagomez 2019
Pristipomoides flavipinnis							NA		NA	
Pristipomoides sieboldii							NA		NA	
Pristpomoides zonatus	f=19[c] m=22[c]	f=35.3[c] m=38.2[c]	f=0.26[c] m=0.29[c]	f=-2.24[c] m=-1.56[c]	0.29[c]	f=1.58[c] m=1.95[c]	NA	f=24.1[c*] m=24.28[c*]	NA	Schemmel et al. in review
Variola louti										

[1] *E. carbunculus* is now known to be comprised of two distinct, non-interbreeding lineages (Andrews et al. 2016). Both species occur in the Samoa Archipelago and were likely both captured by fishermen in the 1980s but reported as one species.
[2] Estimates are for the southern portion of the Mariana Archipelago.
[3] Female estimate is based on functional maturity, male estimate is based on physiological maturity.
[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 (+ in press).

Parameter estimates are for females unless otherwise noted (F=females, M=males). Parameters T_{max}, t_0, A_{50}, and $A\Delta_{50}$ are in units of years; L_∞, L_{50}, and $L\Delta_{50}$ are in units of mm 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. Superscript letters indicate status of parameter estimate (see footnotes below table). Published or in press publications ([d]) are denoted in "Reference" column.

2.2.4.2 Fish Length Derived Parameters

Description: The NMFS Commercial Fishery Bio-sampling Program started in 2009. This program has two components: first is the Field/Market Sampling Program and the second is the LHP, details of which are described in a separate section of this report. The goals of the Field/Market Sampling Program are:

- Broad scale look at commercial landings (by fisher/trip, gear, and area fished);
- Length and weight frequencies of whole commercial landings per fisher-trip (with an effort to also sample landings not sold commercially);
- Accurate species identification;
- Develop accurate local length-weight curves.

In Guam, the Bio-sampling Program was focused on the commercial coral reef spear fishery with occasional sampling of the bottomfish fishery occurring locally and less frequently at the northern islands. However, in 2020 the Program switched focus to the MUS. Sampling is conducted in partnership with the fish vendors and fishermen. The Market Sampling information includes (but not limited to): 1) fish length; 2) fish weight; 3) species identification; and 4) basic effort information.

Category: Biological

Timeframe: N/A

Jurisdiction: Guam

Spatial Scale: Island

Data Source: NMFS Bio-sampling Program

Parameter definition: Identical to Section 2.2.3.2

Rationale: Length derived information is an important component of fisheries monitoring and data poor stock assessment approaches. Maximum length (L_{max}), is used to derive missing species- and location-specific life history information (Nadon et al., 2015; Nadon and Ault, 2016; Nadon, 2019). The length-weight coefficients (*a* and *b* values) are used to convert length to weight for fishery-dependent and fishery-independent data collection where length is typically recorded but weight is the factor being used for management. This section of the report presents the best available information for the length derived variables for the Guam MUS fisheries.

Table 8. Available length derived information for MUS in Guam

Species	Length derived parameters					Reference
	n	L_{max}	$N_{L\text{-}W}$	***a***	***b***	
Aphareus rutilans	184	90.5	86	0.0343	2.77	Kamikawa et al. 2015
Caranx ignobilis	371					
Caranx lugubris	309	80.8	58	0.0250	2.94	Kamikawa et al. 2015
Etelis carbunculus[1]	888	63.4	575	0.0159	3.03	Kamikawa et al. 2015
Etelis coruscans	476	95.0	255	0.0425	2.75	Kamikawa et al. 2015
Lethrinus rubrioperculatus	7681	46.6	2196	0.0228	2.94	Kamikawa et al. 2015
Lutjanus kasmira	1395	30.3	460	0.0128	3.12	Kamikawa et al. 2015
Pristipomoides auricilla	3345	39.0	1210	0.0135	3.11	Kamikawa et al. 2015

Pristipomoides filamentosus	277	67.4	114	0.0225	2.93	Kamikawa et al. 2015
Pristipomoides flavipinnis	657	59.4[1]	223	0.0210	2.95	Kamikawa et al. 2015
Pristipomoides sieboldii	411	63.2	130	0.0243	2.91	Kamikawa et al. 2015
Pristpomoides zonatus	925	57.5	329	0.0180	3.04	Kamikawa et al. 2015
Variola louti	1149	49.0	716	0.0130	3.09	Kamikawa et al. 2015

[1]The value in Kamikawa et al. 2015 is suspiciously high (76.6 cm). Guam Bio-Sampling database L_{max} is more reasonable, albeit still high.