*5.D(1)
124 SSC

Prepared for the
Western Pacific
Regional Fishery
Management Council

Data Limited Assessments of American Samoa’s Coral Reef Fishery

Cassandra B Pardee

8/11/2016

Table of Contents

Abstract

This report is prepared for WPRFMC on data limited methods for estimating sustainable yield for common coral reef fishery species in American Samoa. Overfishing limit estimates and current fishing status were produced for 13 coral reef fish stocks. Four species were then chosen to compare yield estimates using three common data limited methods.

List of Tables

List of Figures

Photo on cover page:
http://www.windows2universe.org/teacher_resources/main/frameworks/ol_ep4.html&edu=high&dev=1the

Introduction to Data Limited Fisheries

Fishing serves an integral part of the Samoan culture (*fa'asamoa*) which drives much of the fishing effort within American Samoa (Craig et al. 1993, Carroll et al. 2012, Severance et al. 2013). Fishing in American Samoa can be divided into two basic groups: shore-based fishing, mostly based in lagoon and coral reef areas; and boat-based fishing which targets bottomfish and pelagic species. Shore-based coral reef fishing mostly relies on rod and reel for groupers and jacks and spearfishing for surgeonfish and parrotfish. Boat-based fisheries mainly troll for skipjacks, and trevally; and bottomfish for emperors, groupers, and snappers (Carroll et al. 2012).

Close to 25,000 lbs of reef fish were landed in American Samoa in 2011 (Carroll et al. 2012). *Acanthurus lineatus* is the primary species caught in the coral reef fishery accounting for 45% of total catch (Craig et al. 1997, Ochavillo et al. 2012). Other species from Acanthuridae, Scaridae, and Holocentridae also dominate the inshore coral reef commercial catch (Ochavillo et al. 2012).

Even though the inshore fishery is an important aspect of the American Samoan culture, the inshore fishery is considered a data limited fishery due to the lack of available life history data and catch time series. Data-limited (DL) fishery refers to a fishery that has few available data, data of poor quality, or raw data that has not been processed into a usable format (Newman et al. 2014).

Before the Magnuson-Stevens Fishery Conservation and Management act amendment of 2006 required Annual Catch Limits (ACLs) for all US fisheries, there were few protocols for assessing these DL stocks. Therefore, many ACLs for unassessed stocks have been based on recent fishery catch statistics without use of other data types (Newman et al. 2014). Current ACLs for American Samoa were set equal to Acceptable Biological Catch (ABC) because the catch was small relative to the biomass estimated from CRED Rapid Ecological Assessment (Carroll et al. 2012). Since more formal stock assessments have not been conducted in American Samoa, ABCs were determined by the 75th percentile of the entire catch time series. Data-limited ABCs are not unique to American Samoa. Currently 70% of all ABC limits in the US are based off of DL methods; with the Western Pacific region having one of the highest proportions of ABCs for DL stocks due to the large number of coral reef fishery stocks (Newman et al. 2014).

In DL fisheries, the goal is to find a moderately high yield that also has a low probability of leading to overfishing and stock depletion (MacCall 2009). The purpose of this study was to estimate sustainable yields and current fishery status for commonly caught inshore coral reef fishery species. A Depletion Corrected Average Catch (DCAC) method was used to estimate sustainable yield for the selected fishery species using the NOAA Fisheries Toolbox (NOAA Fisheries Toolbox 2012). Current fishery status (F/Fmsy) was then estimated using average length data from the Bio-Sampling program (Ehrhardt and Ault 1992). Finally, four species were chosen to compare yield estimates from various common DL methods using the DLM toolkit (Carruthers 2014).

Data Sources

There are two types of catch data available in American Samoa; the CREEL survey program consisting of both boat and shore based surveys, and the Bio-Sampling market surveys.

The objective of CREEL survey programs is to estimate total annual shore and boat based participation, effort, and catch for American Samoa fisheries (Oram et al. 2013a, 2013b). The Department of Marine and Wildlife Resources (DMWR) has been conducting both boat-based and shore based fishing surveys since 1987. Both boat and shore based surveys use a stratified random survey design which includes participation counts and interviews to estimate information of catch and effort (Oram et al. 2013a, 2013b). Participation count is used to record activity of boats coming and going from the four main ports as well as counting the number of people fishing from the shoreline (Oram et al. 2013a, 2013b). Fishermen interviews are used to determine catch, method, length and weight of fish, and species. Data is then expanded at a stratum level to create total estimated landings by gear type (Oram et al. 2013a, 2013b).

The PIFSC commercial fisheries Bio-Sampling program is designed to identify commercially important fishery species and determine life history parameters such as age, growth, reproductive cycles, and size at age data (Ochavillo et al. 2012). DMWR has been managing the Bio-Sampling program since 2010 where it has measured and weighed over 84,000 fish (Ochavillo et al. 2012). During sampling, date of fishing, fisher name, gear type, fishing area, crew number, and hours fished are all recorded along with fish species, weight, and length.

Selected Species

Thirteen species were selected to assess the current fishing status and estimate a sustainable yield for American Samoa inshore fishery species (Table 1). These 13 species were selected based on prevalence in catch from CREEL surveys and Bio-Sampling data, as well as vulnerability scores from a previous Productivity and Susceptibility Assessment (PSA) (Pardee 2015). The selected species represent eight common reef fish families and a variety of life history and ecological niches.

Table 1: Thirteen inshore American Samoa fishery species selected to estimate sustainable yield.

Family	Species	Common Name
Acanthuridae	*Acanthurus lineatus*	Bluebanded surgeonfish
Acanthuridae	*Acanthurus xanthopterus*	Yellowfin surgeonfish
Acanthuridae	*Ctenochaetus striatus*	Striped bristletooth
Acanthuridae	*Naso lituratus*	Orangespine unicornfish
Carangidae	*Caranx melampygus*	Bluefin trevally
Holocentridae	*Myripristis berndti*	Bigscale soldierfish
Labridae	*Cheilinus trilobatus*	Tripletail wrasse
Lethinidae	*Lethrinus amboinensis*	Ambon emperor
Lutjanidae	*Lutjanus gibbus*	Humpback snapper
Lutjanidae	*Lutjanus kasmira*	Blue lined snapper
Scaridae	*Scarus rubroviolaceus*	Redlip parrotfish
Scaridae	*Chlorurus japanensis*	Redtail parrotfish
Serranidae	*Cephalopholis argus*	Peacock grouper

Depletion Corrected Average Catch (DCAC)

The Depletion Corrected Average Catch (DCAC) method is a DL model based off of the potential-yield formula. The DCAC produces an estimate of sustainable catch based on the estimate of average annual catch, natural mortality (M), sustainable fishing mortality over natural mortality (F_{MSY}/M), sustainable biomass over pristine biomass (B_{MSY}/B_0) and an estimate of the amount of depletion throughout the time series (MacCall 2009, Carruthers et al. 2014). The DCAC has been utilized by the Pacific Fishery Management Council to set overfishing limits (OFL) and acceptable biological catch (ABC) (Carruthers et al. 2014).

Total catch (*C*) from CREEL surveys was divided by the time period (n) plus the “windfall” ratio (one time harvest (W) divided by the available potential yield (Y_{pot})) to produce a sustainable yield estimate (1) (MacCall 2009).

$$Y_{sust} = \frac{\sum C}{n + {}^{W}\!/_{Y_{pot}}} \tag{1}$$

The windfall ratio is based on the idea that there is a one-time harvest attributed to reducing the abundance from pristine biomass to B_{MSY}. The windfall ratio can be simplified to equation (2) (MacCall 2009).

$$\frac{W}{Y_{pot}} = \frac{\Delta}{0.4cM} \tag{2}$$

Where the depletion delta (Δ) is an estimate of the change in biomass from the first year in the time series to the last year, M is natural mortality and *c* is a tuning adjustment with a value less than one (MacCall 2009). Substituting equation 2 into equation 1 produces equation (3).

$$Y_{sust} = \frac{\sum C}{n + {}^{\Delta}/_{0.4cM}} \qquad (3)$$

The DCAC can then be calculated using the DCAC tool from the NOAA Fisheries Toolbox (NOAA Fisheries Toolbox 2012). The DCAC tool takes the input parameters and runs the model with a Monte Carlo exploration of DCAC to provide confidence intervals for sustainable yield estimates.

A majority of the input parameters were left at default values suggested by MacCall (2009). Total catch was set as a normal distribution with a CV of 0.2. The precision of catch for DL coral reef species are generally less precise than those of data-rich species; however, the cumulative catch over a long period of time may improve the relative precision (MacCall 2009). The F_{MSY}/M ratio was set at 0.8 as suggested by Walters and Martell (2004) for DL stocks, and was given a lognormal distribution with the default standard deviation of 0.2. The ratio of B_{MSY}/B_0 was left at the default value of 0.4 which is often used for roundfish (MacCall 2009). A bounded beta distribution was used for B_{MSY}/B_0 with a standard deviation of 0.1, an upper limit of 1.0 and a lower limit of 0.0.

DCAC works best on long lived species with a natural mortality rate less than 0.2 year^{-1}. Natural mortality was estimated using Hoenig's (1983) 'rule of thumb' mortality equation with a 5% survival rate (S) at maximum age (T_{max}) (4).

$$M = \frac{-\ln(S)}{T_{max}} \qquad (4)$$

However, many tropical fish species lack maximum age data. For species lacking published maximum age, maximum age was estimated using proxy species and the life history tool from Fishbase.org (Froese et al. 2005). Natural mortality was estimated to have a lognormal distribution with a CV of 0.5 to account for the uncertainty in the *M* parameter (MacCall 2009).

The most sensitive parameter is the depletion delta which is the change in depletion within the time series. For example, if the abundance is assumed to have declined from 80% of B_0 in 1987 to 60% in 2014 then the depletion delta would be set at 0.2 (NOAA Fisheries Toolbox 2012). For American Samoa, the depletion delta was set at 0.3 which would assume a 30% decrease in stock in 28 years. To characterize the uncertainty in this parameter the DCAC was also run using depletion deltas 0.15 and 0.50. The depletion delta had a bounded beta distribution with an upper limit of 1.0, a lower limit of 0.0, and a standard deviation of 0.20. Table 2 provides a summary of input parameters and values.

Table 2: Summary of input parameters for the DCAC model from the NOAA Fisheries Toolbox.

Parameter	Value
SumC (normal distribution)	Sum of catch from CREEL 1987-2014
CV of SumC	0.2
Number of Years (n)	Total years=28. Time series should be > 10 years
M (lognormal distribution)	Natural mortality rate <0.2 is best (MacCall 2009)
Std Dev M	0.5 (MacCall 2009)
F_{msy} to M ratio (lognormal distribution)	0.8 (Walters and Martell 2004)
Std Dev F_{msy}/M	0.2 (MacCall 2009)
B_{msy}/B_0 (bounded beta (1.0,0.0))	0.4 (MacCall 2009)
Std Dev B_{msy}/B_0	0.1 (MacCall 2009)
Depletion Delta Δ (bounded beta(1.0,0.0))	0.15, 0.3, 0.5
Std Dev Depletion Delta	0.2

Originally thirteen species were selected to estimate a sustainable yield for American Samoa inshore fishery species (Table 1). However, six of the thirteen species were not suitable for a DCAC analysis. Species with a natural mortality greater than 0.2 year^{-1} (*C. melampygus, L. kasmira*, and *C. argus)* are not recommended for the DCAC analysis because the depletion correction becomes too small (MacCall 2009). The DCAC works best on stocks with a time series longer than a decade (MacCall 2009). Therefore, species mainly listed in the Bio-Sampling data did not have an adequate time series from CREEL surveys for this analysis (*C. trilobatus, S. rubroviolaceus,* and *C. japanensis*).

Coral reef species are currently managed by family in American Samoa, therefore DCAC was also run for family groupings to compare sustainable yield results with current annual catch limits (ACL). Using family instead of species allowed for a yield estimate to be created for Scaridae (parrotfish) which is not identified to the species level in CREEL data. For the DCAC, *M* was set at the lowest value for selected species in the family, or set at 0.2 if *M* values for selected species were greater than 0.20.

Results and Discussion

The stock for each species was assumed to have depleted 30% in the past 28 years. Median sustainable estimates using a 30% depletion delta ranged from 5,298 lbs (*A. lineatus*) to 71 lbs (*M. berndti*). However, a 30% depletion was just an assumption, therefore two other depletion deltas (15% and 50%) were also used to calculate how much of an effect the depletion delta had on the sustainable yield estimate. All species sustainable yields of 15% and 50% fell within the 95% confidence interval of the 30% depletion delta (Table 3). Average annual catch for all species also fell within the 95% confidence interval.

Table 3: Summary of sustainable yield estimates with 95% confidence intervals given total catch (SumC), natural mortality (M), and depletion deltas: Δ0.15, 0.3, and 0.5. Species are ranked in order of total catch. Bold M values were estimated based on Life History tool.

Input Parameters					DCAC Yield			
Species	**SumC**	**Avg. Catch**	**years (n)**	**M**	**Δ 0.15**	**Δ 0.3**	**Δ 0.5**	**5-95% CI**
Acanthurus lineatus Bluebanded surgeonfish	197,378	7,049	28	0.12	6,184.1	5,297.5	4,478.1	2,832-7,978
Lutjanus gibbus Humpback snapper	74,146	2,648	28	0.17	2,392.0	2,130.6	1,874.1	1,233-3,094
Ctenochaetus striatus Striped bristletooth	44,924	1,953	23	0.09	1,637.6	1,290.5	1,024.8	605-2,104
Naso lituratus Orangespine unicornfish	39,894	1,478	27	0.21	1,350.2	1,223.0	1,093.6	730-1,750
Lethrinus amboinensis Ambon emperor	22,396	1,244	18	**0.19**	1,093.2	939.4	794.9	504-1,410
Acanthurus xanthopterus Yellowfin surgeonfish	22,085	883	25	0.09	747.2	599.2	480.9	288-961
Monotaxis grandoculis Bigeye Bream	1,890	126	15	**0.22**	110.4	94.3	79.5	50-142
Myripristis berndti Bigscale soldierfish	1,653	118	14	0.11	95.7	70.7	53.7	30-123

The main assumption was that the stock has decreased during the 28 year time series. However, if there has been no change in abundance, then the sustainable yield would equal average catch. Conversely, if abundance has increased during the time series, the depletion delta would be negative and the sustainable yield would be greater than average catch (MacCall 2009)

In American Samoa ACLs are set based on family grouping instead of individual species. Family ACLs were set for the most commonly caught coral reef associated families in 2013. In order to compare 2013 ACLs to DCAC sustainable yield, the DCAC was also run using family groupings (Table 4).

Table 4: Summary of sustainable yield estimates for family groupings with 95% confidence intervals given total catch (SumC), natural mortality (M), and depletion deltas: Δ0.15, 0.3, and 0.5. The current ACL is also given for comparison. Species are ranked in order of total catch. M was set at 0.2 (values in bold) for families unless a selected species had a lower M.

	Input Parameters				DCAC Yield			
Family	**2013 ACL**	**SumC**	**Avg. Catch**	**M**	**Δ 0.15**	**Δ 0.3**	**Δ 0.5**	**5-95% CI**
Acanthuridae	19,516	560,624	20,022	0.09	17,138.0	14,023.4	11,430.4	6,991-22,019
Carangidae	9,490	488,877	17,460	**0.20**	15,941.2	14,423.1	12,887.1	8,603-20,665
Lutjanidae	18,839	336,303	12,011	0.17	10,849.5	9,663.9	8,500.5	5,593-14,032
Scaridae	8,145	239,938	8,569	0.20	7,823.9	7,078.8	6,324.9	4,223-10,142
Serranidae	5,600	161,544	5,769	**0.20**	5,267.6	4,766.0	4,258.4	2,843 - 6,829
Lethrinidae	7,350	160,101	5,718	0.19	5,203.3	4,687.3	4,165.8	2,772 - 6,744
Holocentridae	2,585	89,992	3,214	0.11	2,800.2	2,367.0	1,980.9	1,240 - 3,610

With the exception of Carangidae all median sustainable yield estimates using a 30% depletion delta were lower than the 2013 ACLs. However, the ACL did fall within the 95% confidence interval for most families except for Lutjanidae and Lethrinidae. Holocentridae's sustainable yield estimate was the closest to the ACL with only a 200 lb. difference. Lutjanidae ACL had the largest difference from the DCAC sustainable yield probably because this assessment did not take into account the large amounts of snappers caught offshore in bottomfishing activities.

Even though the sustainable yields were close to the ACLs, grouping species by families blurs vulnerability to fishing for individual species. Individual species in a family might need a lower catch limit due to fishing vulnerability, while other species in a family may not be as heavily targeted. Grouping species by family does not take into account species level differences, and therefore the sustainable yields are not as informative as yield estimates for individual species.

Fishing Mortality estimates using Average Lengths

Average length of exploited fishery populations can be used as an indicator of population status because length is highly correlated with population size (Ault et al. 2005). Average length has several advantages for estimating fishing mortality (F) and as an indicator of exploitation rates: (i) the data requirements are based on length frequency compositions and estimates of natural mortality; (ii) the method can apply to fishery dependent and independent data; and (iii) the computational requirements are relatively simple (Ault et al. 2005). The average length (Lbar) method has been shown to be robust at assessing exploitation impacts on Florida's coral-reef fishery community and recently on Hawaii's coral reef fishery community (Ault et al. 2005, Nadon et al. 2015). In Florida, fishing mortality estimates using the Lbar method were comparable to estimated fishing mortality from CPUE time series (Ault et al. 2005).

Bio-Sampling lengths from 2014 were used to calculate fishing mortality (F) and fishing status (F/Fmsy) using the Lbar method (Ehrhardt and Ault 1992). Because the Bio-Sampling program started in 2010, the time frame is not long enough to notice any changing trends in fish length catch. In order to look at changes in catch size over time, CREEL length data was used for 2004 and 2009. Three species (*C. melampygus, C. trilobatus*, and *L. amboinensis*) did not have adequate length samples (n>100) for the analysis, and were therefore excluded from the analysis.

Size frequency distributions were examined in order to determine minimum length at full selectivity into the fishery (L_c) and average length($\bar{L}$). Size at full selectivity into the fishery was determined based on discontinuous breaks in the size composition histogram in order to retain more length samples (Nadon et al. 2015). In addition to capture length, expected length at maximum known age (L_λ) and growth parameters from the von Bertalanffy equation (k, L_∞), were also needed for the equation. Expected length at maximum known age (L_λ) was computed using the von Bertalanffy growth function with an observed maximum age. For species with unknown life history traits, k and L_∞ were estimated using fishbase.org.

Total mortality rate (Z) was estimated using length-based mortality model (5) (Ehrhardt and Ault 1992):

$$\left[\frac{L_\infty - L_\lambda}{L_\infty - L_c}\right]^{Z/K} = \frac{Z(L_C - \bar{L}) + K(L_\infty - \bar{L})}{Z(L_\lambda - \bar{L}) + K(L_\infty - \bar{L})} \qquad (5)$$

In equation five, all variables are known except for Z; which can then be found iteratively.

Natural mortality (M) was also calculated (6) using age at maximum catch length (t_λ) and estimating survivorship at maximum age (S) at 0.05 (Hewitt and Hoenig 2005, Nadon et al. 2015).

$$\mathrm{M} = \frac{-\ln(S)}{t_\lambda} \qquad (6)$$

Natural mortality was then subtracted from total mortality to estimate the fishing mortality of each species (7).

$$\mathrm{F} = \mathrm{Z} - \mathrm{M} \qquad (7)$$

Based on the rule of thumb that F_{MSY}=M (Ault et al. 2005), the current fishing status for each species could then be determined by dividing F by F_{MSY}. Values of $F/F_{MSY} > 1$ indicates a fishing status of overfishing.

Results and Discussion

Table 5: American Samoa inshore fishery species with corresponding Bio-Sampling length samples from 2014 (N), average length ($\bar{L}$), minimum catch length at full selection (L_C), expected length at maximum age (L_λ), von Bertalanffy growth coefficient (k), maximum length (L_∞), and maximum age (t_{max}). All lengths are in cm. Values in bold were estimated from fishbase.org

Species	N	$\bar{L}$(cm)	L_C	*k*	L_∞	T_{max}	L_λ
Acanthurus lineatus	21,335	18.7	15	0.70	22.1	25	22.1
Acanthurus xanthopterus	178	29.1	21	0.29	42.6	34	42.6
Ctenochaetus striatus	1,958	17.9	15	0.75	21.0	34	21.0
Naso lituratus	1,457	22.1	19	0.35	35.1	14	34.8
Myripristis berndti	602	17.2	15	0.15	27.1	27	26.6
Monotaxis grandoculis	134	27.6	20	**0.21**	56.0	**14**	53.0
Lutjanus gibbus	290	28.8	26	0.40	39.8	18	39.8
Lutjanus kasmira	598	21.9	19	0.38	33.0	8	31.4
Scarus rubroviolaceus	570	35.0	22	0.29	52.6	14	51.7
Chlorurus japanensis	1,083	26.0	23	**0.57**	46.0	**5**	43.3
Cephalopholis argus	166	28.8	22	**0.19**	60.0	8	46.9

The minimum capture size (L_c), based on breaks in catch frequency distributions (Appendix 1), ranged from 15 cm to 26 cm (Table 5). Average catch length ranged from 17 cm to 35 cm. Estimated 2014 total mortality (Z), fishing mortality (F), and natural mortality (M) were used to calculate fishing status (Table 6). Based on the rule of thumb that that F_{MSY}=M (Ault et al. 2005), all F values greater than M indicate overfishing. By dividing F/M current fishing status can be determined. Values greater than one are considered species where overfishing is possibly occurring (Table 2).

Table 6: Natural mortality (M), total mortality (Z), fishing mortality (F), and fishing status (F/M) for 2014. F/M values greater than 1.4 are highlighted in red indicating overfishing (F/M>1.5) Values between 0.5-1.4 are highlighted in yellow to indicate fishing status is close to F_{MSY}.

Species	M	Z	F	F/M
Acanthurus lineatus	0.12	0.64	0.52	4.3
Acanthurus xanthopterus	0.09	0.48	0.39	4.3
Ctenochaetus striatus	0.09	0.8	0.71	7.9
Naso lituratus	0.21	1.47	1.26	6.0
Myripristis berndti	0.11	0.67	0.56	5.1
Monotaxis grandoculis	**0.21**	0.78	0.57	2.7
Lutjanus gibbus	0.17	1.57	1.4	8.2
Lutjanus kasmira	0.37	1.45	1.08	2.9
Scarus rubroviolaceus	0.21	0.42	0.21	1.0
Chlorurus japanensis	**0.6**	3.8	3.2	5.3
Cephalopholis argus	0.37	0.84	0.47	1.3

The majority of species had 2014 fishing mortality values above maximum fishing harvest rate (F>1.4) (Table 6). *L. gibbus* had the highest fishing status for all species. Only two species *S. rubroviolaceus* and *C. argus* had fishing mortality rates close to F_{MSY}.

Both of the lutjanid species had enough CREEL length catch data from 2004 and 2009 to compare catch lengths over time (Table 7). The average size for *L. gibbus* decreased 5 cm from 2009 to 2014. The decreasing average size raised the fishing mortality and thus the fishing status from under the overfishing threshold (0.82) to the highest overfishing status (8.2) in 2014. *L. kasmira* had similar average catch size throughout the 10 year time frame. Fishing status also remained steady throughout the time series and remained above the overfishing bounds the entire 10 years.

Table 7: Change in fishing mortality (F) and fishing status (F/M) from CREEL data for 2004 and 2009 for *L. gibbus* and *L. kasmira.*

		Lutjanus gibbus	***Lutjanus kasmira***
	M	0.17	0.37
2004	**$\bar{L}$ (N)**	31.2 (233)	22.1 (301)
	Z	0.66	1.3
	F	0.49	0.93
	F/M	2.88	2.51
2009	**$\bar{L}$ (N)**	33.8 (489)	21.9 (570)
	Z	0.31	1.45
	F	0.14	1.08
	F/M	0.82	2.92
2014	**$\bar{L}$ (N)**	28.8 (290)	21.9 (598)
	Z	1.57	1.45
	F	1.4	1.08
	F/M	8.2	2.9

Fishing effort seen in tables 6 and 7 were unrealistically large with F/M ratios exceeding 2. Several factors could have led to a possibly inflated fishing status estimate such as sampling error in length data and poor life history information. For many of the coral reef species, different life history traits such as maximum age and the von Bertalanffy growth coefficient are unknown. For these species, the unknown life history traits were estimated using either traits from the same species in different regions, traits from other similar species, or estimated using the life history tool in fishbase.org (Table 5) (Froese et al. 2005). Coral reef species have varying growth rates, maximum age, and maximum size depending on region (DeMartini et al. 2014, Taylor and Choat 2014). For this reason, using life history characteristics from other regions could cause bias in the estimation. The current Lbar method is reliant on good life history information, and thus information from other regions may have created inflated Z estimates. Otoliths of common American Samoan reef species collected from the Bio-Sampling program are currently being examined and better growth and age information will help better specify current estimates.

Bio-Sampling data was chosen as the primary data set for this study because every fish obtained is measured leading to reliable minimum, average, and maximum length estimates. Conversely, the CREEL program only measures a small, non-random portion of the fish caught. Therefore, very few small or large specimens are measured within the CREEL surveys. This non-random sampling would preclude information such as minimum size at full selectivity, and could potentially skew average length. A majority of the samples from the Bio-Sampling data come from nighttime spear trips, therefore the values obtained will not be very accurate for species targeted in other fishing methods. Because of the specific fishing sector sampled, species such as *C. melampygus* and *L. amboinensis* did not have ample samples in the Bio-Sampling data to calculate fishing status. The Bio-Sampling program also pays fishers per fish sampled resulting in small fish that would not normally be targeted in the fishery. This issue was avoided by assessing the catch histograms to find the minimum length at entry into the fishery. However, depending on the prevalence of small fish in the Bio-Sampling data, average length could possibly be smaller than in the actual fishery.

Comparison of Data Limited method sustainable yields

The Natural Resources Defense Council (NRDC) created a working group of fishery experts with the goal of evaluating and improving current methods for managing DL fisheries. One of the outcomes of this working group was a Data-Limited Methods (DLM) Fisheries Toolkit (Carruthers 2014, Newman et al. 2014). The DLM toolkit provides a standardized set of readily available methods which can be tested and compared to help set over fishing limits (OFLs) for data-limited fishery stocks (Carruthers 2014). The DLM toolkit analyzes 35 different DL methods. The majority of these methods rely on a catch time series, and various life history parameters to create an OFL.

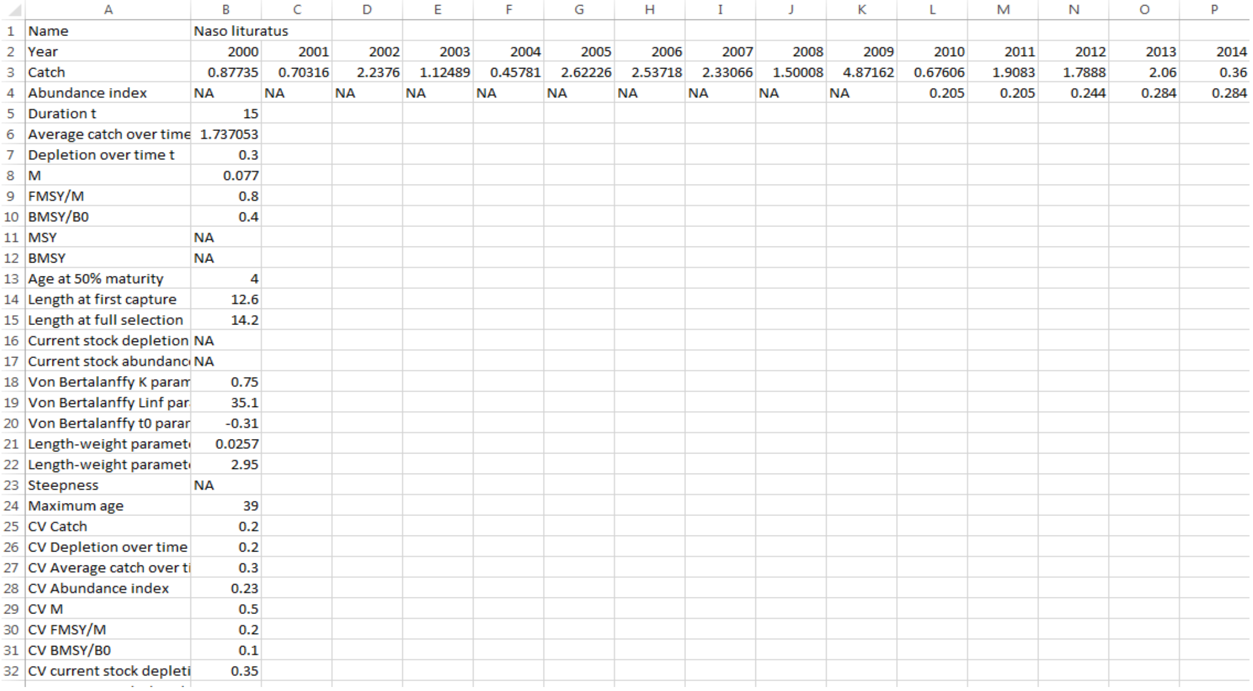
One of the benefits of the DLM toolkit, is various methods can be compared using a management strategy evaluation (MSE). MSE rates the performance of proposed management policies over a fixed period of time with identical conditions and uncertainties by using probability of overfishing, probability of falling below certain biomass indicators, and relative long term yield (Newman et al. 2014).

An MSE was used to evaluate the various performance of the most common DL methods: Depletion-Corrected Average Catch (DCAC), Depletion-Based Stock Reduction Analysis (DB-SRA), and Catch-MSY (SPMSY) in terms of yields, probability of overfishing, and probability of biomass dropping below various B_{MSY} indicators (B_{MSY}, 50% B_{MSY}, 10% B_{MSY}). OFL estimates were then calculated using the DLM toolkit for four common American Samoan fishery species: *A. lineatus, C. striatus, L. gibbus,* and *M. berndti*. These four species were chosen based on level of catch and life history data available. They were also chosen to represent a variety of families, trophic levels, ecosystem niches, and life history characteristics.

MSE and OFL estimates were calculated for *A. lineatus, C. striatus, L. gibbus,* and *M. berndti* using the DLM tool (Version 1.34) package for R (Carruthers 2014). CREEL catch data, and known life history information were compiled for each of the four species (Table 8). Data for each individual species was then entered into a DLM spreadsheet (Figure 1). Any unknown data was given an NA designation.

Table 8: Input values for selected American Samoan fishery species. Values matched input parameters from previous DCAC method (above).

Species	***A. Lineatus***	***C. striatus***	***L. gibbus***	***M. berndti***
Catch (CV)	CREEL 1990-2014 Average: 6,915 (0.3)	CREEL 1990-2014 Average: 2,074 (0.3)	CREEL 1990-2014 Average: 2,829 (0.3)	CREEL 2003-2014 Average: 146 (0.3)
Duration	25 years	25 years	25 years	12 years
Abundance (CV)	CRED 2008, 2010, 2012 (0.06)	CRED 2008, 2010, 2012 (0.06)	CRED 2008, 2010, 2012 (0.16)	CRED 2008, 2010, 2012 (0.21)
Depletion (CV)	Depletion Over Time t: 0.3 (0.2) Current Depletion: 0.5 (0.4)			
M (CV)	0.12 (0.5)	0.09 (0.5)	0.17 (0.5)	0.11 (0.5)
F_{MSY}/M (CV)	0.8 (0.2)			
B_{MSY}/B_0 (CV)	0.4 (0.1)			
T_{mat} (CV)	4 (0.2)	2 (0.2)	1.6 (0.2)	5 (0.2)
K (CV)	0.7 (0.3)	0.75 (0.3)	0.4 (0.3)	0.15 (0.3)
L_{inf} (CV)	22.1 (0.2)	21 (0.2)	39.8 (0.2)	27.1 (0.2)
T_{max}	25	34	18	27



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Name	Naso lituratus														
2	Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
3	Catch	0.87735	0.70316	2.2376	1.12489	0.45781	2.62226	2.53718	2.33066	1.50008	4.87162	0.67606	1.9083	1.7888	2.06	0.36
4	Abundance index	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.205	0.205	0.244	0.284	0.284
5	Duration t	15														
6	Average catch over time	1.737053														
7	Depletion over time t	0.3														
8	M	0.077														
9	FMSY/M	0.8														
10	BMSY/B0	0.4														
11	MSY	NA														
12	BMSY	NA														
13	Age at 50% maturity	4														
14	Length at first capture	12.6														
15	Length at full selection	14.2														
16	Current stock depletion	NA														
17	Current stock abundanc	NA														
18	Von Bertalanffy K param	0.75														
19	Von Bertalanffy Linf par	35.1														
20	Von Bertalanffy t0 parar	-0.31														
21	Length-weight paramet	0.0257														
22	Length-weight paramet	2.95														
23	Steepness	NA														
24	Maximum age	39														
25	CV Catch	0.2														
26	CV Depletion over time	0.2														
27	CV Average catch over ti	0.3														
28	CV Abundance index	0.23														
29	CV M	0.5														
30	CV FMSY/M	0.2														
31	CV BMSY/B0	0.1														
32	CV current stock depleti	0.35														

Figure 1: Example of part of the stock input table for DLM tool program.

Based on the available information for these common American Samoan species, a list of possible DL methods were produced that could estimate an OFL. The viable methods are listed in Table 9 with a description of how each method works (Newman et al. 2014).

In order to evaluate how each of these methods preformed in terms of long-term yield, probability of overfishing, and probability of stock biomass dropping below a percentage of B_{MSY}, an MSE was run using a model fishery. The model fishery used a sample snapper stock because of similarities with the American Samoa reef fish complex. The snapper stock was long lived (t_{max}=40), with a natural mortality rate varying between 0.07 and 0.2 (similar to the American Samoa reef fish complex), and a depletion rate varying between 5% and 60%; because the depletion rate for American Samoa complex most likely falls within that range. The sample fishery fleet was a generic fleet with recent flat effort (Generic_FlatE) and was given some spatial targeting between 1 and 1.5 to model for the effects of targeting reef areas. Finally, an imprecise biased observation error(Impercise_Biased) was used in order to account for data that is most likely imprecise and potentially biased (Carruthers 2014).

A second MSE was also run with SPMSY, DCAC, and DB-SRA in order to better differentiate the performance of these three common DL methods. Those three methods were then used for each of the four selected species to produce OFL estimates along with 95% confidence intervals.

Table 9: List of usable DLM methods given available data for American Samoan fishery stocks. Table adapted from Newman et al. (2014). For description of variations and other DLM methods please refer to Newman et al. (2014)

Method	Description	Variations
Depletion-Based Stock Reduction Analysis (DB-SRA)	Relies on F_{MSY}/M, M, B_{MSY}/B_0 and current stock depletion (Δ). Catch and life history parameters can be used to solve for unfished biomass. Age at maturity is also required to lag the delay difference model. (Dick and MacCall 2011)	DBSRA 40, DBSRA ML, DBSRA 40-10
Depletion-Corrected Average Catch (DCAC)	Relies on F_{MSY}/M, M, B_{MSY}/B_0, average catch for time t, and depletion (Δ) over time t. DCAC calculates average catch after accounting for the "windfall ratio" (one time reduction in stock from pristine levels). (MacCall 2009)	DCAC 40, DCAC ML, DCAC 40-10
Surplus Production MSY (SPMSY)	Uses catch and a range of starting stock depletion and current stock depletion. SPMSY samples from a range or r (intrinsic growth rate) and K (carrying capacity) values and keeps the combinations that fit initial and ending depletion ranges. (Martell and Froese 2013)	
Surplus Production Stock Reduction Analysis (SPSRA ML)	Similar to DB-SRA, this can be used to solve for K given a depletion estimate which can be determined based on mean length using a non-equilibrium estimate of F.	
Delay-Difference stock assessment (DD)	Uses MSY exploitation rate (U_{MSY}) and MSY to simulate changes in biomass by subtracting estimates of mortality and adding recruits (Newman et al. 2014).	DD 40-10
Demographic F_{MSY} (F_{DEM} ML)	The ML extension uses Mean Length to estimate current abundance based on catches and recent F (Gedamke and Hoenig 2006).	
F_{MSY} to M Ratio (F_{RATIO} ML)	F_{MSY} is estimated to be equal to a fraction of M and is then multiplied by current estimate of abundance which is estimated using mean length, catch, and F (Gedamke and Hoenig 2006).	
Algorithmic Management Procedures (MMHCR, SBT1)	MMHCR-harvest control rule using trends in surplus production to make changes to output controls SBT1-management procedure used for Southern Bluefin Tuna relying on simulated MSY	

Results and Discussion

The two Acanthuridae species had the best life history data available with most of the data coming from American Samoa. *A. lineatus* had the highest catch rate out of the selected species. *M. berndti* had the smallest catch record out of the four selected species with available catch only from 2003-2014. Life history information for *M. berndti* was from other locations outside of American Samoa, which may not be as accurate as site specific information. The CRED abundance data for Holocentridae was probably on the conservative side, because these species are more cryptic and hide in rocks and crevices and are not as likely to be observed during dives. However, DCAC, DB-SRA, and SPMSY do not use relative abundance estimates in the calculations.

From the MSE with all applicable DL methods, it appears that DD4010 has the highest probable long term yield. However, DD4010 also had about a 40% probability of biomass falling below B_{MSY} (Figure 2). SPMSY had the lowest probability of overfishing and falling below any of the biomass indicators but SPMSY also had the lowest long term yield. All available methods had less than a 50% probability of overfishing and biomass falling below B_{MSY}.

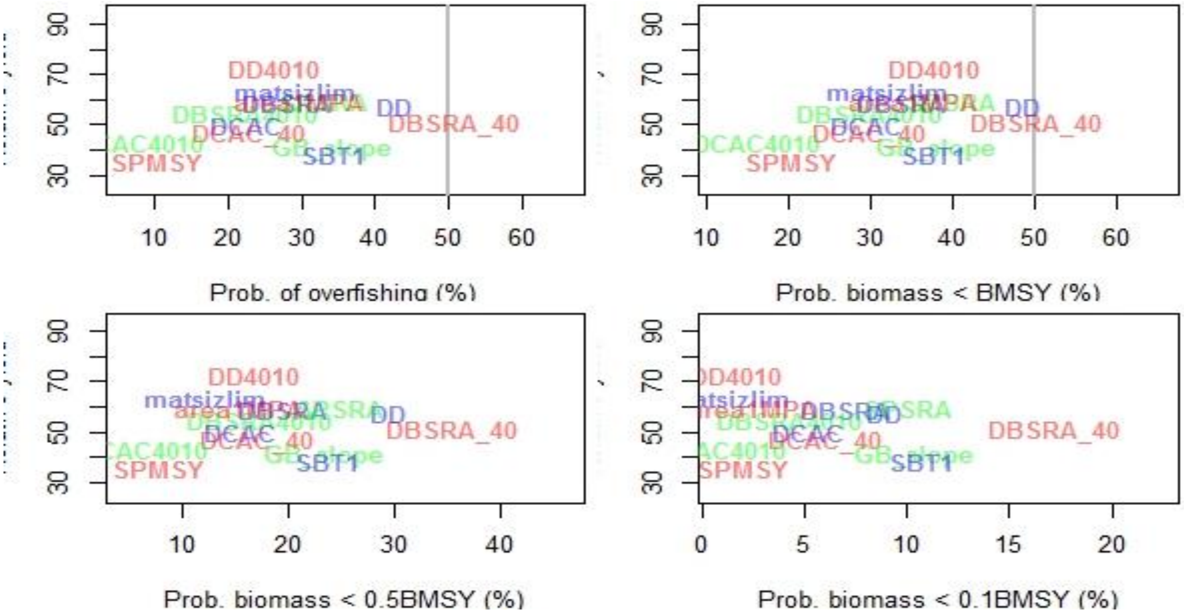


Figure 2: MSE results for usable DL methods given the available fishery data in American Samoa. Y-axis represents relative yield for all graphs. X-axis on graphs from upper left to bottom right: probability of overfishing (%), probability of biomass < B_{MSY}, probability of biomass < 50% of B_{MSY}, and probability of biomass < 10 % B_{MSY}.

The second MSE with only DCAC, DB-SRA, and SMPSY showed all three methods had less than a 35% probability of overfishing, and less than a 25% probability of biomass dropping below the overfished limit of 50% B_{MSY} (Figure 3). The MSE showed that DB-SRA produced a slightly higher long term yield than the other two methods. SPMSY still had the lowest relative yield but also the lowest probability of overfishing and having biomass drop below B_{MSY}. DCAC fell right in between the other two DL models.

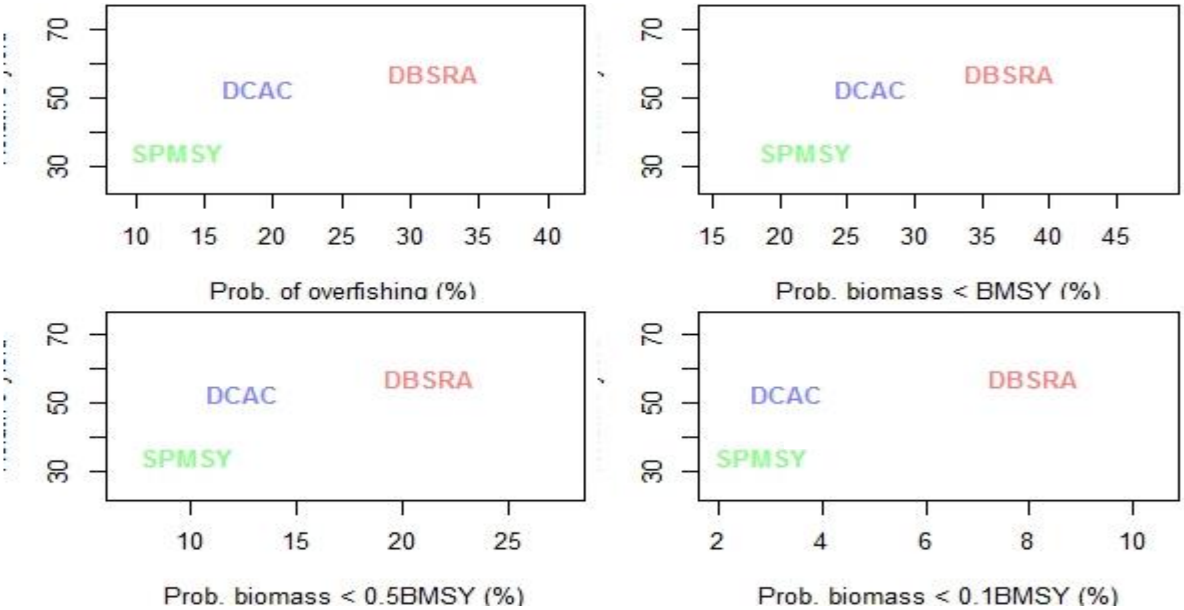


Figure 3: MSE results for top three most common DLM methods. Y-axis represents relative yield for all graphs. X-axis on graphs from upper left to bottom right: probability of overfishing (%), probability of biomass < B_{MSY}, probability of biomass < 50% of B_{MSY}, and probability of biomass < 10 % B_{MSY}

Newman et al. (2014) concluded from various MSE runs with different stock simulations that F_{MSY}/M and DB-SRA with an informed depletion delta outperformed other methods at all biomass levels. However, those assessment methods required estimates of current depletion or abundance. Depletion estimates are the most difficult to obtain in data-limited fisheries (Carruthers et al. 2014). Carruthers et al. (2014) also found that the imprecision (CV) in the depletion delta did not lead to dramatic loss of yield or increase the probability of overfishing. Therefore, it might be beneficial to have depletion delta based off of expert knowledge with a large error variance.

OFL calculations were run with each of the three common DL methods: DCAC, DB-SRA, and SPMSY for all four species. Median estimations with 95% confidence intervals, and the 75th percentile of CREEL recorded catch are listed in Table 10. OFL distributions for each species are in figures 4-7. The various DL methods produced a wide range of OFL yields. Congruent with the MSE, the DB-SRA produced the highest OFL yield for all species.

Table 10: OFL estimates (pounds) with 95% CI for four American Samoan fishery species using three different DL methods. The 75th percentile of historical catch records is also included as reference.

Species	DCAC		DB-SRA		SPMSY		75th Percentile
	Median	95% CI	Median	95% CI	Median	95% CI	
A. lineatus	3,852.6	168.7	6,078.2	1,533.9	2,517.7	266.5	5,900.6
C. striatus	959.9	51.7	1,707.6	459.0	932.8	141.3	1,026.9
L. gibbus	1,684.2	77.2	3,374.0	947.4	1,134.0	138.0	3,255.3
M. berndti	51.0	4.0	105.0	50.7	48.3	5.0	187.6

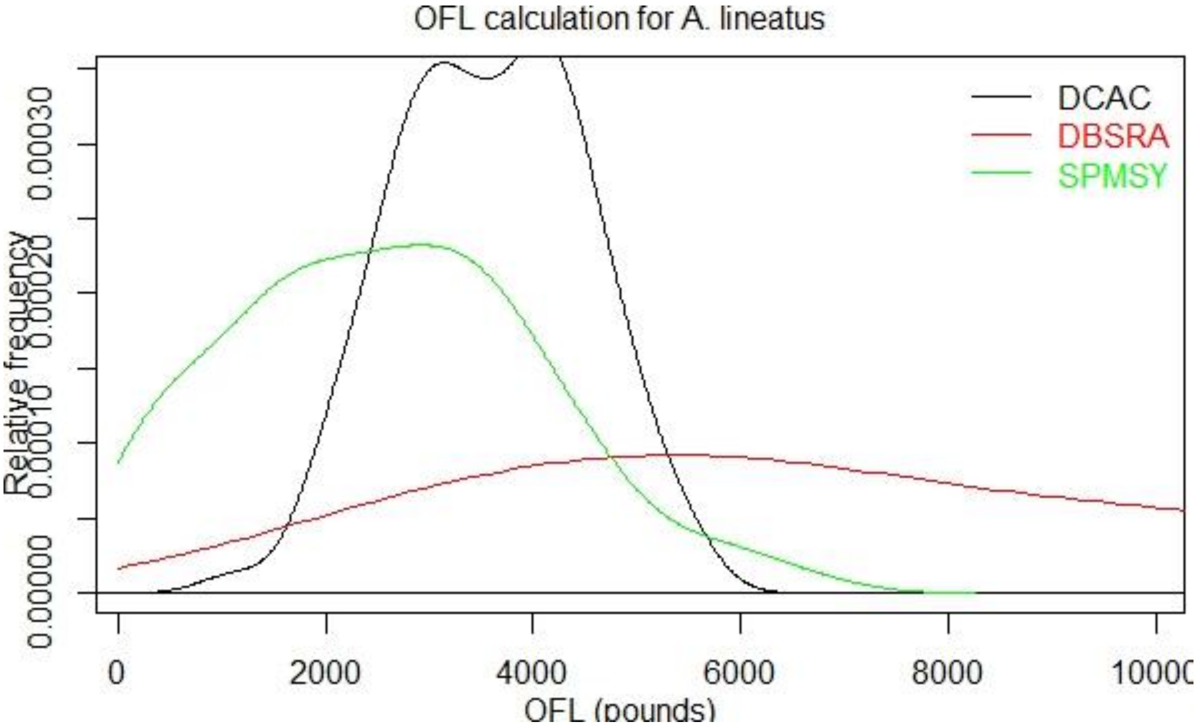


Figure 4: OFL distributions for *A. lineatus*. Black line is DCAC, red line is DB-SRA, and the green line is SPMSY. X-axis OFL (pounds) and Y-axis is relative frequency.

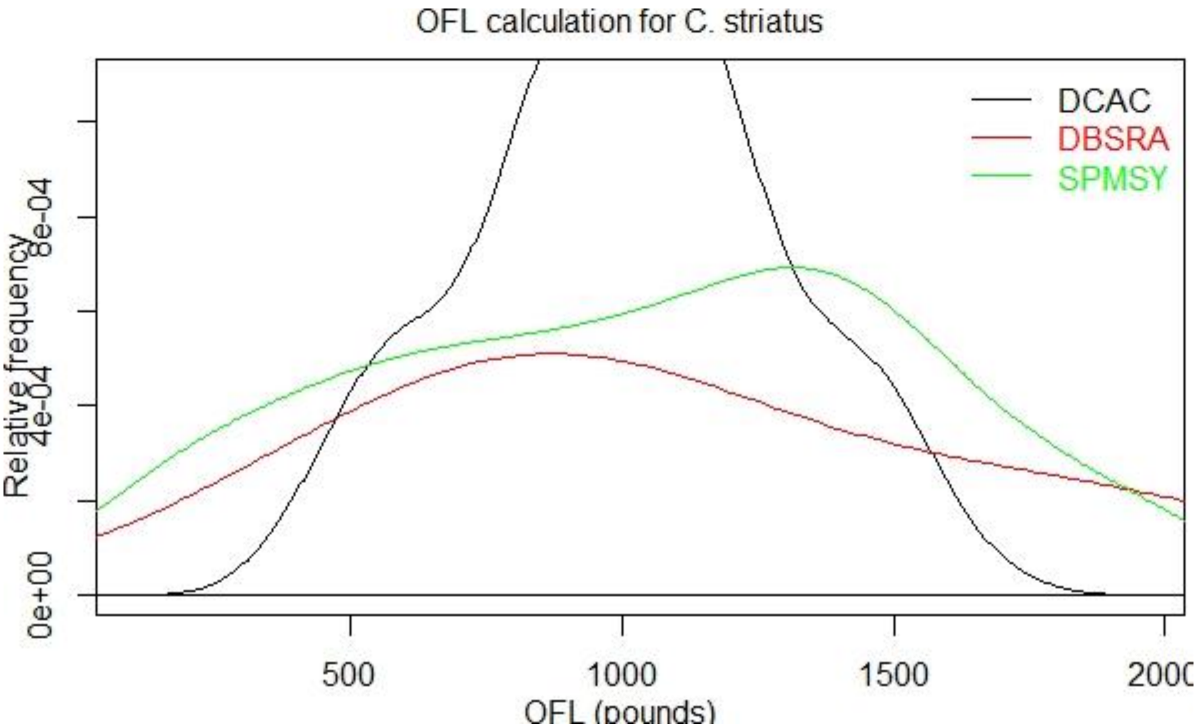


Figure 5: OFL distributions for *C. striatus*. Black line is DCAC, red line is DB-SRA, and the green line is SPMSY. X-axis OFL (pounds) and Y-axis is relative frequency.

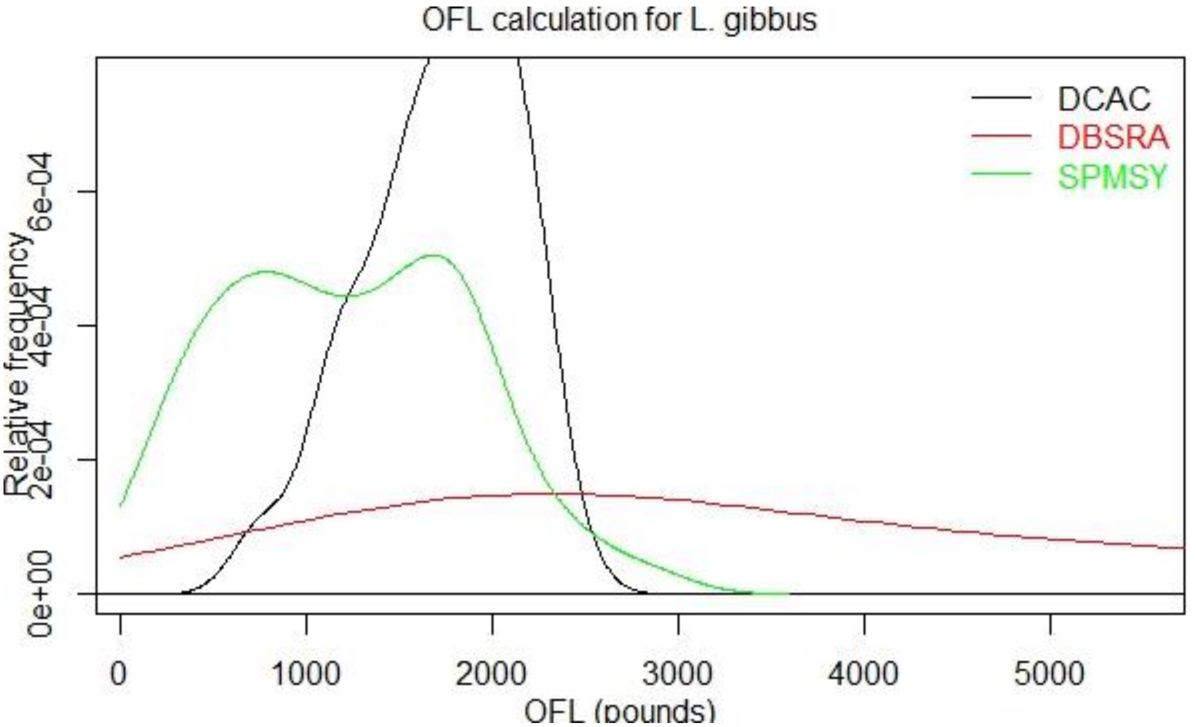


Figure 6: OFL distributions for *L. gibbus*. Black line is DCAC, red line is DB-SRA, and the green line is SPMSY. X-axis OFL (pounds) and Y-axis is relative frequency.

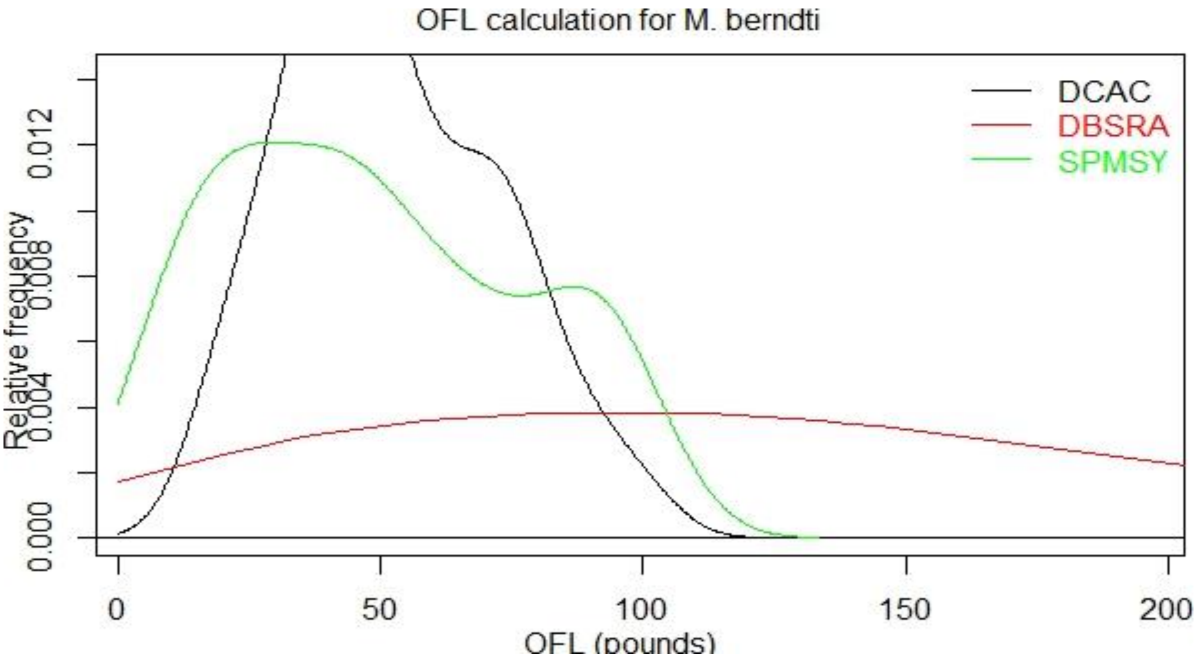


Figure 7: OFL distributions for *M. berndti*. Black line is DCAC, red line is DB-SRA, and the green line is SPMSY. X-axis OFL (pounds) and Y-axis is relative frequency.

OFL estimates and the 75th percentile using recorded CREEL catch were plotted against catch for each species (Figure 8). In three out of the four species the OFL produced by DB-SRA had a slightly higher yield than the 75th percentile. Most of the species had historical catch below both the 75th percentile and the DB-SRA OFL.

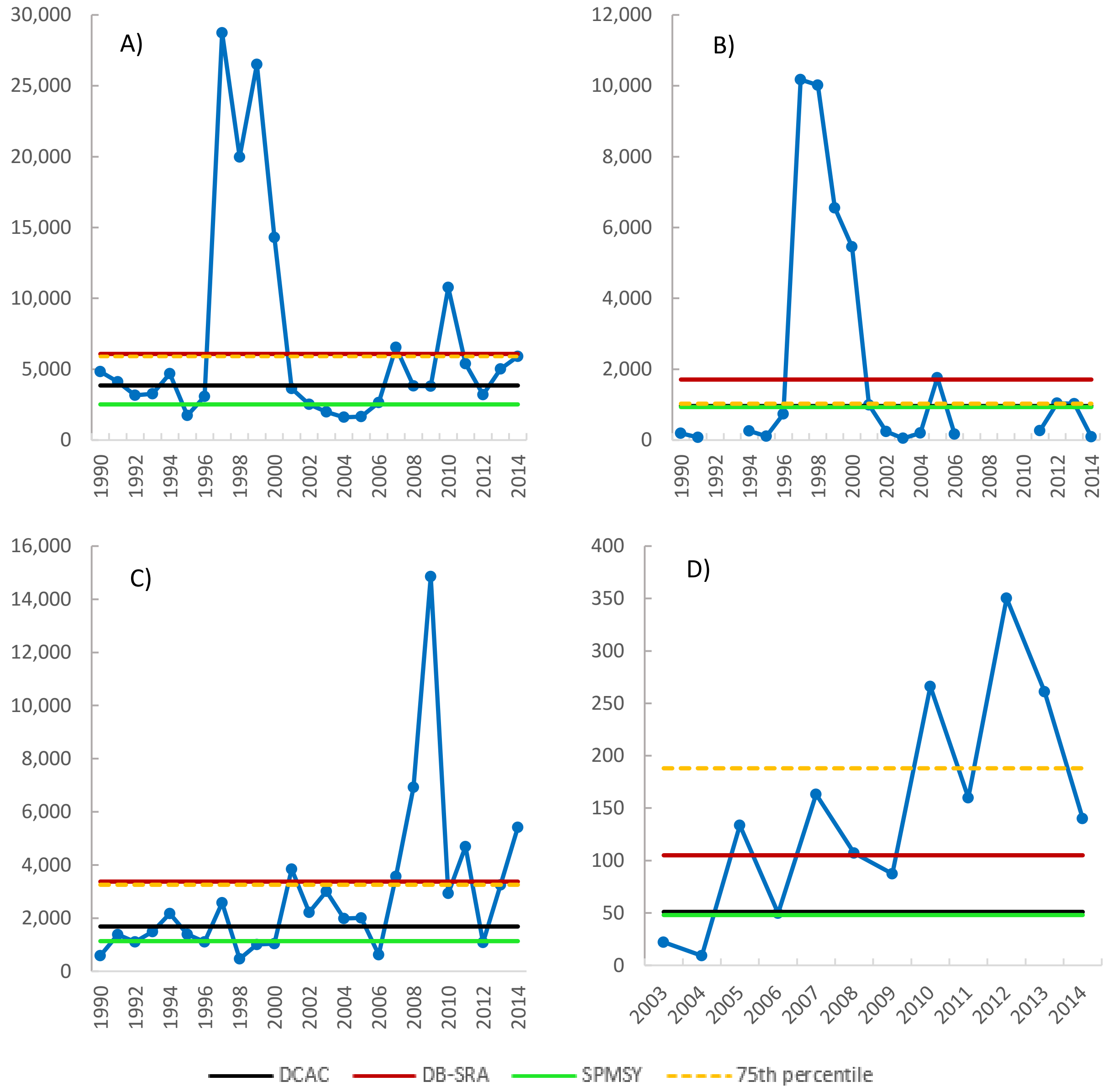


Figure 8: OFL estimates for each method: DCAC (black), DB-SRA (red), SPMSY (green), 75th percentile (yellow dashed), against recorded CREEL catch (blue) for each species: A) *A. lineatus*, B) *C. striatus*, C) *L. gibbus*, and D) *M. berndti*. The y-axis represents catch in pounds, and x-axis is years. Note: the y-axis varies between graphs.

M. berndti had the smallest OFL limits even with the limited catch and the increasing catch within the past 12 years (Figure 8 (D)). In lightly fished stocks, such as *M. berndti*, the time series of catch does not contain sufficient information about the productivity of the stock (Martell and Froese 2013). Therefore, given the light level of reported catch and nearly unexploited status, *M. berndti* is not in immediate need of management and these data limited methods will not produce accurate OFL estimates.

The DLM toolkit provides a comprehensive group of common DL methods that can be utilized for stocks with varying levels of data quality. The MSE is used to compare methods with an identical stock and fishing pressure to determine which DL method would work the best for specific stocks. The toolkit can also provide what data is needed in order for specific methods to be utilized. The four American Samoan species were chosen to represent a variety of data quality, life history traits, trophic levels, catch levels, and ecosystem niches. Even with a variety of species and data quality, DB-SRA produced the highest yield estimate for all species. However, for lightly fished species such as *M. berndti* catch history does not provide adequate information to produce sustainable yield estimates.

Since coral reef species in American Samoa are managed in family groupings, the DLM toolkit could also be used to create OFLs for family complex based on life history data of one species and total catch for the family complex.

Current Limitations

The DL methods tested for this project rely on a reliable catch record. CREEL data is mainly identified to the family level making it impossible to determine total catch of individual species (Ochavillo et al. 2012). American Samoa staff also does not have comprehensive fish identification training, and many common American Samoa fish names are not standardized (Oram et al. 2013b). Both of these issues could lead to misidentification within the data and loss of species specific catch data. CREEL data also does not fully encompass the spear gear type, which is a major gear type for coral reef species. The Bio-Sampling data covers the spear fishery and helps to fill the limitations of the CREEL data. However, neither of these catch records are complete. Using under-estimated catch records may affect the OFL output.

The data limited methods also rely on some estimate of depletion throughout the time period. However, estimating depletion can be difficult. A depletion delta of 0.3 with a CV of 0.2 was chosen for the various methods; but the depletion delta could have ranged from 0 to higher than 0.3. In the DCAC analysis two other depletion deltas (0.15 and 0.5) were tested to compare the OFL output. The OFL did change based on the depletion delta, however it remained in the 95% confidence intervals of the original 0.3 depletion delta. Therefore, the DCAC method is robust to changes in the depletion variable.

Finally the various methods tested all rely heavily on life history data. In coral reef fisheries such as American Samoa, life history data for many species are unknown. When available, life history data from American Samoa was used. Maximum ages from American Samoa are expected to be lower than maximum ages from Hawaii. The difference in age data could be due to longitudinal effects instead of fishing pressure. Maximum age data was selected based on region instead of using the oldest recorded age from any area. Using younger maximum age values, affected natural mortality estimates (M). However, the CV for M was set at 0.5 in order to account for the uncertainty of this parameter. When life history information was unavailable, proxy species were selected and life history parameters were estimated using the life history tool at fishbase.org. The uncertainties in the life history data would introduce uncertainty to the OFL estimations. With better life history data, such as maximum age, L_{inf}, and k, more accurate sustainable yields could be estimated.

Otoliths and gonads have been collected through the Bio-Sampling program for several commercially important reef species for further in-depth life history studies. Dr. Brett Taylor and colleagues from PIFSC are currently working on creating age and von Bertalanffy growth coefficients for *N. unicornis*, *S. rubroviolaceus*, *L. xanthochilus*, and *L. gibbus.* However, work on these species and others are still in progress and could change OFL estimations when more localized life history data becomes available.

Conclusion

Data limited methods are a way for fishery scientists and managers to create OFL estimations using available catch and life history data. The thirteen species selected for this analysis represented commonly caught reef species as well as a variety of common coral reef fishery families, ecosystem functions, trophic levels, and life history characteristics. The DCAC analysis produced OFL lower than the current 75th percentile for both individual species and family groupings.

The current fishing pressure based on average lengths indicate that overfishing may be occurring for a majority of the species. However, this method relies on local life history information. For many of these species, life history information was taken from other regions, other species, or estimated using the life history tool on fishbase.org. The input for the life history information would change the Z estimate, so the results of fishing pressure may be inflated.

Another point is that for lightly fished stocks, such as *M. berndti*, the time series of catch does not contain sufficient information about the productivity of the stock (Martell and Froese 2013). Therefore, given the light level of reported catch and nearly unexploited status, data limited methods will not produce accurate OFL estimates.

Finally, DB-SRA produced the highest OFL yield when comparing three common DL methods. The DB-SRA OFL was also close to the 75th percentile. The DLM toolkit provides a comprehensive group of common DL methods that can be utilized for stocks with varying levels of data quality. The MSE is used to compare methods with an identical stock and fishing pressure to determine which DL method would work the best for specific stocks. The data requirements for DL methods are relatively simple.

The more accurate catch, and life history parameters are, the better the OFL estimates will become. Common coral reef fishery species without life history information should be prioritized for otolith and gonad studies so that future analyses will have better information.

Work Cited

Ault, J. S., S. G. Smith, and J. a. Bohnsack. 2005. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. ICES Journal of Marine Science 62(3):417–423.

Carroll, B., D. Fenner, N. TuiSamoa, T. Aitaoto, and D. Ochavillo. 2012. Chapter 1: American Samoa Fishery Ecosystem Report. *in* M. Sabater, editor. WPRFMC 2012. Archipelagic Fishery Scosystem Annual Report. Western Pacific Regional Fishery Management Council, Honolulu, HI 96813.

Carruthers, T. 2014. DLMtool: Data-Limited Methods Toolkit (v1.34).

Carruthers, T. R., A. E. Punt, C. J. Walters, A. MacCall, M. K. McAllister, E. J. Dick, and J. Cope. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153:48–68.

Craig, P., J. H. Choat, and L. M. Axe. 1997. Population biology and harvest of the coral reef surgeonfish Acanthurus lineatus in American Samoa. Fishery Bulletin 95(4):680–693.

Craig, P., B. Ponwith, F. Aitaoto, and D. Hamm. 1993. ￼￼￼￼￼￼The Commercial, Subsistence, and Recreational Fisheries of American Samoa. Marine Fisheries Review 55(2):1–8.

DeMartini, E., R. Langston, and J. Eble. 2014. Spawning seasonality and body sizes at sexual maturity in the bluespine unicornfish, Naso unicornis (Acanthuridae). Ichthyological Research 61:243–251.

Dick, E. J., and A. D. MacCall. 2011. Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. Fisheries Research 110(2):331–341.

Ehrhardt, N. M., and J. S. Ault. 1992. Analysis of Two Length-Based Mortality Models Applied to Bounded Catch Length Frequencies. Transactions of the American Fisheries Society 121(1):115–122.

Froese, R., M. Lourdes, D. Palomares, and D. Pauly. 2005. FishBase Life History Tool.

Gedamke, T., and J. M. Hoenig. 2006. Estimating Mortality from Mean Length Data in Nonequilibrium Situations, with Application to the Assessment of Goosefish. Transactions of the American Fisheries Society 135(2):476–487.

Hewitt, D. a., and J. M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103(2):433–437.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality-rates. Fishery Bulletin 82:898–903.

MacCall, A. D. 2009. Depletion-corrected average catch: A simple formula for estimating sustainable yields in data-poor situations. ICES Journal of Marine Science 66(10):2267–2271.

Martell, S., and R. Froese. 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries 14(4):504–514.

Nadon, M. O., J. S. Ault, I. D. Williams, S. G. Smith, and G. T. DiNardo. 2015. Length-Based Assessment of Coral Reef Fish Populations in the Main and Northwestern Hawaiian Islands. Plos One 10(8):e0133960.

Newman, D., T. Carruthers, A. MacCall, C. Porch, and L. Suatoni. 2014. Improving the Science and Management of Data-Limited Fisheries : An Evaluation of Current Methods and Recommended Approaches.

NOAA Fisheries Toolbox. 2012. Depletion Corrected Average Catch (DCAC).

Ochavillo, D., S. Tofaeono, A. Tua, E. Schuster, T. Letalie, and A. Soonaolo. 2012. Commercial fisheries biosampling programme in American Samoa. SPC Fisheries Newsletter #139:23–24.

Oram, R., N. Tuisamoa, J. Tomanogi, M. Sabater, D. Hamm, C. Graham, and M. Quach. 2013a. American Samoa Shore-based Creel Survey. Honolulu, HI 96822.

Oram, R., N. Tuisamoa, J. Tomanogi, M. Sabater, D. Hamm, C. Graham, and M. Quach. 2013b. American Samoa Boat-based Creel Survey. Honolulu, HI 96822.

Pardee, C. 2015. American Samoa PSA for Inshore Fishery Species. Honolulu, HI 96744.

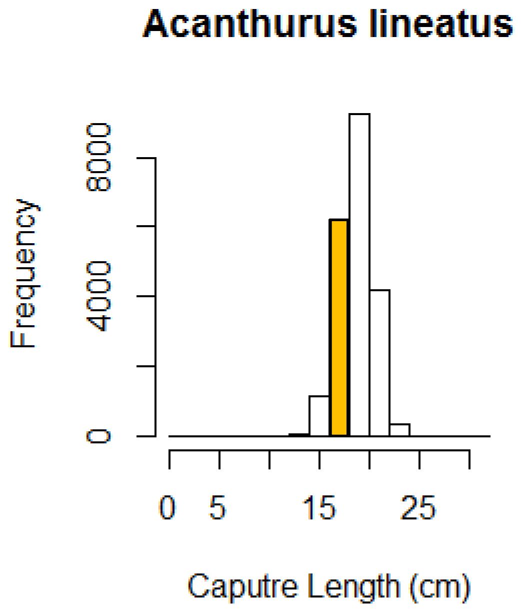
Severance, C., R. Franco, M. Hamnett, C. Anderson, and F. Aitaoto. 2013. Effort Triggers, Fish Flow, and Customary Exchange in American Samoa and the Northern Marianas: Critical Human Dimensions of Western Pacific Fisheries 1. Pacific Science 67(3):383–393.

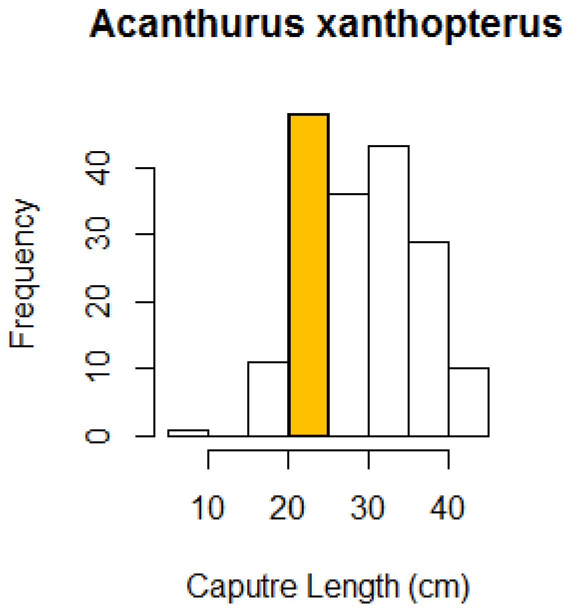
Taylor, B., and J. Choat. 2014. Comparative demography of commercially important parrotfish species from Micronesia. Journal of fish biology 84(2):383–402.

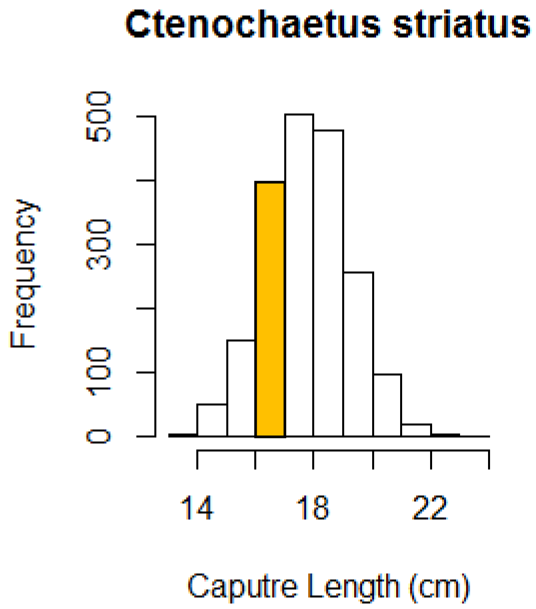
Walters, C. J., and S. J. D. Martell. 2004. Fisheries Ecology and Management. Princeton University Press.

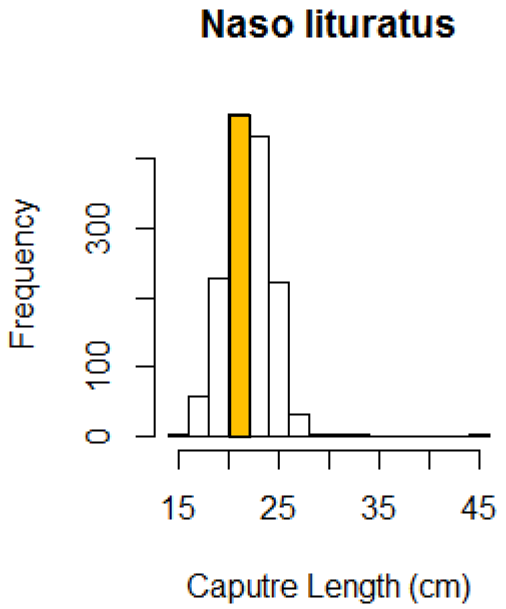
Appendix 1: Length frequency distributions for American Samoa species

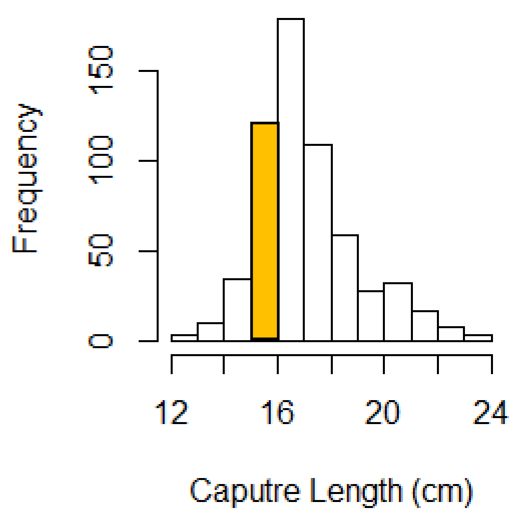
Figures 1-13: Length frequency histograms of capture length (cm) for selected American Samoa coral reef fishery species. Yellow bar represents size at full selectivity. Data obtained from the Bio-Sampling program from 2014.



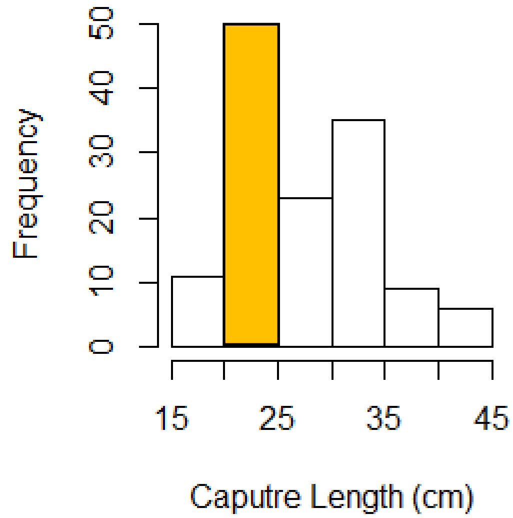




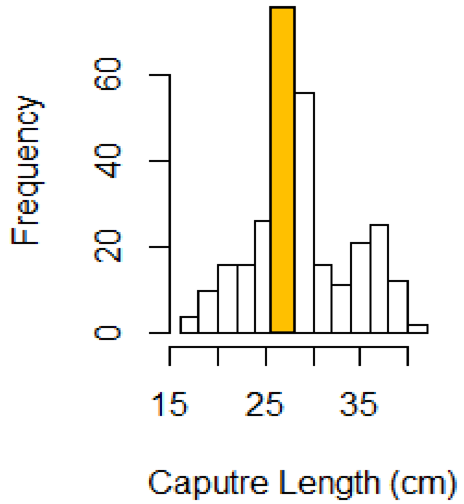




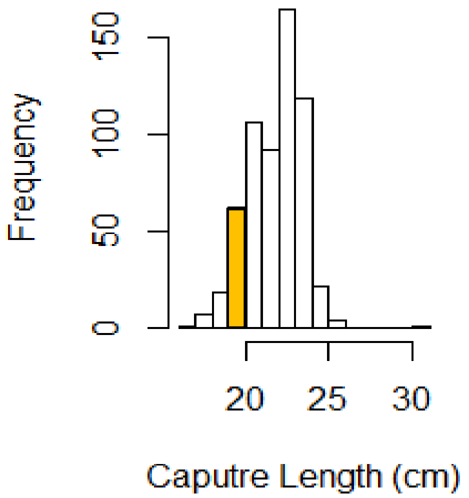
Myripristis berndti



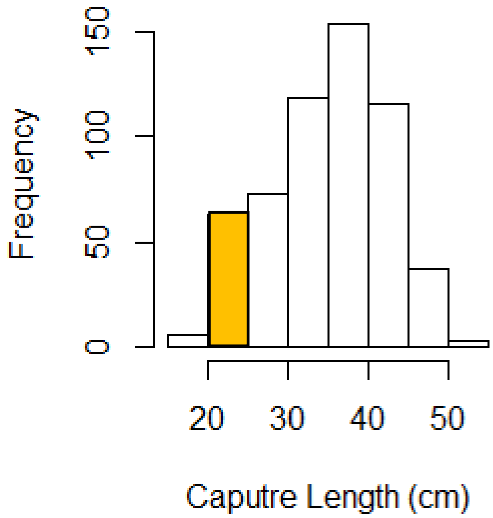
Monotaxis grandoculis



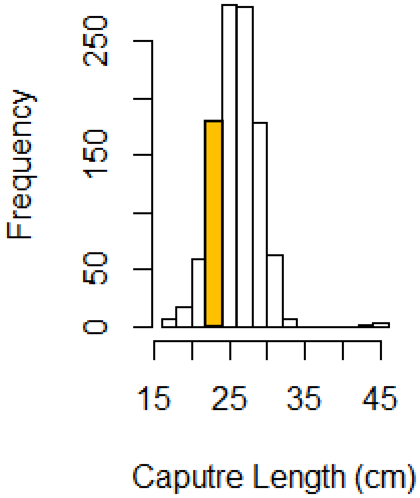
Lutjanus gibbus



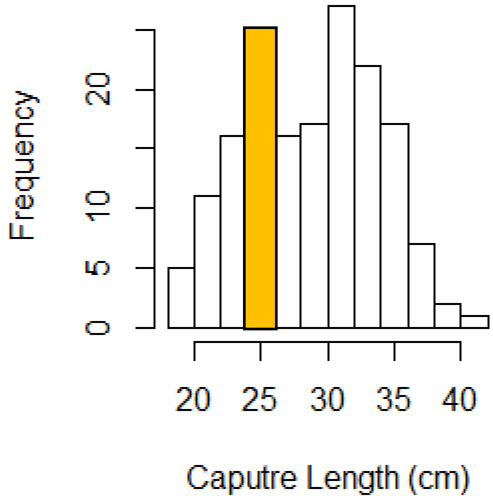
Lutjanus kasmira



Scarus rubroviolaceus



Chlorurus japanensis



Cephalopholis argus