Literature to check

Ralston 1979

Ralston 1980 a

Ralston 1980 b SEE TESTER ABSTRACT

Ralston 1981 a

Ralston 1981 b

Kami 1973 – revised P filamentosus

**Introduction**

Geological features of Hawaiian islands. Basaltic. NWHI shoals pininacles and atolls. These harbor stocks of commercially valuable bottomfish.

Extension of magnuson steven’s act in 1976 + movement of larger vessels into fishery lead to development of Fishery management plan for stocks in NWHI.

The Main Hawaiian Island bottomfish complex includes at least 65 slow growing, late to mature species of fish from four families, Caragidae (jacks), Lethrinidae (emperor fish), Lutjanidae (snapper), and Serranidae (grouper) (Haight et al. 1993). Caught primarily by hook-and-line gear, 19 of these 65 species are harvested in enough abundance to be classified as a management unit species. ((Review of Scientific information for the EFH and HAPC designations for the Federal Fishery Management Unit Species in the Pacific Islands Region). Seven of these species are represent high economic value and are primarily concentrated on by the fishing industry and are referred to as the “Deep Seven”. These seven include six species of snapper *Etelis coruscans* (onaga, long tail red snapper), *Etelis carbunculus* (ehu, red snapper), *Pristipomoides filamentosus* (opakapaka, pink snapper), *Pristipomoides sieboldii* (kalekale, Von Siebold’s snapper), *Aphareus rutilans* (lehi, silverjaw snapper) *Pristipomoides zonatus* (gindai, Brigham’s snapper), and one grouper, *Epinephelus querns* (hapuupuu, hawaiian grouper).

Townsend Cromwell investigated the bottomfish resources of the North West Hawaiian Islands

**1973**

Kami – The Pristipomoides of guam with notes on their biology

**Pre 1976**

NWHI snapper, grouper, and jack fishery has existed since mid-1940s (A.B. Amerson 1971) and possibly as early as the 1930s (Hau 1984, Uchiyama & Tagami 1984). Declining catch rates around MHI (Ralston & Polovina 1982), drove larger vessels to begin targeting fish stocks in NWHI.

**1976**

Magnuson Steven’s fishery act passes.Establishes 8 national fisheries management councils. Extends fishery conservation zone from 3 to 200-mi offshore. Western Pacific Regional Fishery Management Council established with jurisdiction on the Fishery Conservation Zones around Hawaii, Guam, Norther Marianas, and American Samoa (Uchiyama and Tagami 1984).

In November 1976, a spiny lobser fishery developed in the NWHI. Vessels also landed bottomfish (Uchiyama and Tagami 1984).

**1977**

Westpac begins developing management plan for NWHI. Needs to aquire biological information for resource management, see Ralston 1979. (Ralston 1984).

**1977**

March of 1977, Magnuson Steven’s fishery conservation act takes effect (Uchiyama and Tagami 1984).

Southwest Fisheries Center Honolulu Laboratory of NMFS and US Fish and Wildlife Service (FWS) enter joint tripartite research agreement and Hawaii Division of Aquatic Resources (DAR) to study biotic resources of MHI (Ralston 1984; Uchiyama and Tagami 1984). F&W surveys terrestrial resources. DAR inshore fisheries, NMFS offshore fishery. Later NMFS also takes on Hawaiian monk seal and green turtle. (Uchiyama and Tagami 1984)

NMFS takes on study of Bottomfish to determine distribution, and relative abundance in NWHI. Growth , reproduction, feeding habits, and occurrence of ciguatoxin summarized in uchiyama 1984 (Uchiyama and Tagami 1984).

**1978**

UH sea grant joins this research program with the intent of informing management of the handline fishery under project “Development of a biological basis for managing the handline fishery for snapper and grouper population in the Hawaiian archipelago” (Ralston 1984; Uchiyama and Tagami 1984).

F&W surveys terrestrial resources. DAR inshore fisheries, NMFS offshore fishery. Later NMFS also takes on Hawaiian monk seal and green turtle.

**1979**

**Ralston**

In 1979, the jig boat albacore fishery expanded into the centeral North Pacific. At the close of albacore season, some of these boats converted to bottomfishing in the NWHI (Uchiyama and Tagami 1984).

**1980**

**~~Kikkawa~~**

**~~Polovina and Moffit~~**

**~~Ito & Uchida~~**

**Moffit**

**Kikkawa**

Bert Kikkawa of NMFS investigated reproductive potential and spawning season in *P. filamentosus* caught abord the RV Towsend Cromwell in the North Western Hawaiian Islands between 1978 and 1979. Using core samples from the anterior, middle and posterior ovary tissue, 400 randomly selected ova from 21 ovaries were classified by maturation state as primordial, early developing, developing, advanced developing, early ripe, ripe, and residual. Ovary development was determined to be heterogeneous with similar to that of bigeye tuna, *Thunnus obesus* (Yuen 1955), Albacore *T. alalunga* (Otsu and Uchida 1959) and swordfish, Xiphias gladius (Uchiyama and Shomura 1974). No significant correlation was found between gonadal somatic index and fish size. Correllation between GSI and stage of maturity was positive but inconclusive due to a small sample size. A peak in gonadal somatic index occurring in August suggesting an annual September spawn, and lowest levels of GSI occurring in March. More sampling of ripe ovaries during the months of November and July across all size classes was recommended (Kikkawa 1980).

Fig Kikkawa 1980

**Polovina and Moffit**

The history of the bottomfish handline fishery in the Northwestern Hawaiian Islands was officially described by Jeffry Polovina and Robert Moffitt of NMFS in 1980. Covering the period from 1959-1977, their report analyzed catch and effort data from fishermen catch reports, collected by the Hawaii Division of Fish and Game. These reports provided limited information, providing weight, number and value of each species caught, in addition to fisherman name, boat number, license number, area fished, and gear used. Meta analysis of the reports filed indicated fisherman more often reported catches on a per trip basis, thus reports were representative of per trip, rather than per day data. At the time, data were sored on computer tape.

Bottom handline gear was the principle method by which bottomfish in this fishery were captured, with an insignificant proportion of bottomfish caught by fish trap during this time. In almost 20 years, 50 metric tons of bottomfish were caught in the NWHI with a single vessel responsible for 95.5% of the catch. At this time, 10 species of Bottomfish had been identified from the NWHI as commercially important with the bulk of the catch made up of ulua, with some taxonomical uncertainty *Caranx spp.* and *Caragoides spp.,* *Epinephelus quernus* (Hapu’upu’u), *Seriola dumerili* (Kahala), and *P. Filamentosus (*opakapaka).

The number of boat trips during this period reached a maximum (20 trips), during 1973 and 1977, and a minimum in 1969. Trends in effort reported indicated average of 14 trips per year occurred between 1959-1964, with a decline to 4 trips in 1969 and a subsequent increase to 17 trips per year from 1971-77. It is believed economic factors largely drove this trend with the increasing price of fuel and other fishing associated costs reducing the financial feasibility of fishing the relatively remote area. Increases wholesale prices after 1969 lead to an increase in profitability of such endeavors.

Total weight caught paralleled the effort trend, with a general decline in weight. Species composition by weight also changed. Early on catch was dominated by ulua, however after 1965 saw an increase in hapu’upu’u as the most abundant species by mass (Polovina and Moffitt 1980).

**Ito & Uchida**

Ciguatera is a disease with neurotoxic and gastroenteritic symptoms brought on by eating fish who have bioaccumulated the toxin produced by the dinoflagelate *Gambierdiscus toxicus*. Screening of tissue for ciguatera in offshore fishery species in the Northwestern Hawaiian Islands occurred between April 1979 and December 1979 aboard the RV Townsend Cromwell. Researchers found a high incidence of ciguatera positive Kahala. The rejection rate spiked in April when 63% of Kahala sampled tested positive for the toxin and then hovered around low of 3% between July and October bofore rising to 10% in December. There was a low but positive significant correlation (R = 0.101) between toxicity level and size of kahala. *P. filamentosus,* particularly those caught at Necker Island and French Frigate Shoals,had a rejection rate of 15%, though to that time, it had not been implicated in ciguatera poisoning in Hawaii (Kubota 1972). Between 30 and 33% (someone is bad at math…) of all *E. carbunculus* tested positive for hazardous levels of ciguatoxin.The authors attribute this to the possibility of “false positives” arising from the radioimmunoassay method used to test fish for the presence of ciguatera, as well as indicating that many, if not all individuals may have some undetectable level of the ciguatera-like compounds(M and Uchida 1980) .

**Moffit**

**1981**

**~~Ralston~~**

**Ralston**

Tester symposium talk about applying Graham-Schaefer surplus production model to three depth groups, classified by fishing bank. Basing his comparison of the different banks, he estimates sustainable yield of 300kg per nautical mile of 100-fathom isobaths “appears possible” (Ralston 1981a).

**1982**

**~~Ralston and Polovina~~**

**Polovina and Moffit**

**~~Ralston~~**

**Ralston & Polovina**

*Here is a good place to explain CPUE?*

Thirteen species of bottomfish were identified as commonly harvested from water depths ranging between 60-350m. 85% of all bottomfish catch occurred in the Main Hawaiian Islands (MHI) with of all catch was coming from the Maui-Lanai-Kahoolawe-Molokai bank. Making up 86% of the catch in 1978, dominant species by weight in the MHI fishery were Opakapaka, ulua, uku, onaga, hapu’upu’u, and kahala and fetched an average price close to $5.00/kg ex-vessel (Ralston 1979). HDFG catch reports were used to perform a cluster analysis of catch identifying three species groups by depth distribution (Fig Ralston, Polovina 1982 1).

Fisherman-days were determined to be more suitable than catch-records for use in a stock production analysis based on factors including a negative correlation with catch per unit effort (CPUE). Grouping species by depth distribution provided significant improvements over a species by species application of the stock-production model proposed by Schaefer (1957). Application of a Total Biomass Schaefer model grouping all 13 bottom fish species together produced similar results. Due to uncertainty regarding recreation bottomfish catch, lower bounds for maximum sustainable yield for all commercial species of bottomfish per nautical mile of 100-fath contour isobaths, was estimated using the Total Biomass Schaefer Model. MSY was determined to range between 105 kg/nmi around Oahu to 272 kg/nmi for the Maui, Molokai, and Lanai bank complex (MLKM) (Ralston and Polovina 1982). Limitations in the reporting of locations fished disallowed estimation of sustainable yield through production analysis for the banks or regions of the NWHI (Polovina and Moffitt 1982).

**Ralston**

An investigation of catch and size selectivity of hook size was performed in the NWHI by Stephen Ralston of the University of Washington. Selecting a range of hook sizes utilized by the fishery (Nos. 28, 30, 34, and 38), no substantial effect was found on overall catch with all variation in size and catch associated with variance in days and location. A one way ANOVA on catch of *P. filamentosus* (opakapaka), and to a lesser extent, *Pseudocaranx dentex* (Pig Ulua) were caught in higher abundance with the smaller hooks, though this was only significant for opakapaka (p<<0.005). Relative insensitivity to hook size was believed to have been the result of insuffient sampling, and a narrow selection of hook size. Hook size selection was composed of sizes typical of the fishery however, and thus concluded that little size bias is attributable to the gear selection of the fishery (Ralston 1982).

**1983**

**~~Ralston & Miyamoto~~**

**~~Barans & Holiday~~**

**Ralston and Miyamoto**

Attempted to analytically formalize the notion that otolith width could be used as a measure of otolith growth rate to provide annual age estimates. Marking with oxytetracycline produced a visible time-mark in otoliths in six wild caught juvenile opakapaka, revealing daily deposition of growth increments in immature fish (< 40 cm). The presence of gravid/spawning ovaries in samples indicated that females reach maturity around 40 cm FL corresponding to a 6,250 um length ototlith. “Males indicated similar patterns of gonad maturation (Ralston 1981)”.

Marking experiments concluded that daily incriments are formed in subadult paka up to three years old.

The age of 81 otolith samples was estimated using an equation relating otolith size to age:

(Equation Ralston Myamoto 1)

and integrated with an equation comparing fork length to fork otolith :

(Equation Ralston Mymoto 2)

to produce a model for age at length

(Equation Ralston Mymoto 3)

This model was used to determine age, that along with fork length, was fitted to the von Bertalanffy growth model using a non-linear regression procedure in Statistical Analysis System (SASS) (Ricker 1979). When fit freely to data, many

samples were predicted to exceed 70 cm fl. Data was refitted with the model constraint L(infinity) = 78 cm FL, corresponding to the largest observed specimen.

This study was constrained by the assumption that the pattern of growth after maturation could be extrapolated from growth patterns prior to sexual maturity. The authors note that any factor which may temporarily arrest the growth of the fish may underestimate the number of daily otolith increments. It was assumed that one increment forms daily in preproductive individuals, for which lab experimentation with oxytetracycline validated across the 27-35cm FL range. Further, it was assumed that otolith growth is greatest as growth and age approach zero, however this was determined to be unreasonable, however taking this into consideration, the largest absolute difference was found to be 18d, and most pronounced for fish < 1 month of age. Because the results presented were intended to describe annual growth, the authors felt these assumptions were reasonable. Discrepancies between this and the previous growth models of Moffit (Moffitt 1980) were explained by Moffat’s use of complete growth increment count underestimating age based on growth interruptions in adults. (Ralston and Miyamoto 1983).

**Barans & Holiday**

Work by Barans and Holiday used side scanning sonar to estimate Snapper/Grouper stocks off Charleston SC, an endeavor that continues to be applied to Hawaii’s bottomfish stock assessment with limited success.

**1984**

**~~Uchiyama & Tagami~~**

**~~Ralston~~**

**~~Kikkawa~~**

**~~Everson~~**

**~~Shaklee~~**

**Uchiyama & Tagami**

Investigation into life history and distribution of bottomfish in the northwestern Hawaiian Islands. Pristipomoides filamentosus dominated at Necker Bank (44.4% of catch), French Frigate Shoals ( 52.5% of catch), and Brooks Banks (40.0% of catch) not present at Midway bank despite having been known to occur there and not farther west of Nero seamount. Paka caught in lobster pots at bank no. 8, but not on handlines. Ehu (*E carbunculus*)dominates northwest of Lisianski bank (45.6 – 96.5% of total catch). Catch rates and size increases in northwestern end of archipelago. No gindai caught west of Ladd seamount. Composition similar to Moffitt 1980.

Traps, trawls and handlines used to sample vertical distrubtion at various depths across banks.

Refit vonB curve using Annuli (annual marks laid down in the early summer of each year). Ralston & Miyamoto’s integrated approach suggests growth rate 33%-50% that of Uchiyama et al (in prep). Estimations with electron scanning microscopes by Radtke (unpublished manuscript) looked at dialy increments. Estimated age-length similar to Uchiyama (in press), for fish 20-56cm. Estimated ages higher for fish > 60cm compared to Uchiyama, but lower than those by Ralston and Miyamoto (in press). Also fit Von B parameters to Gindai using annual marks. All other Von B fits used daily increments only.

Length weight relationships for NWHI. All except Onaga separated into sex, cruise, and location of capture. Compared by ANCOVA. No signific differences between sexes for ehu, paka, kalekale, gindai, pig ulua, and kahala. Not tested for hapuupuu. Siginificant difference between cruises for Opaka and hapuupuu. Since these are most important species in the handline fishery, could be fisheries based selection over time.

Reproduction. See Kikkawa and Everson.

MSY estimated for MHI assuming abundance and population dynamics similar to the MHI.

Early diet work. Opaka diet consists of fish, crustaceans, molluscs and chordates (Uchiyama and Tagami 1984). Uniquely high in Pyrosoma sp. Pelagic tunicates, and other chordates (Uchiyama and Tagami 1984). Hapuupuu ate large number of small crustaticans.

**Ralston – Biological constraints on production and related management issues in the Hawaiian deepsea handline fishery**

Surplus-production analysis of bottomfish.

Stock production models simulate the optimum balance between the harvest and removal of biomass from a fishery, and the fishery’s ability to sustainably replace that biomass. Application of the Graham-Schaefer model to 20 years of DAR catch records (Ralston and Polovina 1982) investigated the MSY for the fishery, however it made assumptions of homogenous stock distribution throughout the archipelago. Shaklee failed to detect genetic differences in paka between the NWHI and the MHI, suggesting the potential of intermixing stocks between these regions. Other criticisms include pooling catch statistics for multiple species into the total biomass model, treating all species as a single stock, different island areas as separate stocks, and the lack of complete catch records for the NWHI, as well as MHI recreational catch. The only statistically valid results were obtained from the MLKM stock.

Peak harvest occurred in 63-64 in moderate excess (18%) of MSY, before falling 38% below MSY in 1970. In 1980, harvest 10% below MSY (estimated). Believed this trend is related to trends in fishing effort. Following the sustained increase in fishing effort in 1973-74, yields from the MLKM bank were consistently less than the estimate for MSY (Ralston and Polovina 1982), an indication that optimum catch had been exceeded.

Two policy decisions mentioned, first using KLKM stock to derivive MSY under the assumption that the ratio of exploitation for bottomfish species remains constant and therefore the Schaefer model provides insight. Second, if the ratio of fish can be manipulated, for instance, by varying fishing effort across different depth distributions, a larger sustainable yield may be possible. However, linkages between species is not well understood and removal of one species group may allow another species to thrive in the newly vacant niche. As price/pound differs per species, this may be a desirable or undesirable consequence, but impossible to predict with current knowledge.

Yield-per-recruit models considers the size of an individual’s biomass as a function of fishing pressure. The classic Beverton and Holt (1957) model takes into account mortality, both natural, and from fishing, as well as growth rate to calculate Yield-per-recruit, estimating spawner-recruitment relationships at different mortality levels. The total biomass of the harvested crop is determined by the number and weight of the fish caught. With greater higher levels of fishing pressure, more fish are caught at relatively younger ages, leading to a large crop of small fish and removing potential size gains they might incur later in life. With reduced fishing pressure, fewer fish are removed from the system. By allowing the remaining fish to grow to greater size before capture leads to a small crop of large fish. Yield-per-recruit analysis is used to find the optimum year class to fish a stock to maximize biomass removal from the fishery, while minimizing effort. The Beverton-Holt model is a classic YPR model. Growth overfishing is the term given to over fishing of stocks leading to a suboptimal catch size (Beverton and Holt 1957).

Growth estimates for YPR analysis came from Ralston and Myamoto (1983). Total mortality is a function of natural mortality and fishing mortality. Estimates for total mortality were based on a natural mortality of 0.25 per year based on catch records for Maro reef where fishing mortality was assumed to be negligible, and predictions by Pauly 1980. Estimates for fishing mortality could then be calculated for each reporting area by subtracting natural mortality from total mortality.

Fishing decreased with distance from Honolulu. Penguin Bank was fortuitously close to ideal YPR with a time of capture of 4 years and Fishing mortality at 0.48 per year (Total mortality 0.73). Because optimal MSY is often less than YPR (Deriso 1982), thus it is still possible that stocks may be fished at unsustainable levels while maximizing individual production. Furthermore, only when the spawner-recruitment curve is dome-shaped, that is recruitment compensation is high and unexploited stocks have severely less recruitment, does the optimum level of fishing pressure exceed 1.5x natural mortality (Deriso 1982).

This study found esxcessive fishing relative to MSY but near optimal levels of YPF in the MLMK complex. The danger of recruitment-overfishing is likely in this situation, however historically stocks have remained stable. This is not likely to last, and management of MHI bottomfish resources are worth considering. NWHI resources represent untapped potential where fishing mortality is sub-optimal or non-existant. Calculations of sustainable yield from NWHI could represent $2 million annually to fishermen, substantially more than that from the MHI.

**Everson**

Examined ovaries of *E. carbunculus (Ehu)* and found gonadal maturation phase beginning in May with spawning likely to occur from July-September. Females favor males 2:1 (553:273) and have greater size ranges. This changes during spawning months when males increase to 41% of population and then decrease to 18% during peak spawning in August suggesting behavioral changes such as feeding response and female spawning aggregations. Fecundity of ehu 38.3 to 50.8 cm estimated from 5 ovaries that appeared ripe and frozen at collection. Ova were mixed into solution and stirred, then estimated using the formula (Formula Everson 1984). Fecundity estimated to be between 349,500 and 1,325,600 ova. Ehu was most common fish caught, and 3rd most common by weight in NWHI during Townsend Cromwell sampling from 1977 to 1981. Size at maturity determined from 300 ovaries samples preserved or frozen. Maturity determined by those fish with developing ova and with the potential to spawn during the current season. In July 95% of ehu caught were mature and measured between 29.67 and 63.5 cm FL. The smallest mature fish was 29.8 cm. 50% matureity was reached in the 25 to 30 cm size classes. No regional differences found. Ehu ovaries develop asynchronously (Wallace and Selman 1981) but during maturation, develop synchronously with batches of ova ripened and spawned. Possible that the absence of ripe or hydrated ova later in the year is because of barotrauma.

**Shaklee**

Starch gel electrophoresis looked at 44 enzyme coding loci in Paka for genetic variation. 5 polymorphic loci detected with 2 common alleles each. Distribution of polymorphic loci agreed with Hardy-Weinberg equilibrium expectations. Siginificant differences found between fish ages 2-5 years and 5-14 years for alcohol dehydrogenase and lactate dehydrogenase-C. No differences found between Mario Reef, FFS, Necker, Molokai, and Hawaii or more broadly between NWHI and MHI. Average values of Wright’s F\_st for the loci were 0.005, indicating little differentiation among subpopulations.

**Kikkawa**

Looks at maturation, spawning a fecundity of Paka in NWHI. Follow up to 1980. Hooked paka on no. 28 size hooks. Plotted relationships of fecundity to fish length and body weight using least squares.

log(#ova) = a + b\*fish length(cm)

ova in Paka develop heterogeneously. Fecundity estimated from 478,000 for 48.7 cm fish to 1,462,000 for 76.3 cm paka. See Kikkawa Eq 1 1984. Fish size positively correlated with GSI (r = 0.447) and fish size and maturity also correlated postiviely (r = 0.873). Plotting GSI against month of caputure indicated spawning commences in June, and peaks in August concludes in December. Size at maturity determined by % change in gonad weight at each 5-cm size class bin. Largest change assumed to be time when fish matures. This occurred in the 40-50cm class, and likely occurs around 42.5cm. Sex ratio of females to males was deviated singficantly from 1:1 on 4 occasions. Males more prominent in January, females more in feb. During August, females 2.43 times more prodomenent. By size, females dominate the 30-39cm class (1.92:1) and the largest class 70-79cm (1.96:1).

**1985**

**Polovina et al** – Fisheries Resource Assessment of the Mariana Archipelago, 1982-85

In 1980 NMFS began a 5 year program to quantify the distribution of sustainable fisheries resources in the Mariana Archepelago and assess their economic potential. Data from research cruises as well as commercial landings by the Governments of Guam and the Commonweath of the Northern Marianas were used to assess potential economics and importance for subsistence fishing. Deepwater snapper and grouper were the second most important group after Tuna identified.

Six cruises by the Townsend Cromwell between 1982 and 1984 systematically sampled seasonal and geographic variation in dewater bottomfish abundance across 22 islands and banks in the 125-275m depth range. Intensive fishing was used to calculate catchability/CPUE (catch per unit line hour) for bottomfish. Gindai (*P. zonatus*) accounted for just over half of the catch (51.2%).

By Bank type, seamounts were most productive (CPUE = 4.68) followed by the northern and southern islands (3.19 and 2.46 respectively). The difference between islands is likely due to exploitation by fishermen in the more inhabited northern islands. Accounting for fishing mortality, no difference between the stocks in the northern and southern islands was expected. The depth distribution of *P. filamentosus* was slightly lower than reported for the MHI, falling between 164 and 183m and overall distributions were similar through out the archipelago. Lehi were also common at these depths. Gindai were most abundant between 183-201m. Kalekale, hapuupuu, ehu and onaga were most frequently captured below 201m.

CPUE was combined with the amount of preferred habitat in the area and an estimated relative abundance to arrive at the total exploitable bottomfish biomass fo rhe region. Application of the Beverton Holt yield equation with growth and mortality estimates from earlier otolith data was used to determine age of entry for each species to the fisher as well as the size which would maximize the yield per recruit. Equilibrium yield equations for the 125-275m depth range produced an annual equilibrium yield for the total archipelago of 222.4 kg/n.mi (CI 165.3-279.6). In comparison, for waters in Hawaii, the lower bound estimate from stock production models applied only to commercial data is 272 kg/n.mi of 200 m bathymetric contour(Ralston and Polovina 1982). For the Marianas, this produced an F0.1 value of 109 annual tons (CI 81 – 137)(Polovina et al. 1987) with 70% of the yield from the southern islands and banks, 27% from the north, and 3% from seamounts. This level of fishing pressure would reduce virgin spawning stock biomass to 20-42% of their unexploited level.

Between 1980 and 1984, bottomfish landings increased from 6 tons to 20 tons with an estimated 65-95% of the catch coming from the waters around Guam. Based on an estimated 17.2 tons for the equilibrium yield around Guam, these waters were thought to be fished to MSY or beyond.

**Ralston & Kawamoto –** A preliminary analysis of the 1984 size structure of Hawaii’s commercial opakapaka landings and a consideration of age at entry and yield per recruit

-Decline in size of entry for opakapaka to fishery. Evidence for growth overfishing.

Demand for bottomfish expanded in the 1970s and 80s with promotion and an increase in Hawaiian tourism and leading to a sustainable and stable market for the fishery. Landings of *P. filamentosus*, the fishery’s most abundantly caught species, increased from 24 to 106 Metric tons during this period.

Despite earlier evidence that the level of exploitation at penguin banks, the most important fishing ground for bottomfish in the MHI, was “optimal”, recent anecdotal evidence from fishermen and a sampling program initiatied in 1984 by the Western Pacific Fisheries Management Council suggested that the fishery for opakapaka was in rapid decline. This data, including average weight, number of fish, fishing location, and price per pound were collected daily at the Honolulu fish auction at the United Fishing Agency for Opakapaka.

Size variation within lots was small relative to overall variation so average fish weight was determined by dividing each lots total weight by the number of fish within that lot. This data was used to summarize weight frequency distributions of *P. filamentosus* within the MHI and NWHI. Weight at entry to the fishery was determined to be 0.63kg in the MHI and 1.36 kg in the NWHI and correspond to sizes of 36 and 41 cm FL and ages of 1.8 and 3.4 years. Earlier estimates indicated that time of entry to the fishery for opkapaka to be 4 years (Ralston 1981b). For fish in the MHI, this could be the result of substantially smaller opakapaka harvested since 1980 or changing distribution channels for small paka away from the fish auction with the first interpretation favored by the author. Because *P. filamentosus* matures at 40cm FL, entry into the fishing in the MHI occurs before sexual maturation. Pre-mature opakapka were represented in 36% of the catch in the MHI and 5% from the NWHI. Median opakapaka landed was 1.9 kg in the MHI and 2.8 kg in the NWHI.

Assuming no change in fishing pressure from 1980 to 1984, yield per recruit dropped from 0.36 to 0.3 kg/per recruit. Across a range of fishing mortality rates, YPR increased with increasing age of entry. Hawaii prohibits paka less than 0.45kg to be sold, which corrospondds to an age of 1.4 years, however the fishery is thought to begin harvesting when paka approach 2 years of age (0.68 kg). Increasing MHI size minimums to levels comparable to the NWHI (3.5 years, 1.36 kg) results in a YPR increase of 25%, however, changing minimum size of capture would result in temporary economic losses for the fishery while adjusting to the new equilibrium.

Age growth curves (Ralston and Miyamoto 1983) were combined with fecundity estimates (Kikkawa 1984) and spawning frequency (Ralston 1981b) to estimate reproductive output as a function of the increasing size limits of opakapka. With a fixed fishing morality rate of 0.5 /year, and natural mortality corresponding to 0.25/year, a cohort of 1000 paka were expected to produce 300 million more eggs compared to 185 million under the current law. With a 25% increase in yield per recruit, this is thought to profoundling increase the yield from the MHI opakapaka fishery.

Ralston??

**1986**

**Ralston, Gooding, and Ludwig** Bottomfish resource assessment (Submersible versus handline fishing) at Johnston Atoll

CPUE is dependent on the assumption that catch rate is proportional to stock abundance and generally linear. This study compared distribution and abundance of bottomfish at Johnston Atoll sighted by submersible and the amount of fish caught by handlining off a research vessel (RV TC!) to test this CPUE assumption.

Surveryed Deep slope (100-365m) of Johnson Atoll in submersible to survey abundance of commercially important bottomfish species by visual census. Compared results to hook-and-line fishing Noted 69 species from submersible but only 10 from fishing. BF abundance estimates varied by site but were not in disagreement with one another. Estimated catchability 0.0215 hectare/line-hour with daily variability. P. filamentosus located in upcurrent sites. Along with E coruscans aggregated near underwater promontories and headlands, but at different depths. *E coruscans*  were found generally deeper. (Ralston 1986).

**1987**

Parrish – **The trophic biology of snappers and groupers**

Groupers and snappers are high level trophic predators. Because of their heavy top down pressure, removal of snapper or grouper species is thought to enhance populations of prey species including other snappers and grouper. Groupers are relatively more sedentary and thus it is believed habitat dependence is stronger than in snapper. Snapper tend to feed by widespread foraging where grouper have higher incidences of ambush predating. Grouper actively feed throughout the day where snapper feed primarily at night. Snapper and grouper are major predators of benthic fish and invertebrates and draw on a diverse range of diet resources, thus changes in population to any one prey species is not thought to have a dramatic impact on predator populations. These overlap of prey species likely cause some inter-sepecific competition, but the diversity of species, high levels of competition for prey items is not likely. For this reason, habitat competition may be more important than diet. Broad diets also make these predators resilient to changes in the trophic environment. Dominate prey items are other fish and decapod crustaceans. Little basis for estimating feeding depths other than the range of depths from which the species has been reported or fished. Little is known about the substrait on which feeding occurs other than a preference for steep slopes and high relief. Because fish bite at both the bottom and several meters above, it is unknown if the environment provides better feeding opportunities or is appealing for other reasons.

Leis – **Review of the early life history of tropical groupers (Serranidae) and snappers (Lutjanidae)**

Snapper and grouper larvae are distributed evenly in the vertical water column at night but during day are distributed deeper. Lutjanids eggs are spherical with a diameter of 0.65 to 1.02mm and released into pelagic waters where they settle after 25 to 47 days. They possess a smoth chorion, unsegmented yolk, and single oil droplet of 0.12 – 0.20mm diameter. Incubation time is dependent on species and temperature ranging between 17 and 36 hours. Visual identification of lutjanid eggs not possible. Spines of the dorsal fin and pelvic fin are the earliest fin elements to form for larval lujanids. Larvae may be confused with gemphylid and epinepheline serranids, but are otherwise distinct from other families. Lutjanid larvale are relatively rare compared to other larvae making quantitative studies challenging. In Hawaii lutjanid larvae, sampled by midwater trawl, were captured close to the leeward shore of Oahu between May and December peaking between July and September.

**Polovina et al. – Assessment and management of deepwater bottom fishes in Hawaii and the Marianas**

When size of entry to a fishery exceeds the size of sexual maturity, fishing mortality should not exceed twice the natural mortality. This is the case in the NWHI. However in the MHI, the size of entry is less than or equal to that of sexual maturity therefor fishing mortality should not exceed natural mortatlity.

Application of potential yield estimates for deepwater bottomfish in the Marianas (Polovina et al. 1985) to Hawaiian fish stocks is used to evaluate the management of the bottomfish fishery in Hawaii resulted in an estimated annual sustainable yield of 274 metric tons (Current 2015 ACL is 57% of this number). Equilibrium yield estimations assumed that growth was deterministic following the Von Bertalanffy curve, that the mortality of fish above the smallest length represented in the catch occurred at an instantaneous rate, that recruitment was constant annually, and that the resource is essentially virgin. The fishery in the Marianas was assumed to be unexploided for this work. Estimates of Mortality came from the Beverton and Holt formula for Mortality/Growth.

Yeild assessment was performed on seven individual species representing 92% of the total catch as well as a grouping of species which in total represented the remainder. This resulted in an annual equilibrium yield at F = 1.0 of 109 MT (Polovina et al. 1985) with total yield for the archipelago 222.4 kg/nmi of 2000-m contour or 0.3MT/km2. The ratio of Yeild to biomass estimates fromt eh beverton holt equation correspond to those from the Pauly Gulland approximation for 4 of the 7 species. Beverton Holt estimates were slightly less Pauly Gulland aproximations the for p.filamentosus and p. aracilla, and substantially above for *P. flavapinnis.* Based on these estimates, a fleet in the Marianas composedof 15 small vessels with two hydraulic or electric reelhs fishing 12 hours a day for 200 days a year could produce an approximately optimal fishing effort of F = 1.0.

Applied to the 13 species groups harvested in the Hawaiian deepwater handline fishery, the estimated MSY based on the total biomass Schaefer model for the MLKM bank is 106 MT or 272 kg/nmi of 200-m contour (Ralston and Polovina 1982). The lengths of this contour in the NWHI is 977 nmi and in the MHI it is 1231 nmi. Estimated MSY for the MHI is thus 266 metric tons. And 335 metric tons for the NWHI, adding to 601 metric tons for the whole archipelago. Opakapka is the largest contributor to the catch at 23%.

Hawaiian fishery has been fished at least as early as 1930s with a hiatus during WWII . After WWII, catch records indicate commercial landings were approximately 450 metric tons from the archipelago but soon declined to approximately 180 metric tons by 1959 where it stayed until 1974. During this period, most fishing efforts occurred in the MHI. Renewed interested in the NWHI began in the mid 70s and reported landings began to increase to an estimated 662 metric tons in 1984. Species composition of bottomfish landed did not fluctuate for most species during the period of record, however Onaga increased due to increased fishing pressure at the greater depths they inhabit and ulua and uku catch declined as incrased fishing pressure lead to overfishing of their shallow water habitat.

Single species models did not fit catch trends well as multispecies modling because effort was measured in vessel-days, but a vessel day produces an undirected multi-species catch. Changes to the age at fist capture rather than an increase in fishing pressure is likely more responsible for changes to overall yield of opakapaka. Because changing the minimum age of capture reduces yield in the short term, management is advised to gradually increase age of capture rather than all at once.

Assuming annual recruitment to the fishery is not constant but rather a probability distribution, analysis of the coefficient of variance indicates that exploitable biomass for the opakapaka spawning stock may be closer to 6% than 10% as previously believed. In 1984, the biomass of opakapka exploited around the MHI was estimated to be coincident with this 10% level.

**1988**

**Ralston & Williams – Depht distributions, growth and mortality of deep slope fishes from the Mariana archipelago**

Fork length for fish caught in the Marianas were compared to depth of capture. Results were largely insignificant accounting for an average of <6% of the total variation in fork length. Only 4 correlations were found significant, primarily due to larger sample sizes. Of Deep 7 species, *P. zonatus* and *A. rutilans* were the only species represented with corresponding r values of 0.22 and 0.30 respectively. Overall trends in abundance by depth for individuals species were distinct with *P. filamentosus*  encountedred primarily at depths < 200 m. *P. zonatus and p. aurcilla* had depth distributions centered at 220 m. *P. seiboldii* ‘s distribution was even greater.

Analysis of otoliths showed decreasing otolith growth rate with increasing otolith length for all species. Asymptotic size (Linfinity) was estimated for Van Bertalanffy growth curves through both length frequency and ototlith analysis. For some species, the two values varied substantially from one another. Values for asymptotic size using otoliths must have large old fish represented in the data and therefore otolith values, when not in agreement with length-frequency estimates, were considered suspect.

Among Lutjanids, an inverse relationship was observed between growth coefficient and asymptotic size (K/Linfinity). Constraining the asymptotic size parameter, Von Bertalanffy curves present an estimate of the growth parameter, K. The growth parameter can then be insterted into the morality to growth ratio (Z/K), to produce estimates for mortality. Ralston showed snappers and groupers have a relatively linear relationship between natural mortality rate (M) and the Von Bertalanffy growth coefficient (K), with M taking a value approximately twice as large as K. As stocks in the Marianas were considered largely unexploited, M is a considered a representative estimate of natural mortality. The mortality to growth ratio for Mariana bottomfish largely fell between 2 and 3, with *Caranx lugubris* on the low end at 1.17 and *P. flavipinnis* and *E. carbunculus* on the high end with ratios of 4.46 and 7.11 respectively. *P. filamentosus’*s ratio was 2.54. Maximum size of *E. carbunculus* has been observed to vary throught out Pacific ranging from as great as 110 cm in Vanuatu to 54 cm in the Marianas and 65 cm in Hawaii (Everson 1984). Thus the population biology of Ehu requires more study.

**Ralston ???**

**1989**

**Parrish – Identification of habitat of juvenile snappers in Hawaii.**

Until this study, no opaka had been caught <18cm FL and no information regarding location, size or habitat of Hawaiian lutjanids was available. A fisherman caught live Paka and *Aprion virescens* in September of 1988 in Kaneohe bay, leading to exploratory fishing in the area as well as off Lahilahi Point off windward Oahu where 37 juvenile *P. filamentosus*, 5 juvenile *Aprion virescens* and 1 juvenile *Aphareus rutilans* were collected by handline in waters ranign from 40-76 m. Based on landings, a minimum depth of 61 m for juvenile *P. filamentosus* is suspected.

Diving on capture sites revealed the bottom was relatively flat and devoid of relief other than that produced by sparse benthic biota. No juvenile fish were seen on these dives, however some juvenile *P. filamentosus* were caught immediately before and after dives at the same location. The lack of visual sighting may be attributable to avoidance behavior by juveniles. The selection of relatively shallow and sparse benthic environments with little slope by juvenile *P. filamentosus* may be further evidence for avoidance of adult lutjanids observed in high relief, high slope environments in close proximity but not overlapping with observed juvenile habitat. There is no evidence to prove that juveniles avoid adult habitat, however there is no evidence that they don’t. Diet analysis showed prey catagories are largely representative of adult diets with small crustaceans occurring most frequently and most often. Gelatenous plankton, juvenile fish, fish scales, and cephalopod remains were also found in the 22 juvenile stomachs yielding discernable prey items. None of the stomach contents were endemic to hard substrate environments.

**Moffitt et al**

**1990**

**Somerton & Kobayashi – Some effects of increasing the minimum commercial size limit of opakapaka, *Pristipomoides filamentosus***

Following work indicating recruitment overfishing of opakapaka in the MHI, work was undertaken to determine the economic repercussions of increasing the minimum size limit. Economic analysis was mixed with YPR analysis to determine how long it would take for the yield an increase in the minimum age of capture for opakapaka to compensate for initial losses from excluding smaller fish from the overall catch of the fishery. It was determined that at a fishing pressure of 0.6, increased equilibrium yield would balance fishery losses after a minimum period of 24 years, ignoring inflation and opportunity cost losses resulting in missed investment opportunities for fishery participants. When fishing pressure was 0.3, break-even was never achieved. Other assumptions were that undersized fish released would survive, however release of deepwater snapper would still likely result in barotrauma death. It is also noted that the recreational fishery would likely still have a substantial effect on the mortality of undersized fish. Analysis results indicate that, best case, even moderate levels of fishing mortality on undersized fish all economic gains from greater yield are eliminated. Finally, difficulties in aging opakapaka and other tropical snapper mean growth and mortality estimates may not accurately reflect their true values. While increases in spawning biomass would be substantial, it is unknown whether increases in spawning biomass would result in higher recruitment rates. Even so, yield increases would be small and their effects not seen for years.

**1993**

**Ellis & DeMartini – A comparison of baited video camera and kali longline for indexing the abundance of juvenile opakapaka *(Pristipomoides filamentosus)***

Essentially a one camera botcam vs. a longline shoot out to compare precision, accuracy and efficiency of the camera system in indexing abundance of juvenile *P. filamentosus*. Opakapaka were second most observed and caught fish after puffer fish *Lagocephalus hypselogeneion*. Camera analysis indicated the video index where the maximum number of fish was seen (MaxN) was best correlated with longline CPUE. It is noted that *L. hypeselogeneion* removes hooks from the longline and is representative of hook competition with *P. filamentosus* and functionally mimics gear saturation. A sample size of 26 stations was determined necessary to detect a 50% change in abundance of juvenile *P. filamentosus* over a 10 minute bottom time using the baited camera system using 3 video drops per station. For long line sets, an estimated 33 sample stations were required.

**Unknown - Develop opakapaka (pink snapper) tagging techniques to assess movement behavior**

Tagging was undertaken at 14 sites off penguin banks where 839 *P. filamentosus,* ranging from 9 – 21 inches FL, were tagged and released. 6.3% of tagged fish were recaptured with almost all recaptured within 3 miles of their release location. One opakapaka was recaptured 15 miles from its release location. This data was used to assess movement behavior and collect growth information. A preliminary project took place off Ewa Beach and tagged 122 juvenile opakapaka with a 21% recapture rate within 4 days at the release site. Tagging procedures developed included placing captured fish in a container of seawater, puncturing the stomach of inverted fish that were full of gas with a fish hook, removal fo scales and a slight incision anterior of the anal opening and lateral of the midline to release trapped gas in the body cavity and air bladder. Placing fish back into container to determine survival prior to release. Slow (2 ft /second) or fast (5 ft / second) was not found to have a significant effect on barotrauma symptoms, nor did fish size or depth of capture. Mortality by sharks occurred as did barotrauma of opakapaka. Larger fish released were more likely to survive tagging. Total time at liberty ranged between one and 396 days. Paka exhibited rapid growth during summer months compared to relative slow growth during the winter. 6% recovery of tagged fish within the short period of time was seen to be indicative of a very heavily fished resource.

**Kobayashi**

**Haight et al. 1**

**Haight et al. 2**

**Moffit**

**1994**

**Leis & Lee**

**1995**

**Ellis & Demartini**

**1996**

**Moffitt & Parrish**

**1997**

**Williams & Lowe**

**Parrish et al.**

**2000**

**Starr et al.**

**2001**

**Kent et al**

**2002**

**Snelgrove**

**2003**

**Benoit-bird, Au, Kelly**

**Uchiyama & Kazama**

**Quinn**

**Grandcourt**

**2004**

**Kobayashi & Polovina**

**2005**

**Sackett et al**

**Kent et al**

**2006**

**Kelly & Ikehara**

**Kelley et al**

**Martell et al.**

**Moffitt et al**

**2007**

**Parke**

**2008**

**Zeller**

**2009**

**Martindale & Hejnol**

**Brodziak et al**

**Methot**

**Dierking & Meyer**

**Jones et al**

**2011**

**Andrews, et al**

**Hospital & Beavers**

**Brodziak et al.**

**Merritt et al**

**Courtney & Brodziak**

**Gaither et al**

**Moffit et al**

**2012**

**Hospital & Beavers**

**Andrews et al**

**2013**

**Brodziak**

**Weng**

**Moore et al**

**Misa et al**

**Williams et al**

**2014**

**Sackett et al**

**Blue ocean inst.**

**2015**

**Parrish**

**O’malley**

Haight WR, Kobayashi DR, Kawamoto KE (1993) Biology and Management of Deepwater Snappers of the Hawaiian Archipelago. 55:20–27.

Kikkawa BS (1980) Preliminary study on the spawning season of the Opakapaka, Pristipomoides filamentosus. Proc Symp Status Resour Investig Northwest Hawaiian Islands 226–232.

Kikkawa BS (1984) Maturation, spawning, and fecundity of Opakapaka, Pristipomoides filamentosus, in the Northwest Hawaiian Islands. 149–160.

M IB, Uchida RN (1980) Results of ciguatera analysis of fishes in the Northwestern Hawaiian Islands. Proc. Symp. Status Resour. Investig. Northwest. Hawaiian Islands. University of Hawaii Sea Grand College Program, pp 81–89

Moffitt RB (1980) a Preliminary Report on bottomfishin in the Northwestern Hawaiian Islands. In: Grant U of HS (ed) Procedings from Symp. status Resour. Investig. Northwest. Hawaiian ISlands. Honolulu, Hawaii, pp 216–225

Polovina JJ, Moffitt RB (1980) Commercial bottom handline fishery in the Northwestern Hawaiian Islands, 1959-77. Honolulu, Hawaii

Polovina JJ, Moffitt RB, Ralston S, et al (1985) Fisheries Resource Assessment of the Mariana Archipelago, 1982-85. Mar Fish Rev 47:19–25.

Polovina JJ, Polovina JJ, Ralston S, Ralston S (1987) Assessment and management of deepwater bottom fishes in Hawaii and the Marianas. 505–532.

Ralston S (1984) Biological constraints on production and related management issues in the Hawaiian deepsea handline fishery. 248–264.

Ralston S (1982) Influence of Hook Size in the Hawaiian Deep-sea Handline Fishery. Can J Fish Aquat Sci 39:1297–1302. doi: 10.1139/f82-171

Ralston S (1986) Bottomfish Resource Assessements (Submersible versus handline fishing) at Johnston Atoll. Fish 141–155.

Ralston S, Miyamoto GT (1983) Analyzing the width of daily otolith increments to age the Hawaiian snapper, Pristipomoides filamentosus. Fish Bull 81:523–535.

Ralston S, Polovina J (1982) A multispecies analyis of the commercial deep-sea handline fishery in Hawaii. Fish Bull 80:435–448.

Ralston S V. (1981a) A multispecies production analysis of Hawaii’s offshore handline fishery. Pacific Sci 34:337.

Ralston S V. (1981b) A study of the Hawaiian deapsea handline fishery with special reference to the population dynamics of opakapaka, Pristipomoides filamentosus (Pisces: Lutjanidae). University of Washington, Seattle

Uchiyama JH, Tagami DT (1984) Life history, distribution, and abundance of bottomfishes in the Northwestern Hawaiian Islands. In: Grigg RW, Tanoue KY (eds) Proc. Second Symp. Resour. Investig. Northwest. Hawaiian Islands. pp 229–247

Ralston, S. V. D. (1979). *A description of the bottomfish fisheries of Hawaii, American Samoa, Guam, and the Northern Marianas*.