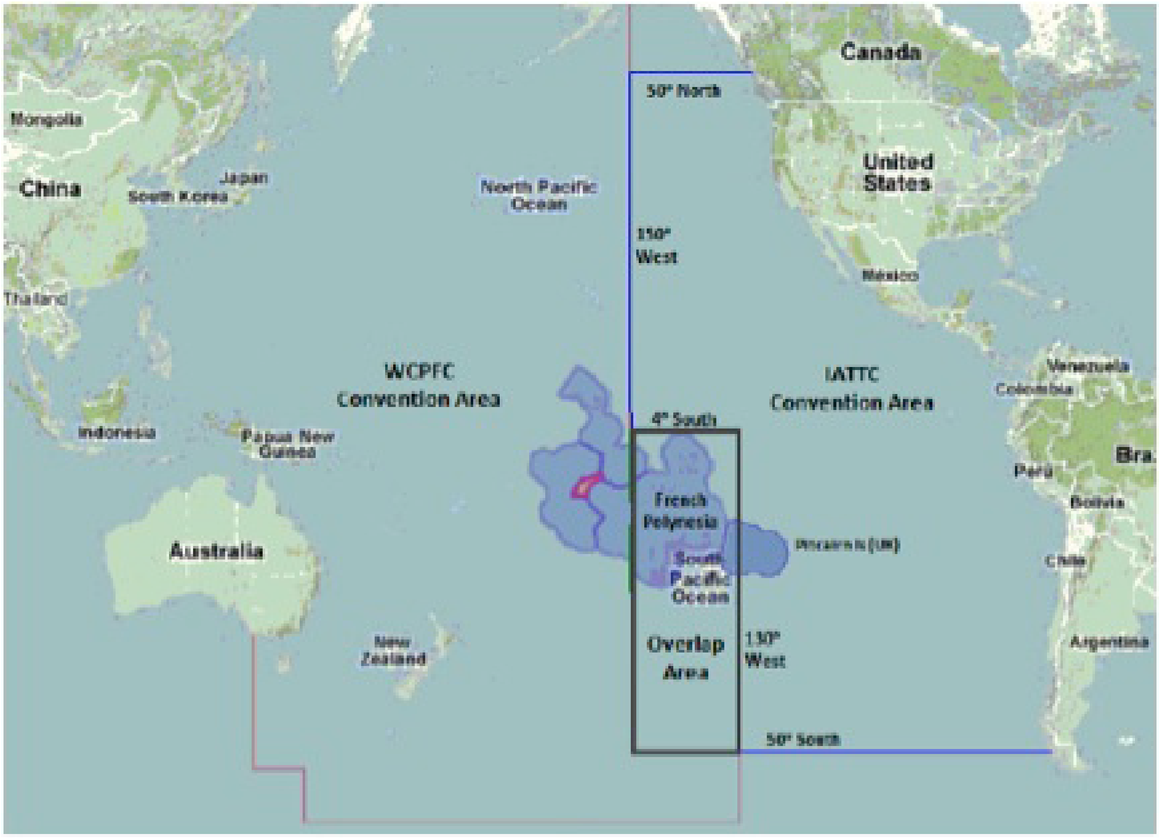
Workshop on Pacific Bigeye Movement and Distribution



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Western Pacific Regional Fishery Management Council
1164 Bishop Street, Suite 1400, Honolulu, HI 96813

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1 EXECUTIVE SUMMARY

An international workshop was convened in Honolulu, Hawai‘i, 22-24 April 2014, with invited experts on the fisheries, biology, population dynamics and management approaches relevant to Pacific bigeye tuna. The movements, distribution, and impacts from fisheries were examined through tagging studies, otolith chemistry, genetics, and climate mediated impacts on distributions. Alternative stock assessment assumptions, modeling, and management approaches were explored. A list of key points arising from the meeting are given below, many of which point to the need for additional research and information to inform management. A list of identified data gaps and research priorities are included in Section 12.

- Current information supports the view that bigeye are distributed as a continuum across the Pacific Ocean with interaction decreasing as the distance between locations increases; the “separation by distance” hypothesis;
- There appears to be significant variability in bigeye maturity and growth rates across the Pacific that advance in a west to east progression with a cline around 170°W, coincident with changes in oceanography;
- Pacific wide studies of the age, growth, and reproductive biology of bigeye tuna are needed to better understand these apparent phenotypic differences;
- Tagging studies to date reveal some complex Pacific wide movement dynamics, with regions of lower dispersion observed in the far-eastern and western equatorial Pacific, in the northwestern Pacific off Japan, and in the Coral Sea, Australia, in the southwestern Pacific;
- Regional differences in geography, oceanography and productivity may be driving area-specific variation in rates of movement and variation in life history parameters (age, growth, and maturity);
- In contrast, greater longitudinal movements of bigeye have been observed between about 120W and 180W in the equatorial Pacific between about 10°N and 10°S;
- Primary spawning habitat stretches across the Pacific from about 15°N – 15°S in areas of high productivity and sea surface temperatures > 24°C and optimally at higher SST >28°C;
- Unlike yellowfin tuna, bigeye tuna do not regularly spawn at the higher latitude of the Hawaiian Islands but have been observed to spawn slightly south of the Hawaiian Islands exclusive economic zone (EEZ), in agreement with the 15°N–15°S spawning observations;
- Evidence from otolith chemistry studies support linkages of bigeye caught in the Hawaiian Islands to areas directly to the south of Hawai‘i and from the central equatorial Pacific;

However, bigeye movements determined from tagging data between the central equatorial Pacific and Hawai‘i have been rare despite considerable tagging in both areas;

- Pacific bigeye tuna are now effectively targeted at all age classes > 6 months due to the expansion of purse seine fishing targeting tuna aggregations associated with drifting fish aggregation devices (FADs), in combination with longline fishing effort;
- There are very strong west to east increases in bigeye catch per unit effort (CPUE) for both purse seine and longline in the Pacific that likely indicate a higher abundance and catchability of bigeye tuna as the depth of thermocline becomes shallower across the equatorial Pacific (west to east);
- Increased landings of juvenile bigeye tuna by purse seine vessels targeting skipjack tuna on drifting FADs in the 10N-10S region of the central Pacific straddling the WCPFC and IATTC convention areas may require co-ordination between the two RFMOs to ensure effective implementation of management policie;
- Effective conservation of bigeye tuna in the Pacific will require measures that will reduce fishing mortality on all age classes throughout the range of the stock.
- Work is progressing in developing improved stock assessment and habitat-based movement models with stronger links to biology and life history characteristics of bigeye tuna. The utility of these alternative modeling approaches to management strategies should be explored and their inclusion encouraged;
- The use of spatial management or a mixture of different management policies in different areas (zoning) should also be explored.

Data Gaps and Distribution of Pacific Bigeye Tuna

- Comparable studies on the age, growth and reproduction of bigeye tuna are needed throughout the Pacific to better understand these differences and their role in movement and stock parameters.
- East-west differences in life history and movement parameters and in some cases, regional fidelity of Pacific bigeye tuna are recognized. The significance of these differences to movement, connectivity and stock structure need to be better defined.
- North-south movements of bigeye tuna between equatorial nursery areas and higher latitudes from tagging data is not well supported, but do occur as concentrations of adult bigeye exist at higher latitudes, (i.e. east of Japan, north and northeast of Hawai‘i, east of Australia). These animals form the basis of regionally important fisheries, but their connectivity to the larger equatorial stock and recruitment sources are poorly understood.

A better understanding of bigeye population structure, and the movements, dispersion, and mixing among stocks is essential for input into stock assessments and to meet conservation and management objectives. Information that provides fisheries managers with a robust understanding of the source population(s) of the resources they manage, key spawning locations of this resource and the seasonal movements of the resource is required to ensure the development of sound management policies.

2 INTRODUCTION

Bigeye tuna in the Pacific Ocean have historically been assessed and managed as two separate stocks from the eastern Pacific Ocean (EPO) and Western and Central Pacific Ocean (WCPO). This has largely been for jurisdictional reasons with stock boundaries replicating those of the two tuna Regional Fisheries Management Organizations (RFMOs), the Inter-American Tropical Tuna Commission (IATTC) and the Western and Central Pacific Fisheries Commission (WCPFC) which are responsible for the conservation and management of bigeye tuna in the Pacific Ocean (Figure 1). To date, genetic evidence has not supported this demarcation of stocks (Grewe and Hampton 1998). Actual stock boundaries or structure, if they do exist are uncertain at this point.

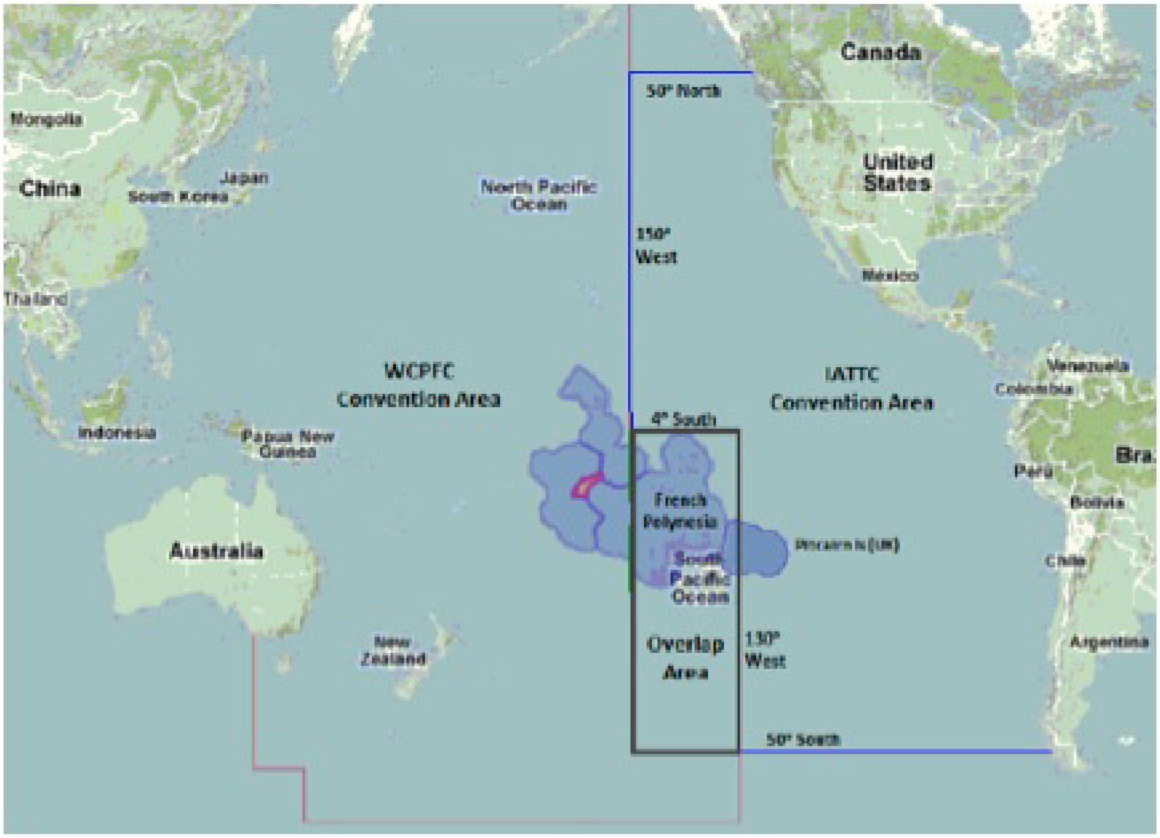

Figure 1 The Pacific Ocean and the management areas of the Western and Central Pacific Fisheries Commission and the Inter-American Tropical Tuna Commission. (Note the central Pacific area of overlapping jurisdictions at 130°W – 150°W).

Results from tagging studies have demonstrated that bigeye tuna are capable of extensive longitudinal linear displacements (Schaefer et al. 2015), but also show a high degree of site fidelity to some regions (Hampton and Gunn 1998). The general consensus from a biological perspective supports a "separation by distance" view that bigeye tuna are distributed as a continuum of meta-populations across the Pacific Ocean with interaction decreasing as the distance between locations increases. Following this line of thought, bigeye in the extreme western Pacific are not expected to interact regularly with bigeye from the extreme east, but bigeye in the central Pacific interact with both eastern and western stocks. Aggregated bigeye catch data by gear type provides a representation of where the resource is vulnerable to fisheries but is likely an under-representation of total distribution (Figure 2).

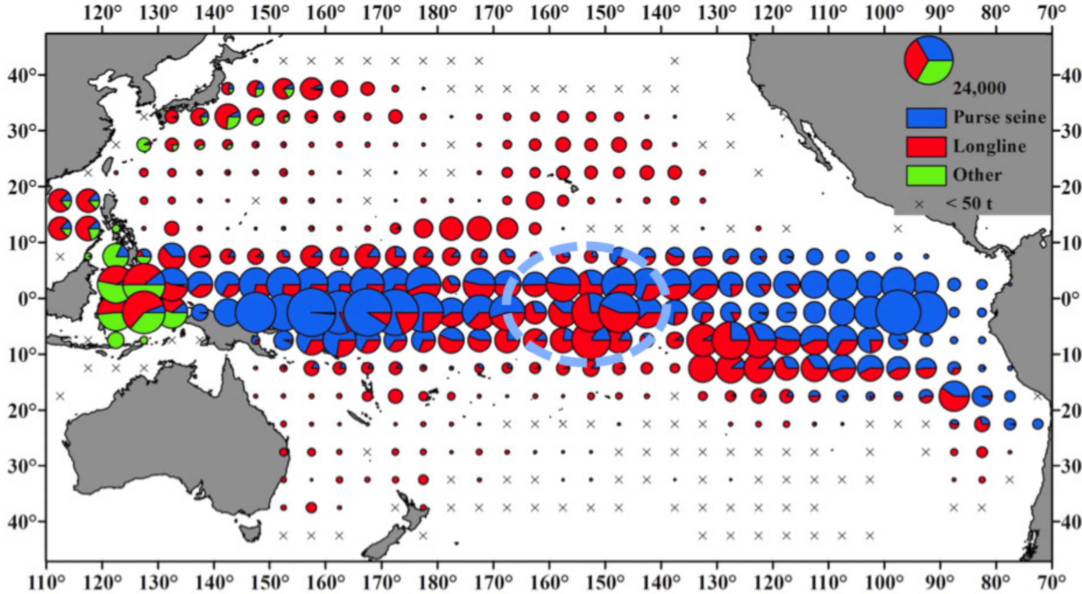

Figure 2 Distribution of the catches of bigeye tuna, by gear type, in the Pacific Ocean 2008-2012. The sizes of circles are proportional to the amounts of bigeye caught in those 5° by 5° areas (from Schaefer et al., 2015).

The majority of commercial harvest of bigeye tuna in the Pacific are located 15°N – 15°S, which coincides with the region considered to be optimal spawning habitat. However, higher latitude concentrations of adult bigeye are evident in areas of high productivity off the east coast of Japan and north/northeast of Hawaiʻi with smaller numbers of adults caught in the Tasman Sea and off Peru and Chile. There was some speculation from workshop participants that unexploited stocks of bigeye may still exist, such as in the southern oceans below 20°S. What draws bigeye to high latitude regions, how long they remain and where they originate from remain a significant data gap that must be addressed to inform management.

Prior to 2000, Figure 2 would have only shown longline effort across the central Pacific in the 10°N – 10°S, 170°W – 140°W region. Small bigeye tuna are now caught by purse seine vessels in mixed species tuna aggregations associated with drifting FADs in this area (Figure 2, blue oval). Tuna fisheries management in the Pacific Ocean needs to incorporate information on the connectivity between regions and the impact of fishing on all age classes. These issues were examined and discussed at the workshop described in this document.

3 WORKSHOP STRUCTURE, OBJECTIVES AND OUTPUTS

The management of tropical tunas under the WCPFC, and in particular the setting of increasingly restrictive catch limits for longline caught bigeye across the Commission area was discussed at the 114th Meeting of the Scientific and Statistical Committee (SSC) of the Western

Pacific Regional Fisheries Management Council (Council), October 8-10, 2013. It was noted that the WCPFC had identified that overfishing of bigeye had been occurring within the WCPO since the mid-1990s. The stock is currently considered overfished.

In discussing the state and management of the bigeye stock in the WCPO, the SSC noted a number of considerations of relevance to the Council (i) the Hawai‘i longline fishery operates outside of the core equatorial Pacific region in which the majority of fishing mortality on bigeye occurs from purse-seine and longline fisheries; (ii) Catch per unit effort and the average size of bigeye caught by the Hawai‘i longline fishery have demonstrated a stable trend through time; and (iii) large-scale tagging programs have documented very few movements of bigeye from equatorial regions to north-central Pacific waters around and north of Hawai‘i where the fishery operates.

SSC members observed that the geospatial origins of bigeye tuna surrounding Hawai‘i and harvested by the Hawai‘i-based domestic fisheries are not well understood even though bigeye tuna dominate catches by the Hawai‘i longline fleet. A considerable amount of bigeye tagging has been conducted around Hawai‘i in recent years, but the connectivity of bigeye in the central Pacific is still poorly defined. The application of stable isotope and otolith micro-chemical analyses for examining tuna origin and movement was then discussed.

As a result of discussions, the SSC provided the following recommendations to the Council:

The SSC recommends that the bigeye otolith stable isotope study be completed and published. Similar studies helped resolve spatial distribution and connectivity of Hawai‘i yellowfin tuna. Further, the bigeye study should be expanded to include sampling of otoliths from other locations not yet sampled (e.g. northwestern Pacific).

The SSC recommends that the Council convene a workshop on bigeye movement and distribution, with the objective to design a collaborative study of bigeye movements in the Pacific and the data requirements to support such a study.

In April 2014, an international workshop was convened by the WPRFMC to review the current status of information on the movement of bigeye tuna to develop a research plan to fill critical knowledge gaps. The workshop agenda is attached as Appendix I.

The genesis of the workshop stemmed from a question facing many nations participating in the management of transboundary stocks such as bigeye tuna; “How connected is the population in my EEZ with the broader population and what contribution do management measures implemented outside and within my EEZ make to the overall conservation status of the stock?”

On a more basic level, management should be asking where the nursery ground or source is that recruits to a fishery, where do those fish eventually spawn when mature and how does this resource move seasonally throughout the year or in response to oceanographic conditions. Remarkably, this information is often unknown or poorly understood.

The workshop was hosted by the WPRFMC in Honolulu, Hawai‘i, and chaired by Paul

Dalzell (WPRFMC staff) and David Itano (NOAA Fisheries). The meeting gathered tuna fishery scientists and managers from several countries with expertise on Pacific bigeye tuna. A list of meeting participants is attached as Appendix II. The meeting reviewed what is known about the life history, fisheries, movements, and stock structure of Pacific bigeye tuna. The distribution and movements of Pacific bigeye were discussed based on data and analyses from conventional and electronic tagging, otolith microchemistry and genetics investigations and climate mediated changes in distribution. On Day 2, inputs and options for the management of bigeye fisheries were discussed.

The objectives of the workshop were to review what is known about Pacific bigeye tuna with an emphasis on movement and distribution; identify data gaps and research needs, and to identify sources of funding to address these data gaps, preferably within the framework of a collaborative study to examine connectivity and distribution of Pacific bigeye tuna. This document provides a technical summary of the outcomes of the workshop following each agenda item as are listed in Appendix I. A list of data gaps and research needs identified by the workshop is included in Section 12 that follow a brief description of presentations. Presenter supplied abstracts are provided in Appendices III to X.

4 HISTORY AND BIOLOGY

Kurt Schaefer (IATTC) and Simon Nicol (SPC-OFP) presented a synopsis of information on life history and biology, summarizing information on age, growth and reproductive biology of bigeye tuna in the Pacific Ocean and geographic variability in parameter estimates. An abstract of the presentation is attached as Appendix III.

4.1 Age and Growth

Pacific bigeye tuna can live to at least 16 years as evidenced by conventional tagging data and reach large sizes above 240 cm. The deposition of daily growth increments on saggital otoliths has been validated and is useful to around 3.5 years after which annuli have been validated with tagging data to 12 years of age. However, the ability to use annular increments diminishes at low latitudes where environmental variability is low.

Growth rates for bigeye males and females appears to be similar to about 150 cm. Good correspondence between otolith derived age estimates and tagging data exist for the eastern Pacific Ocean providing confidence in a robust growth model for EPO bigeye up to about 10 years (Aires-da-Silva et al, 2014) However, studies in the WCPO based on smaller sample sizes have higher levels of uncertainty attached with variation in length at age estimates moving westward. Based on available studies it appears that on average, bigeye length at age is larger in the EPO in comparison to the WCPO.

4.2 Reproductive Biology

Spawning of bigeye occurs across the Pacific basin during most months of the year in tropical regions between approximately 15°N – 15°S, and can occur seasonally at higher latitudes (Nikaido et al. 1991) Spawning is generally regarded as occurring where sea surface temperatures are above 24°C but data from the eastern Pacific suggest that very little spawning occurs below 28°C. This may explain the patchy distribution of dense concentrations of bigeye larvae sampled across the Pacific (Nishikawa et al. 1985).

Histological examination of tuna ovaries is considered the method that provides the greatest precision when assessing reproductive status of tunas, i.e. maturity, spawning frequency, and periodicity (Schaefer 1998). Only one study, based on samples collected in the eastern and central Pacific used histological methods coupled with a reasonable sample size of fish from over a broad geographic range (Schaefer et al. 2005). Spawning was reported to occur between 15°N – 15°S and about 105°W – 175°W during months with elevated sea-surface temperatures with spawning occurring primarily at night between about 1900h – 0400h.

Results from this study indicate a length at 50 percent maturity (L50) for female bigeye of 135 cm. Mature females spawn, on average every 2.6 days, with reproductively active females spawning on average every 1.3 d. This near daily spawning periodicity has been well documented for other tropical tuna and tuna-like species, although the duration of repeated spawning behavior is not known.

This L50 estimate of 135 cm from the EPO differs significantly from estimates of bigeye maturity from the western Pacific that utilized similar histological methods. The study sampled longline caught bigeye in Taiwanese waters estimated L50 at around 105 cm (Sun et al., 1999). Results from a similar dataset recently published an L50 estimate for bigeye tuna of 102.85 cm (Sun et al., 2013). A third study estimated a L50 of 102.4 cm based on ovaries collected from bigeye tuna caught off the east coast of Australia (Farley et al. 2006). It is unclear whether maturation of tunas is best regarded as a function of length or age (Schaefer 2001).

Only two studies (Nikaido et al. 1991; Schaefer et al. 2005) have applied appropriate methods to estimate fecundity. There is a large discrepancy in the estimates of bigeye relative batch fecundity between those studies and those from Yuen (1955) and Sun et al. (1999).

4.3 Life History: Discussion Summary

Significant variability in growth and maturity indices is apparent, both by latitude and longitude across the Pacific Ocean. Some of the observed variability may be due to sampling and/or method biases, which highlights a significant data gap and research need to better quantify such biases and reduce uncertainty in region-specific life history parameters. Gear selectivity of sampling platforms should also be considered. The most significant differences in reproductive and growth parameters were noted to occur in the Pacific basin east and west of about 170°W longitude. If the spatial variability noted is supportable, then these differences may provide support for hypotheses of bigeye stock partitioning in the Pacific Ocean.

It was noted that estimates of L50 for western Pacific bigeye around 102 – 105 cm appear low in comparison to many estimates made since the 1950s for WPO bigeye for size at first maturity of around 100 cm. It was acknowledged that the earlier estimates were made using non-histological methods but some recent studies also suggest a size at first maturity close to 100 cm. To develop from first maturity to L50 in less than 10 cm of growth seems unlikely when compared to other Thunnus species highlighting the need for more and larger scale studies on reproductive biology of bigeye by region.

It was suggested during the workshop that regional environmental factors might be a driver of area-specific variations in life history parameters. Given differences in the large-scale oceanography between the far eastern and far western Pacific regional oceanographic conditions (e.g. sea-surface temperature, mixed layer depth, productivity, trophic systems) should be considered when quantifying spatial variability in life history parameters.

Discussion followed on whether or not bigeye tuna spawn in the waters surrounding the main Hawaiian Islands. It was confirmed that bigeye larvae, (verified by genetic means) have been collected in Hawaiian coastal waters but are relatively rare, confirming that some bigeye spawning takes place close to the Hawaiian islands. It was also noted that studies by Yuen (1955), Nikaido et al., (1991) and Schaefer (2005) confirm spawning of bigeye tuna as far north as about 15°N, just a few hundred miles south of the main Hawaiian Islands (Figure 3). In discussion, it became apparent that it depended on which definition of “around Hawai‘i” is being considered and that bigeye tuna do spawn occasionally near the islands and to a greater extent just to the south of the Hawaiian Islands. It was noted that 300 – 400 miles south of Hawai‘i falls well within the 15°N – 15°S band already noted to represent prime bigeye spawning habitat.

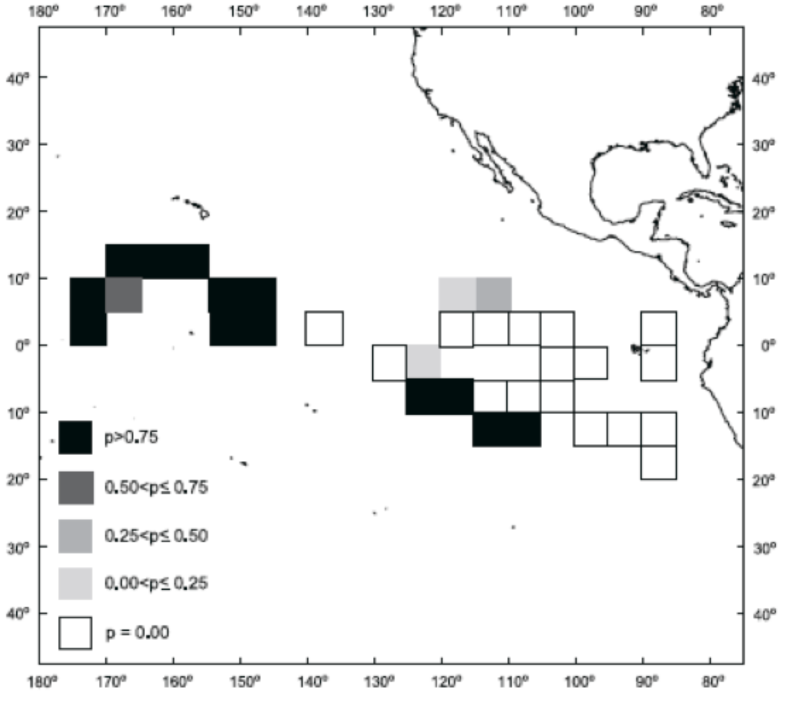

Figure 3 Annual spawning distributions of bigeye tuna represented as the proportions of reproductively active females relative to the total numbers of mature females captured within 5-degree areas (from Schaefer et al. 2005). Note the high proportion of reproductively active females located south of Hawai‘i at 10°N 0 15°N.

4.4 Life History: Data Gaps and Research Needs

Comparable datasets derived from histological studies of gonads to establish reproductive parameters, in particular indices of maturity and fecundity, for bigeye across the Pacific Ocean are clearly lacking. Robust growth models, particularly for regions of the western and central Pacific are also lacking. Studies are particularly needed in the western and central Pacific Ocean, but also in the eastern Pacific Ocean.

In response to this need, the WCPFC has been supporting a research project since 2012 that is being administered by the science provider to the Commission (SPC-OFP) to conduct a study on the reproductive biology of WCPO bigeye to reduce uncertainty in biological inputs to stock assessments. The project utilizes WCPFC observers to collect gonads and associated otoliths on both purse seine and longline vessels across a sampling matrix accounting for size and sex. Despite best efforts in project design, spatial data gaps exist at higher latitudes and in the Central Pacific, with the majority of samples being collected from equatorial fisheries of the western Pacific. It is anticipated that 1000+ bigeye gonads and 2000+ otoliths will have been collected by mid-2015. Efforts to address current spatial data gaps may be possible at least in collecting otoliths as the sampling can theoretically be conducted at the time of unloading, rather than being needed to be done on board the vessel. At present the project is focused on sample collection only; further funding will need to be identified in order to have the samples processed and analyzed.

Another significant data gap exists regarding the spawning ecology, origin and life history parameters of bigeye tuna found at higher latitudes in subtropical and temperate regions.

5 FISHERIES SYNOPSIS: KEY POINTS BY REGION

Kurt Schaefer (IATTC), John Hampton (SPC-OFP) and Keith Bigelow (NMFS) provided summaries of commercial fisheries catching bigeye tuna in the EPO, WCPO, and from Hawai‘i. Key points from their presentations are summarized below. Presenter supplied abstracts for the three presentations are included in Appendix IV.

5.1 Eastern Pacific Ocean

1. Purse seine fishery began exploiting tuna aggregations associated with drifting FADs in 1994, which dramatically increased the catch of bigeye tuna.
2. Longline catches of and effort on EPO bigeye has dramatically declined as purse seine catches have increased to around 60,000 mt/year.
3. Purse seine fleet has been quite stable at about 206 vessels.
4. Pole and line fleet has essentially disappeared from the region.
5. Purse seine drifting FAD associated catches of bigeye in the eastern Pacific contain a considerable amount of fish >100 cm, unlike the western Pacific that takes mainly small-sized bigeye <~60 cm.
6. The purse seine drifting FAD fishery is considered to have the greatest negative impact on bigeye in the Eastern Pacific Ocean.
7. In response, the IATTC has adopted a number of conservation measures, including 62 mandatory no fishing days per year, a one month spatial closure in a high FAD use area and fixed bigeye catch limits for the major distant-water longline fleets.

5.2 Western and Central Pacific Ocean – Equatorial

1. The total WCPO bigeye catch in the last 15 year period has fluctuated around 140,000 – 160,000 mt/yr.
2. The majority of that total catch (~75 percent) has been distributed across in the 10N – 10S zone, with about equal amounts of catch being taken by purse seine floating object effort and longline fisheries.
3. Longline catch has been declining since mid-2000s.
4. There are distinct peaks evident in north Pacific longline CPUE during winter months.
5. There are very strong west to east gradients in both purse seine and longline CPUE for bigeye that likely indicate both higher abundance and catchability of bigeye tuna as the depth of the mixed layer becomes shallower across the equatorial Pacific from west to east;
6. Eastern areas of the WCPO are now exploited by large, efficient European Union purse seine vessels flagged to Central and South American countries operating primarily on drifting FADs.

5.3 Hawai‘i Longline

1. Consists of a US domestic fleet of approximately 135 vessels/year operating in US waters (Hawai‘i and the US Pacific Remote Island Areas) and international waters surrounding Hawai‘i). The majority of effort takes place in international waters.
2. The fishery is primarily a deep-set fishery targeting primarily bigeye tuna with smaller shallow-set fishery targeting swordfish
3. Both deep and shallow-set fishery sectors land a fresh and iced product.
4. Bigeye CPUE in the deep-set fishery has remained stable over time since 2000.
5. Longline effort has steadily increased due to an increasing number of trips and hooks set per trip. Longline effort was almost 50 million hooks in 2013.
6. An increasing amount of longline effort is being focused north and east of the Hawaiian archipelago and increasingly in the IATTC area targeting high grade bigeye tuna for sashimi markets.
7. The average size of bigeye in catches by the fleet has remained constant for many years at about 35 kgs.

Figure 4 shows aggregated (1966-2006) Pacific-wide longline CPUE (Japan) of bigeye tuna for illustrative purposes. High equatorial CPUE is evident as are areas of high CPUE at higher latitude in the north and south Pacific (red shaded areas).

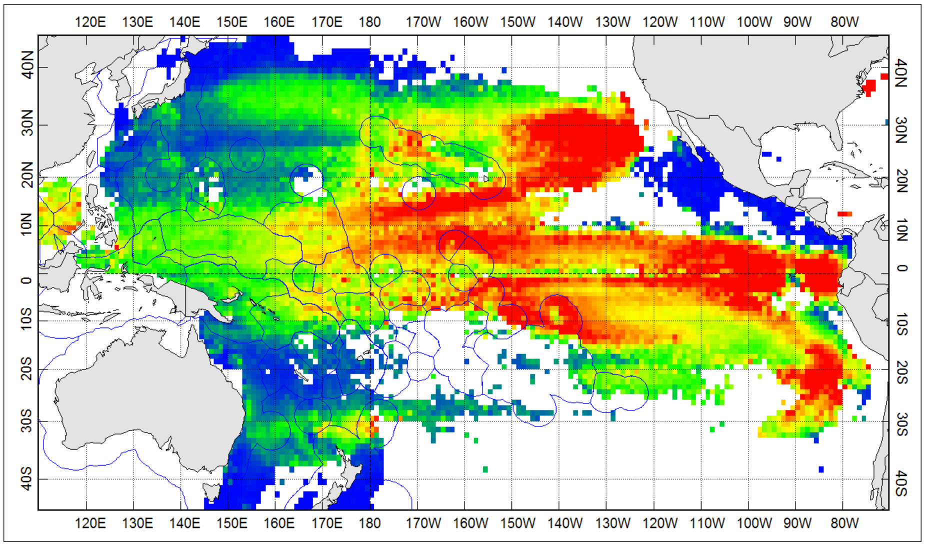

Figure 4 Pacific-wide longline CPUE (Japan), aggregated data (1966-2006). CPUE ranges from Blue (lower) to Red (higher) areas of CPUE.

6 STOCK STRUCTURE AND ASSESSMENT: CURRENT ASSUMPTIONS AND HYPOTHESES

6.1 Presentation overview

Pierre Kleiber (NMFS, retired) provided a presentation on concepts and perceptions inherent in defining tuna stocks and how they are or could be used in stock assessment models. An abstract of the presentation is attached as Appendix V.

The presentation noted that current stock assessments deal with a “stock” as a necessary entity or abstraction within a model that may have little relevance to actual tuna or tuna populations. Dealing with tuna in this way is convenient for producing integer numbers and projections of management interest, such as MSY or impacts of fishing mortality expressed as biomass. For the purposes of the workshop objectives and improved modeling, it was suggested that a tuna stock would be better dealt with as a biological continuum with spatial variability and introduced the stock concept of “isolation by distance”.

The presenter encouraged the development of improved models with stronger links to the biology and motivations for movement and life history functions of real tuna as exemplified by the ecosystem model SEAPODYM. In discussion, it was noted that robust observations of life history across the Pacific (e.g. growth curves, maturity schedules) will be necessary to accurately define gradients in population parameters across the Pacific supporting a stock concept of “isolation by distance”. It was further noted that the “isolation by distance” concept needs to also take into account other factors such as geography, as per the “island effect” noted in a tagging study based in the Solomon Islands (Kleiber and Hampton 1994).

7 TAGGING STUDIES: CONVENTIONAL, ACOUSTIC, ARCHIVAL

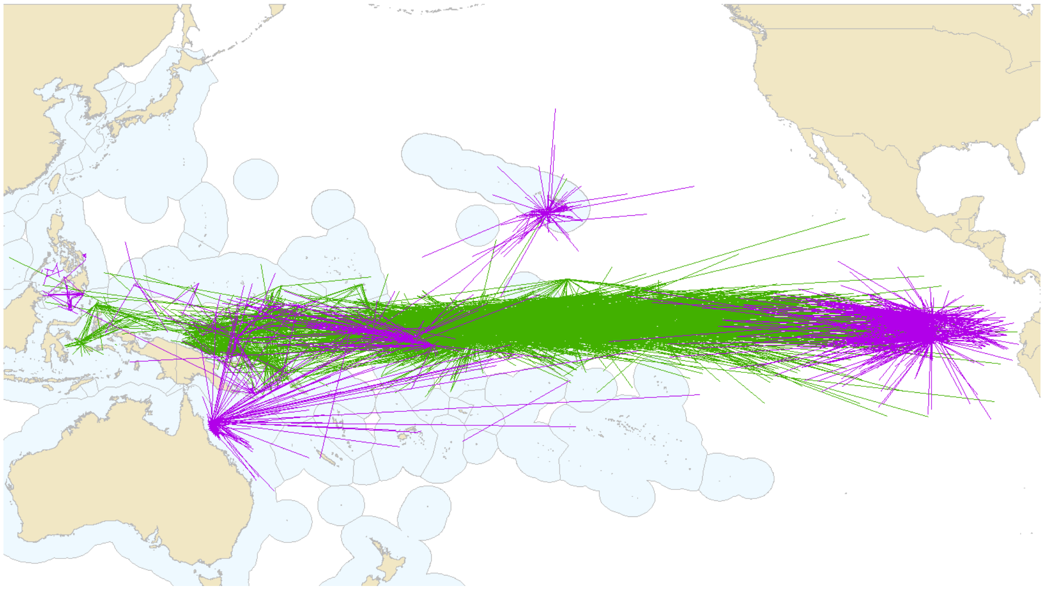

Figure 5 Straight-line displacements of bigeye tuna derived from conventional tagging data across the Pacific Ocean.

Figure 5 shows linear displacements of bigeye tuna derived from conventional tag recapture data for the Pacific across multiple programs. Note that most fish released at 15°N to 15°S remained in this latitudinal band. Only two significant datasets at higher latitudes are shown: the Hawai‘i Tuna Tagging Project, HTTP (1995-2001) and tag releases in the Coral Sea of Australia from the SPC Regional Tuna Tagging Programme, RTTP (1988-1992). Of the two datasets from higher latitudes shown, most releases remained close to the point of release, with a smaller number moving into the equatorial stock. The pattern of restricted north – south documentation of movements is apparent.

Details of tagging studies were presented from the eastern and central Pacific (Kurt Schaefer/IATTC); the western equatorial Pacific (John Hampton, Simon Nicol/SPC-OFP); the western Coral Sea (Karen Evans, Rob Campbell/CSIRO); waters around Japan (Takayuki Matsumoto/NRIFSF) and waters around Hawai‘i (Kim Holland/HIMB, David Itano/NOAA) were provided. Key points from presentations given are summarized below. Presenter supplied abstracts describing all presentations are included in Appendix VI.

7.1 Tagging: Eastern and Central Pacific Ocean

1. Bigeye tagging experiments were conducted in the:

    a) equatorial eastern Pacific (2000-2006)

    b) equatorial central Pacific (2008-2012)

2. Total tag releases comprised:

    a) 49,941 plastic dart tags

    b) 772 internal archival tags

3. Tag cohorts were released at or near the 95°W, 140°W, 155°W, 170°W and 180°
4. Tag recaptures to date, exhibit varying longitudinal displacements within the 10°N - 10°S band
5. Movement patterns of bigeye derived from archival tag data indicated:

    a) 95°W releases: regional fidelity to EPO waters with restricted westward movement

    b) 155°W releases: fairly strong regional fidelity to central Pacific waters

    c) 140°W and 170°W releases: broader movement primarily to the east

6. Conventional and archival recapture data suggest that three putative spatial populations with boundaries at 120°W and 180° may exist within the 10°N - 10°S latitudinal band

7.2 Western and Central Pacific Ocean

1. Three major tagging experiments from 1970s to present have been conducted with over 53,000 conventional tag releases, mostly from the most recent Pacific Tuna Tagging Programme (PTTP; 2000 – present)
2. Recapture rates of tags from bigeye released under the PTTP are now approaching 30 percent
3. Tag release cohorts by area:

    a) Philippines – short times at liberty and high site fidelity

    b) western Coral Sea – very long times at liberty and high site fidelity with some long-distance movements eastward

    c) western equatorial Pacific – some long distance displacements east to west

    d) equatorial east of 180°- greatest long distance displacements of all regions

4. Movement patterns of bigeye derived from conventional tag releases across equatorial regions were primarily east to west
5. To date very few observations of movements of bigeye between equatorial regions and higher latitudes have been recorded
6. It was recommended that a Pacific-wide integrated analysis of bigeye archival and conventional tag data be conducted

7.3 Western Coral Sea

1. Connectivity of bigeye tuna off eastern Australia examined through tagging studies (conventional and archival tag), age/growth/maturity studies and catch data
2. Conventional and archival tags deployed in the Coral Sea suggest that bigeye are largely resident in this region, but that some undertake excursions into the Pacific (i.e. Solomon Islands, PNG) before returning to the Coral Sea
3. Movements provide some support for the hypothesis of greater retention of fish near land masses
4. A similar issue to that faced by the fishery around the Hawaiian Islands – what is the origin and distribution of bigeye tuna within a reasonable small regional fishery on the periphery of the much larger fisheries in the equatorial regions - is being asked by the fishing industry operating off the east coast of Australia.

7.4 Japan

1. Two tagging projects have been conducted to the southwest of Japan and in offshore waters/central Japan (2000 – 2010)
2. 4,453 bigeye were released with conventional tags (10.4 percent recapture rate) which included 211 fish with archival tags (35 recovered, 16.6 percent recapture rate)
3. Qualitative analysis of movement derived from bigeye tagged off southwest Japan showed some relationships with regional oceanography (Kuroshio Current)
4. Generally, strong site fidelity was noted
5. Larger fish showed greater dispersion
6. Higher associative diving behavior noted for fish <60 cm
7. No association with bathymetric features noted
8. A potential movement route was identified with releases from southwest Japan moving northeast with the Kuroshio current, remaining off north central Honshu and then dispersing east and south

7.5 Hawai‘i

1. The Hawai‘i Tuna Tagging Project (HTTP; 1995-2001) tagged 9,537 bigeye and 8,449 yellowfin with conventional tags (12.6 percent recapture rate). The majority of releases were juvenile fish (median 58 cm)
2. Bigeye movements derived from tags are strongly influenced by natural and anthropogenic structures
3. 94 percent of bigeye were recapture inside the Hawai‘i EEZ were seamount or FAD associated
4. Attrition curve analysis of tag recaptures indicated a typical ‘residence’ time at Cross

seamount in the range of a few weeks

5. In contrast, tagging bigeye with acoustic tags monitored by receivers on seamounts revealed some residence times of at least a year with departures and revisitation over time
6. Coupled diet studies support that bigeye gain a feeding advantage over intermediate depth seamounts
7. Some longer distance conventional tag recaptures have been recorded as fish recruited to the pelagic longline fishery, including movements south of 14°N
8. Some long distance recaptures north of Hawai‘i have been recorded in an area where the longline fleet operates seasonally - little is known about bigeye in this region
9. Acoustic and archival tagging studies revealed dramatic diel changes in depth distribution that is underpinned by behavioral and physiological thermoregulation
10. Floating objects (e.g., FADs) disrupt the typical diel vertical behavioral patterns and cause bigeye tuna to remain within the surface mixed layer during both day and night. This finding has significant management implications
11. Acoustic tagging studies revealed bigeye tuna residence times at anchored coastal FADs in Hawai‘i to be quite brief (a few days)

8 OTOLITH STABLE ISOTOPE AND MICRO-CONSTITUENT ANALYSES

Jay Rooker and David Wells (Texas A&M) provided a presentation on the use of natural tracers within hard parts or otolith chemistry to examine natal origin, residence and movement of tuna. Key points from their presentations are summarized below. A presenter-supplied abstract is attached in Appendix VII.

8.1 Presentation overview

1. Natural tracers within hard parts (otolith chemistry) can serve as a natural tag to examine natal origin and movement of pelagic fish.
2. Studies involve the collection of otoliths from very small individuals (i.e. young of the year) at different sites; one otolith is examined for trace elements and the other for stable isotopes of carbon and oxygen (δ18O and δ13C).
3. High precision micro drills were used to core out the portion of the otolith that corresponds to the first few months of life. This can be done for any age class.
4. Trace elements and stable isotopes derived from the otoliths provide a chemical signature for the water mass in which the fish spent its early life, i.e. a nursery area signature.
5. Trace elements have been used to successfully discriminate age-0 and age-1 Atlantic and Pacific bluefin tuna to nursery origin (Rooker et al. 2001; 2003) and have also

been used to assess movement and homing of Atlantic bluefin (Rooker et al. 2008).

6. Stable isotopes derived from yellowfin tuna have been used to discriminate individuals from different areas of the western Pacific and also to predict nursery origin of yellowfin tuna in the Hawaiian Islands region (Wells et al. 2011).
7. Stable isotope signatures were characterized from the otolith core of age-0 bigeye and yellowfin from four regions of the WCPO:

   a) Hawai‘i

   b) Central equatorial (Line Islands, Kiribati)

   c) West equatorial (Marshall Islands, Solomon Islands)

   d) Far west equatorial (Philippines/Indonesia)
8. Results showed that:

   a) Local production is the source of age 1-2+ bigeye in the western equatorial region

   b) Local production as well as limited contribution from the central equatorial region is the source of 1-2+ yellowfin in west equatorial region

   c) Local production is the source of age 1+ yellowfin in the Hawai‘i region

   d) Bigeye sampled in Hawaiian waters are sourced from the central equatorial (65 percent) and Hawai‘i regions (35 percent)

8.2 Discussion associated with the presentation

Stable isotope signatures derived from the otoliths of bigeye collected in the Hawai‘i region indicated that 65 percent had the same chemical signature as bigeye sampled in the central equatorial region (Line Islands), over 1000 miles south of Hawai‘i. This suggests that those fish may have recruited into the Hawai‘i region from the central equatorial region. The remainder of the bigeye otoliths (35 percent) had what the study termed the “Hawai‘i” signature. In light of what is known about bigeye spawning in this region of the central north Pacific, it is possible that fish with the “Hawai‘i” signature originated from an area just south of Hawai‘i around 15°N where spawning of bigeye has been observed (see Figure 3) and then moved north into waters around Hawai‘i where the fishery operates Sampling in the region between Hawai‘i and the Line Islands would be required to further determine linkages of bigeye between the two regions. No signature indicative of other western Pacific nursery areas were observed in samples derived from the Hawaiian fishery, indicating no exchange from regions to the west.

A similar analysis of stable isotopes in yellowfin otoliths from the same four regions has been done, providing a useful comparison to the results from bigeye (Wells et al. 2012). Of all otoliths analyzed, 91 percent of the Y-1 sub-adult yellowfin otoliths contained a stable isotope signature consistent with the Hawai‘i signature with 9 percent having a signal consistent with the central equatorial (Line Islands) signal. These results suggest that most yellowfin sampled were the product of spawning population in Hawaiian waters while the majority of bigeye tuna sampled originated from outside, neighboring regions.

Trace element chemistry was also investigated as a complimentary method of establishing nursery area signatures and was found to improve classification of age-0 bigeye and yellowfin into each of the four regions when used in conjunction with stable isotopes.

9 FISHERY AND CLIMATE MEDIATED CHANGES IN DISTRIBUTION

9.1 Presentation overview

Patrick Lehodey and Inna Senina (CLS) provided presentations describing the ecosystem model SEAPODYM (Spatial Ecosystem and Population Dynamics Model). This included an overview of recent improvements and ongoing developments and potential applications of the model as a predictive and environmentally reactive model to examine bigeye movement and distribution. The model represents tuna as a population of predators within a spatial context in relation to two critical drivers: optimal feeding and spawning habitat. These motivations to move adjust in response to environmental variables (i.e. SST, thermocline depth, currents, primary production, euphotic depths, etc), predicted forage abundance and life history (size, maturity, physiological tolerances). Fisheries within the model are defined by effort, which is used with a catchability and selectivity function to predict catch. The predicted and observed catch is used to optimize model parameters.

The predictive power of the model is dependent on the quality and scope of environmental and life history data available and accuracy and resolution of fishery data. Progress towards the development of an operational SEAPODYM bigeye tuna model were described incorporating fishing data and conventional tag data. An abstract covering both presentations is provided in Appendix VIII.

10 GENETIC STUDIES

10.1 Presentation overview

Peter Grewe (CSIRO) reported on recent improvements on the application of genetics for stock discrimination based on work in conjunction with several colleagues (Mark Bravington, Campbell Davies, Peta Hill, and Rasanthi Gunasekera). CSIRO has used southern bluefin tuna as a test bed for research and development with techniques developed transferrable to other tuna species, i.e. bigeye. Previous genetic work on bigeye based on broad scale and well coordinated sampling in all oceans using DNA microsatellites and mitochondrial DNA had proved uninformative to management (Grewe and Hampton 1998). The work could not demonstrate stock structure in the Pacific but neither could it confirm a single gene pool.

Sequencing of whole genomes has revealed markers that can achieve much higher resolution than was possible using the techniques employed in past studies. These include a new type sequencing technologies including RAD (restriction-site associated DNA) genotyping of a class of markers called SNPs (single nucleotide polymorphisms; Baird et al. 2008). These markers, which are linked to genes under selection, have already been used to demonstrate that some traits can evolve to dominate in specific ecological regions and these can be used to identify individuals that form clusters from these specific areas.

Fine-scale resolution of fish populations (e.g., Atlantic cod, sole, haddock, Pacific salmon) has been achieved through the examination of SNPs (e.g., Wirgin et al. 2007; Narum et al. 2008). The advantage of SNP markers once discovered and combined with gene arrays spotted on glass chips is that they provide a powerful low cost method for high through-put analysis of individuals. Combined with whole genome sequencing approaches this can deliver fish stock data that is very cost competitive in comparison to current conventional monitoring and assessment methods (e.g. conventional tagging, traditional surveys, stock structure studies). More importantly, RAD genotyping of SNPs can be performed in organisms for which few genomic resources presently exist. Development of tuna SNP chip platforms provides research opportunities on several fronts. Firstly, they provide platforms that reduce inter-lab variability; an issue identified as a major hurdle for large-scale analysis of genetics fish populations using markers such as DNA microsatellites. Secondly, species identification SNPs can easily be incorporated on a SNP chip using markers already developed in-house and in the public literature, thereby reducing incorrect species identification and providing opportunities for traceability of products. Finally, SNPs can be used to identify regions of the genome linked to sexual dimorphism, providing for gender identification of individuals.

The CSIRO, is developing such markers as a foundation to Genomics Based Fishery Management procedures. In an effort to curb/combat IUU fishing, CSIRO's initiative is being driven by issues associated with the identification of individual fish at the level of (i) species, (ii) population, and (iii) individual. Application of genomic profiling of individuals at these three key levels provides fishery independent methods for estimating population biomass and (iv) alternatives to conventional tags through the application of new technologies such as RAD-tag genotyping of SNPs. Using novel genetic based mark-recapture approaches (e.g. examination of close-kin) through genomics based on RAD tags, key fishery management information can be obtained such as biomass estimation, fecundity and mortality rates. Furthermore, results from these methods are currently in the process of being incorporated into the operating model and management plan for southern bluefin tuna. These markers are also being used in investigations of population structure in skipjack, yellowfin, and bigeye tuna throughout the Indonesian archipelago and are providing preliminary evidence of population structure across the WPO. Preliminary testing and modeling of these markers on southern bluefin tuna has demonstrated their capacity as alternatives to conventional tags (gene tags) and provided positive results for further development as analyses have become cost competitive. An abstract of the presentation is provided in Appendix IX.

11 INPUTS AND IMPLICATIONS FOR BIGEYE MANAGEMENT

11.1 Presentation overview

Paul Dalzell (WPRFMC) provided an overview and timeline of bigeye-specific conservation and management measures adopted by the WCPFC and IATTC for longline and purse seine, noting the increase and impact of purse seine FAD fishing on the stock and generally declining longline catches in both jurisdictions.

John Sibert (UH Emeritus) provided a presentation on new approaches to the management of fisheries that harvest bigeye in the WCPO. The steady increase in bigeye fishing mortality by purse seine fleets associated with the adoption of drifting FAD use in the mid 1990s was noted. These levels of juvenile catch combined with high catch of adults by longline gear far exceed estimates of MSY exemplifying a classic mixed age class, mixed gear fisheries problem. Historical milestones in bigeye management advice were noted, including a recommendation from the Standing Committee on Tuna and Billfish 14 (2001)

“Recognizing the continuing concern of the SCTB about the status of bigeye tuna stocks in the WCPO, and recognizing the increasing catchability of juveniles of this species in surface fisheries, particularly those using FADs, SCTB 14 recommended that there be no increase in fishing mortality in surface fisheries on bigeye in the WCPO until uncertainties in the current assessments have been resolved.”

This recommendation was not taken seriously. Numerous additional recommendations from the Scientific Committee to the Commission arising from periodic stock assessments have not been effectively adopted by the Commission, resulting in a failure to reduce bigeye mortality to levels necessary for the conservation of the stock. Management measures have been crippled by imposing only minor constraints on the purse seine skipjack fishery, a continuation of status quo management with minor catch reductions and attempting to regulate through flag-state allocations that are difficult to impose and enforce. Numerous exemptions for some Commission members and in archipelagic waters further reduce the efficacy of current management schemes. However, it was noted that the Commission has been willing to consider the use of some area-based conservation measures. A paper that examined several area-based management measures was discussed (Sibert et al. 2012). Area based measures alone have had little effect on bigeye stock recovery and it was noted that measures that conserve both juvenile and adult bigeye such as a prohibition of purse seine FAD use, coupled with restrictions on longline effort in spawning areas would be more effective.

It was suggested that effective bigeye conservation will require measures that will reduce fishing mortality on all life stages and throughout the range of the stock. Flag-state allocations will always be difficult to set and enforce and should be avoided as a management tool. Abandoning this approach and moving to area-based management policies, while also providing practical suggestions for implementation of management advice was suggested. It was noted however that spatial management can be motivated by political or profit driven goals. The preferable justification for area-based management would be science driven and conservation burden would be apportioned over both gear types and specific areas where a greater benefit to bigeye may be expected, i.e. areas of high bigeye abundance and/or catchability.

Research and management was encouraged to search for new and innovative approaches to manage fisheries that harvest bigeye tuna and to abandon the use of MSY in favor of impact assessments and the use of limit reference points. An abstract of both presentations is provided in Appendix X.

11.2 Bigeye Management: Discussion

It was noted that MSY estimates from MULTIFAN-CL for the WCPO were nearly halved due to the impact that the purse seine fishery has had on the stock, particularly as a result of large numbers of small fish taken on FADs.

On the subject of the use of MSY, It was noted that the WCPFC has agreed to a limit reference point equal to a depletion of 20 percent of unexploited spawning biomass for bigeye, which to some degree implies a move away from traditional MSY-based management. In setting these limit reference points, the objective is to avoid these whenever possible.

Incentive-based initiatives for adoption and support of management measures by industry were discussed, such as higher price/mt for free-school "FAD-free" skipjack. This approach has been pursued by the Parties to the Nauru Agreement (PNA) through MSC certification. However, it was noted that the cost and complexity of supporting the chain of custody system has discouraged participation.

It was noted that the Commission has formerly implemented some spatial management of the fishery with closure of some enclosed international waters and also temporal FAD closures throughout the fishery. These were acknowledged but still deemed to be inadequate to effectively address bigeye overfishing.

The area of the central equatorial Pacific that straddles the WCPFC/IATTC boundary was noted as a potentially useful area to consider in respect to spatial management. This was in reference to gradients in purse seine and longline CPUE for bigeye put forward in the presentation on WCPO fisheries indicating both higher abundance and catchability of bigeye tuna in the central Pacific. It was also noted that the IATTC tagging presentation on tagging programs in the eastern and central Pacific suggested that bigeye tagged in this area (155°W, 5°S – 5°N) were observed to demonstrate higher site fidelity compared to other regions investigated in the same study. It was suggested that if spatial management were to be seriously considered, then all these issues should be considered and compared.

Further discussion explored the possibility of and potential implications of areas where adult bigeye are not currently exploited but may exist, such as areas south of 10°S in the western Pacific where longline effort for bigeye is currently absent. If such areas have significant bigeye resources, it would mean that the fishery was not exploiting the full range of the stock as is currently assumed. This could have positive implications on stock resiliency. Biomass "sink" areas have been hypothesized to serve in this manner.

An example of the opposite situation was noted in the central equatorial Pacific, which is characterized as having high CPUE of bigeye tuna by both purse seine and longline fisheries. This area was formerly fished only by longline gear, but large purse seiners using drifting FADs now harvest all three tropical tuna species with a high proportion of bigeye in the catch. This area straddles the border between the WCPFC and IATTC. The idea of spatial management in both Commission areas was raised, thus sharing the conservation burden.

Another suggestion noted that it might become necessary to combine and harmonize policies between Commissions to deal with Central Pacific management issues. This would also serve to spread the management burden between the Commissions and align conservation measures. In association the potential for a Pacific-wide bigeye stock assessment to be undertaken by staff of the SPC OFP and IATTC in 2015 was raised.

12 DATA GAPS, RESEARCH NEEDS and NEW TECHNOLOGY

12.1 Life history and biology

1. Maturity schedules using histological methods.
2. There is insufficient spatial coverage and estimates of bigeye maturity schedules across the Pacific. Spatial variability in length and age at maturity throughout spawning distributions is required.
3. *Note critical gap in data and sampling from Central equatorial Pacific region
4. Growth rate variability of BET throughout Pacific basin.
5. Identification of spawning hotspots.
6. Regional size dependent batch fecundity studies using comparable methods, i.e. migratory nucleus and hydrated oocyte method.
7. Clarification on relationships between lengths and ages at maturity.
8. Information on seasonality of spawning in areas higher than 15° north and south of the equator.
9. Life history parameters of bigeye in sub-tropical and temperate latitudes.
10. Need to understand the origin of large fish within regions. Funding to process and analyze gonad and otolith samples collected by SPC for WCPFC Bigeye Study.

12.2 Fisheries synopsis

1. Need finer scale (spatial and operational data) for management driven research.
2. FAD information

   a) FAD types and deployment dates and locations by vessel per trip.

   b) FAD trajectories from satellite buoy data.

   c) Finer scale operational data related to floating object sets and ability to track individual FADs.

   d) More detailed information on FAD attributes.

   e) Potential use of trajectories and FAD buoy echo sounder information for research.

12.3 Stock structure and assessment

1. Further development of alternative stock reference points for management other than MSY.
2. Further development of stock assessment models that treat populations more as a continuum with spatial variability rather than a mosaic with defined boundaries.

    a) How to set up spatial structure in a broad population to accommodate regional differences and characteristics (biology, growth rates, rates of exchange).

3. Further development of population models that are better adapted to biological and environmental factors.

    a) Identify characteristics that influence movement.

4. Develop improved area based policies.

12.4 Tagging studies and movement

1. General data gaps:

    a) Size range of fish released too restricted to small sizes in some areas, gear selectivity issues.

    b) Low return rates from longline gear is a significant data gap.

    c) Need to broaden spatial scope of releases.

    d) Need to tag fish at high latitudes.

    e) Need to broaden size range of tag releases, particularly the 75 – 105 cm class.

    f) Investigate question whether some bigeye are naturally resident while others are movers.

    g) Concerns over tag reporting by longline fleets. Significant problem with purse seine transshipments or vessels that transfer catch between wells with confidence in tag recovery information.

    h) Need fishery independent means to obtain information from areas where conventional tagging is difficult (due to difficulty in release and low probability of recapture).

    i) General Recommendations:

    - Conduct a Pacific-wide integrated analysis of bigeye archival and conventional tagging data
    - Deploying research drifting FADs for tagging and then dispersing aggregation post-tagging.
    - Need to develop new tags and tools to examine movement and motivations for movement.
    - Need to examine bigeye behavior regionally and examine regional influences to movement and behavior.
    - Need to incorporate the influence of size and maturity on movement in studies (appropriate for model development).

- Studies on the influences on the early life history of bigeye (larval and small juvenile) similar to those conducted at the IATTC Achotines Lab on yellowfin.

2. Eastern and Central Pacific Ocean

   a) Need broader spatial and temporal deployments of plastic dart and archival tags.

3. Western Equatorial Pacific Ocean

   a) Need to broaden spatial range of bigeye tag releases across Pacific and in other areas that are regionally important.

4. Western Coral Sea

   a) Need to understand what drives movement and influences a fish to move or stay.

   - Note: need to be sure the technology applied will address the question at hand.
   - Influence of release location on perceived movement
   - Note: If you want to know where your fish come from you should not tag fish where you are.

5. Japan

   a) Need to understand connectivity of east coast of Japan to larger biomass to the south.

   - Tagging of fish to the south of Japan near Philippines.

   b) Need to understand connectivity or link between Japan and Hawai‘i and examine the role of the Kuroshio Current.

   - Use of Fukushima radioactive signal.
   - Possible collaboration with JAMARC charted tagging vessel for EPO.

6. Hawai‘i

   a) Need to understand connectivity of Hawai‘i in all directions, notably to northwest (Japan), north and northeast to longline grounds and south.

   b) Develop tagging, bio sampling and otolith chemistry work in area between Japan and Hawai‘i and north of Hawai‘i to understand connectivity.

   c) Collaborate with longline vessel associations to tag larger bigeye at high latitude areas with popup satellite tags.

7. New Technology: development and use of more fishery independent means of gaining movement data.

   a) Single-point pop up tags

b) Otolith chemistry

c) Genetic tagging

d) Remote sensing, investigation of sea surface height anomalies and bigeye abundance

12.5 Otolith stable isotope and micro-constituent analyses

1. Need to obtain bigeye otolith samples from critical areas not yet sampled by previous study.

    a) Area just south of Hawai‘i EEZ to Johnston Atoll.

    b) Area northwest of Hawai‘i between toward Japan, i.e. Emperor Seamounts and into the Kuroshio system.

    c) Areas north and northeast of Hawai‘i at high latitude where Hawai‘i longline fishery operates.

2. Need to obtain YOY Yellowfin otolith samples from EPO and western Pacific areas and areas just south of Hawai‘i.

3. Need to establish baseline sampling of Age 0 fish and analysis for more areas of the WCPO to build baselines.

4. Need to examine size/age specific movement patterns. Small bigeye move into the Hawaiian Islands from somewhere. Large fish move north of Hawai‘i where they are fished by the longline fleets.

5. Expand scope of methodology, not just expanding regional examinations. Note: think about how the technology can be used in a broader geographic scope and the design of a study that can provide information to MFCL.

6. Comparison of archival tag data and otolith transecting.

    a) Consider collecting otoliths from archival tag recaptures with considerable TAL, whether they move or not.

    - Note: CSIRO has large hard parts collection from bigeye and other tuna species, including from tag recaptures.

    b) Collect otoliths from very large/old bigeye.

7. Coupling otolith microchemistry with genetic studies.

8. Recommendations

    a) Utilize drifting FADs to aggregate Age 0 and Age 1 bigeye in areas where they are otherwise unavailable.

    b) Collect otolith samples from fish landed at the United Fishing Agency in Hawai‘i.

12.6 Fishery and climate mediated changes in distribution

1. Need access to basin scale high res standardized, validated georeferenced fishing data by fishery with corresponding size frequency data.

   a) Publish this data for accessibility by scientific community.

2. Need collection of acoustic survey data using a standardized methodology for micronekton models.
3. Information on larval density, ground truth with research cruises to validate model of spawning grounds.
4. Estimations of mean linear speed by fish size.
5. Access to archival geo-location tag data from other researchers to improve and inform models.
6. Need larval bigeye data in a more accessible format than Nishikawa map plots.
7. Influence of temperature on growth rates.
8. Collection of muscle tissue in conjunction with Fukushima nuclear disaster to investigate connectivity issues between Japan and other regions.
9. Expand empirical database on blood chemistry and oxygen tolerance of bigeye of different sizes and their prey.
10. Continue to develop predictive ability of model to look at where recruitment is coming from for a particular region.
11. Recommendations:

    a) Need basin scale analysis of vertical and horizontal behavior of bigeye.

    b) Conduct research cruises to validate SEAPODYM bigeye model.

12.7 Genetic studies

1. Validation of SNP species ID markers for other tuna species.
2. Need to find out who is doing similar work to promote collaboration to build more robust genome maps.
3. Need broader sampling coverage for finer scale resolution of structure and to further test method.
4. Need to get management agencies interested with proof of concept to attract external funding for further development.
5. Need to streamline:

   a) Tissue sample acquisition

b) DNA extraction (sub-sampling tissues in lab)

c) DNA profiling

12.8 Bigeye management

1. Data gap suggested as lack of imagination as to what can be done with novel modeling approaches and how they can inform management.
2. Recommendations:

- Further work on impact assessment analyses and development of limit reference points rather than management by MSY.
- Explore the use of spatial management solutions or a mixture of different management policies (closed zones, transfer of effort to free school, temporal gear type bans) in different areas, termed zoning.
- If spatial management is to be considered, avoid political or profit drivers. Evaluate geographic areas on all relevant biotic and fishery criteria, i.e. oceanography, productivity, spawning habitat, abundance, catchability and availability of size classes of bigeye to fishery.
- Use behavior, movement and other information to inform stock assessment models and model regions.

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Appendix 1 Meeting agenda

WESTERN
PACIFIC
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FISHERY
MANAGEMENT
COUNCIL

Workshop on Pacific Bigeye Movement and Distribution

April 22-24, 2014, 8:30 a.m. - 5:00 p.m.

8:30 a.m. – 5:00 p.m. Tuesday, April 22, 2014

13. Introduction	Kitty Symonds
14. Workshop structure, objectives and outputs	Paul Dalzell / David Itano
15. Life history and biology (9:00 a.m. – 10:00 a.m.)	Kurt Schaefer / Simon Nicol
Tea Break 10:00 – 10:30 a.m.)	
16. Fisheries synopsis (10:30 a.m. – 12:00 noon)	
A. Eastern Pacific Ocean	Kurt Schaefer
B. WCPO equatorial	John Hampton
C. Hawaii	Keith Bigelow
Lunch Break (12:00 a.m. – 1:30 p.m.)	
17. Stock structure and assessment: current assumptions and hypotheses (1:30 – 2:30 p.m.)	Pierre Kleiber
18. Tagging studies: conventional, acoustic, archival (2:30 – 5:30 p.m.) *(Presenters will be allotted 45 minutes—30 minutes presentation/15 minutes discussion—in this session. There will be no formal tea break except for a 10 minute bathroom break at about 4:00 p.m.)*	
A. Eastern and Central Pacific Ocean	Kurt Schaefer
B. Western Equatorial Pacific Ocean	John Hampton / Simon Nicol
C. Coral Sea	Karen Evans / Rob Campbell
D. Japanese studies	Takayuki Matsumoto
E. Hawaiian studies	Kim Holland / David Itano

8:30 a.m. – 5:00 p.m. Wednesday, April 23, 2014

19. Otolith stable isotope and micro-constituent analyses (8:30 a.m. – 9:30 a.m.) Jay Rooker / David Wells

20. Fishery and climate mediated changes in distribution (9:30 a.m. – 10:30 a.m.) Patrick Lehodey / Inna Senina

Tea Break (10:30 a.m. – 11:00 a.m.)

21. Genetic studies (11:00 a.m. -12:00 noon) Peter Grewe

22. Inputs and implications for Bigeye management (12:00 noon – 1:00 p.m.) John Sibert / Paul Dalzell

Lunch Break (1:00 p.m – 2:00 p.m)

23. Research plan development **All Participants**

- A. **Review of previous workshops and relevant studies**
- B. **State of knowledge of bigeye tuna**
- C. **Major needs, data gaps and new technology**
- D. **Objectives and final product**

8:30 a.m. Thursday, April 23, 2014

11. Research plan development (continued)

- E. **Recap of discussions**
- F. **General methodology to achieve objectives**
- G. **Identification of funding levels and potential sources**
- H. **Identification of collaborations and assignments to achieve Objectives**
- I. **Meeting Summary**

PAU

Appendix 2 Participants list

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Appendix 3 Life History and Biology (Abstracts)

Spatial variability in estimates of reproductive biology, length at age, and growth of bigeye in the Pacific Ocean.

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The peer-reviewed and grey literature was reviewed to evaluate the existing evidence for spatial variability in bigeye life history in the Pacific Ocean. Our findings are:

- Although there have been several studies on bigeye life history, most have been location specific and/or applied methods that are considered inappropriate.
- The EPO study (Schaefer et al., 2005) is the only study that has used reliable methods with an adequate sample size to estimate maturity schedules. In the WCPO, a larger number of studies have occurred, however either the methods or the sample sizes limit their conclusions. Notwithstanding these limitations a comparison between studies indicates variability in the estimated L_{50} for females with longitude with female bigeye on average maturing at greater lengths in the EPO. All studies estimated the length at first maturity for bigeye to be around 100 cm.
- Spawning is reported to occur throughout the tropical Pacific Ocean (15°N – 15°S), during most months of the year, where SSTs are 24C or higher. In subtropical regions, spawning has been reported to be seasonally restricted. Larvae are reported to occur over a large latitudinal range in the Western Pacific from southern Japan to the northern Coral Sea (Nishikawa et al., 1985).
- Only two studies (Nikaido et al. 1991; Schaefer et al., 2005) have applied appropriate methods to estimate fecundity. There is a large discrepancy in the estimates of bigeye relative batch fecundity between those studies and those from Yuen (1955) and Sun et al. (1999). The study in the EPO by Schaefer et al. (2005) indicated that the average female spawned every 2.6 d, and reproductively active females spawned every 1.3 d.
- Estimates of growth rates using length at age estimates from sagittal otoliths and from stock assessment models indicate apparent differences in growth rates, both longitudinal and latitudinal in the Pacific Ocean.
- If the variability observed in these life history parameters is not due to sampling and/or method biases, then these comparisons provide some support for hypotheses of bigeye stock structure in the Pacific Ocean.

Appendix 4 Fisheries synopsis (abstracts)

A. Eastern Pacific Ocean

Summary of the Eastern Pacific Ocean Bigeye Tuna Fishery and Assessment

Staff of the Inter-American Tropical Tuna Commission, La Jolla, California, USA

The fishing capacity of the purse-seine fleet fishing in the eastern Pacific Ocean (EPO) increased rapidly during 1995 to 2005, but has been fairly steady since about 2006, slightly above 200,000 cubic meters of well volume. The reported nominal longline effort has fluctuated between about 300 and 100 million hooks set annually over the past thirty years. Since the highest peak in 2002-2003 of about 300 million hooks there was a distinct decline to about 100 million hooks, but in recent years has increased to about 150 million hooks.

There have been substantial historical changes in the bigeye fishery in the EPO. Beginning in 1994 purse-seine catches increased substantially from targeting tunas associated with drifting fish-aggregating devices (FADs) in the equatorial EPO, between about 10°N and 15°S. The 2012 purse-seine catch distributions were very similar to the average annual distribution of catches during 2007 to 2011. The 2012 catches of 69,000 mt were 3,000 mt higher than the average for the previous 5 years, a 4% increase. Longline catches have been relatively low during the past 7 years, versus the previous 23-year period, and the estimated longline catch in 2012 of only about 19,500 tons is the lowest on record in the past 30 years.

The current stock assessment method being used for bigeye is STOCK SYNTHESIS III. A full assessment was conducted in 2013, which included some major changes in methodology to the previous full assessment, including a new growth model. Recruitment estimates have been variable since 1975. Recent estimates indicate that the bigeye stock in the EPO is not overexploited (S>Smsy), and that overfishing is not taking place (F<Fmsy). The current status of the stock is considerably more pessimistic if a stock recruitment relationship is assumed, if a higher value is assumed for the average size of the older fish, and if lower rates of natural mortality are assumed for adults.

A tuna conservation resolution was adopted by the IATTC in June 2013, for the three-year period (2014-2016), extending the previous resolution, which expired at the end of 2013. This includes an EPO wide closure for purse-seine (>182 mt) fishing of 62 d in each of those years, along with a 30 d closure of a core offshore FAD fishing area. There is a special provision for class 4 vessels (182-272 mt) which permits 30 days of fishing during the EPO closure provided an observer is aboard. For longline vessels (>24 m) the resolution includes fixed bigeye catch limits for China, Japan, Korea, and Chinese Taipei, and other CPCs not to exceed 500 t or their respective catches in 2001, whichever is greater.

B. WCPO equatorial

Bigeye Tuna Fisheries in the Tropical Western and Central Pacific (with some Pacific-wide observations)

John Hampton, SPC Oceanic Fisheries Programme, Noumea, New Caledonia

Bigeye tuna catch in the WCPO is concentrated in equatorial waters, 10°N - 10°S. The WCPO catch is currently approximately 160,000 mt per year, approximately 120,000 mt of which is taken in the equatorial zone. The WCPO longline catch peaked at about 90,000 mt, but has now declined to 60,000 – 70,000 mt in recent years. Approximately 60-70% of the WCPO longline catch of bigeye is taken in the equatorial zone. CPUE has declined in both the equatorial and North Pacific regions since 2000. Seasonally, CPUE is fairly stable in the equatorial zone, but in the North Pacific is low in the summer and highest during winter. There is a very strong increase in CPUE from west to east in the equatorial zone, which continues into the eastern tropical Pacific. This and other spatial patterns in longline CPUE are evident in 1x1 degree plots, highlighting the value of such high resolution fisheries data in interpreting stock structure and distribution. The purse seine catch in the WCPO is almost entirely taken in the equatorial zone, and is dominated (90%) by sets on floating objects, particularly fish aggregation devices (FADs). The total catch by purse seine has varied between 40,000 and 70,000 mt since the late 1990s. Purse seine CPUE has shown different trends west (declining in recent years) and east (increasing) of 180°, the latter being due to the arrival of large, efficient Spanish and Latin American purse seiners in this region. Like longline, purse seine CPUE also increases strongly from west to east. The key observations from the fisheries are:

- Bigeye catch is concentrated in equatorial zone for both purse seine and longline;
- There are very strong west to east increases in bigeye CPUE for both purse seine and longline that likely indicate both higher abundance and catchability of bigeye tuna as the depth of the mixed layer becomes shallower across the equatorial Pacific;
- The seasonal CPUE patterns in the North Pacific and equatorial zone are fairly independent; and
- Spatial longline CPUE patterns are suggestive of discontinuities in distribution at around 10^0N and the Equator.

C. Hawaii

Keith Bigelow, NMFS Pacific Islands Fisheries Science Center, Honolulu, Hawaii

United States longline fisheries in the Pacific Ocean primarily operate from Hawaii. During 2013, 135 vessels were active in the Hawaii-based fleet with participation in the fishery being nearly constant over the past ten years. Longline fishers made 1,379 longline trips in 2013, including 1,328 using deep-set gear to target tuna and 51 using shallow-set gear to target swordfish. The Hawaii-based longline fishery deployed a record 47.9 million hooks in 2013. A growing proportion of hooks are being set outside the U.S. Exclusive Economic Zone (EEZ) — 70% of the total hooks set in 2013. The remainder were deployed in the main Hawaiian Islands EEZ (20%), Northwestern Hawaiian Islands EEZ (7%), or in the EEZ of the Pacific Remote Island Areas (PRIA, consisting of U.S. possessions Wake Island, Jarvis Island, Howland Island, Baker Island, Kingman Reef, Palmyra Atoll, and Johnston Atoll) (3%). In 2013, the Hawaii-based longline fleet caught a record 192,806 bigeye tuna. The trend of bigeye tuna catch has been generally upward since the first year of logbook monitoring in 1991. The Hawaii-based longline fleet operates in both the Western and Central Pacific Commission Area (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). Approximately 85% and 15% of bigeye tuna is captured by the Hawaii-based fleet in the WCPFC and IATTC, respectively.

Appendix 5 Stock structure and assessment: current assumptions and hypotheses (abstracts)

Musings on Stock Structure and Stock Assessment Models: Can we get the stock out of the box?

Pierre Kleiber, NMFS Pacific Islands Fisheries Science Center (retired)

Harkening back a few decades, stock structure of tunas was thought to consist of geographically separated, self-reproducing populations. Western Pacific skipjack, for example were thought to be a separate subpopulation bounded on the east by "Fujino's (1972) line". The evidence for this was based on expression of mitochondrial genes. Subsequent genetic sampling showed a gradient in gene frequencies rather than a sharp demarcation, suggesting a population structure in which fish are more or less related to each other depending on the distance separating them – the so called "isolation by distance" notion. More modern genetic work confirms a population structure consisting of a genetic continuum rather than a mosaic with definite boundaries.

Stock assessment models deal with an abstraction called a "stock" that is not necessarily equivalent to the population. This is an entity in the model that can wax and wane according to various rules built into the model. Individual fish in the stock are implicitly identical to each other. In fact individual fish don't really exist in the model except insofar as abundance might be measured in integers. The more sophisticated stock assessment models might carry more than one sub-stock, as in different age cohorts connected by reproduction and growth, or as in more than one geographic box connected by movement across boundaries. But these models are only an approximation to a continuum. The stock defined in them is boxed into one, or a few, geographic regions. However, because the stock is a specific entity in the model, stock - wide quantities of management interest, such as MSY, are readily determined. Thus such boxed - in concepts of a stock lend themselves to management regimes where the boxes can be adapted to practical and political considerations perhaps at the expense of biological considerations.

There are other population models, such as SEAPODYM, that can be better adapted to the biological reality of a continuum. Though the output from such models does not necessarily slot directly into current management concepts, it might pay to imagine out-of-the-box population structures and associated models that could lend themselves to out-of-the-box concepts for managing the productive capacity of pelagic fishes.

A. Eastern and Central Pacific Ocean

Movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus*) tagged and released in the equatorial Eastern and Central Pacific Ocean, with conventional and archival tags

Kurt Schaefer[1], Daniel Fuller[1], John Hampton[2], Sylvain Caillot[2], Bruno Leroy[2], David Itano[2, 3]

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Bigeye tagging experiments conducted in the eastern and central Pacific Ocean, were successful in releasing 49,941 fish with plastic dart tags (PDTs), and 772 fish with archival tags (ATs). PDT and AT returns are about 43% and 50%, respectively, for fish released near the 95°W, and 32% and 16.3%, respectively, for fish released between the 140°W and 180°. The median and 95% of the days at liberty were 146 and 549 d, respectively, for fish released near the 95°W, and 164 and 515 d, respectively, for fish released between the 140°W and 180°. The median and 95% of the linear displacements, from release to recapture positions, for fish at liberty for ≥ 30 d, were 259 and 1,016 nmi, respectively, for fish released near the 95°W, and 1,013 and 3,677 nmi, respectively, for fish released between the 140°W and 180°. 99.4% of those linear displacements were confined to between 10°N and 10°S. The linear displacements were predominantly westward (80.4%), from releases near the 95°W, and predominantly eastward (71%), for fish released between the 140°W and 180°. The data indicate significant differences in the linear displacements by release locations, days at liberty, and fish length at release.

Analyses of AT data, utilizing the unscented Kaman filter model with sea-surface temperature measurements integrated (UKFsst), enabled the reconstruction of most probable tracks (MPTs) of individual fish, estimation of 95% volume contours for all positions along MPTs by release longitudes, and estimation of movement parameters by release longitudes. Considerable variation was observed in movement patterns, obtained from AT data, among individuals from within release longitudes, and among individuals from between release longitudes. The movement patterns for the releases along the 155°W illustrate fairly strong regional fidelity to release location, but those for the releases along the 140°W and 170°W, illustrate less regional fidelity, but, more so, extensive eastward movements. In comparison, for releases at 95°W, the predominant movement patterns indicate strong regional fidelity to release location, with restricted westward movements.

These analyses of PDT and AT data suggest that 3 putative stocks (eastern, central, and western) occur across the equatorial Pacific Ocean, between 10°N and 10°S, with stock boundaries at about 120°W and 180°.

B. Bigeye Tuna Tagging in the Western and Central Pacific Ocean

John Hampton, SPC Oceanic Fisheries Programme, Noumea, New Caledonia

SPC has conducted three major tagging programmes in the WCPO, the Skipjack Survey and Assessment Programme in the late 1970s, during which few bigeye were tagged and no recoveries recorded; the Regional Tuna Tagging Project (RTTP) in the early 1990s, during which approximately 8,000 bigeye were released and approximately 12% recovered; and the Pacific Tuna Tagging Programme (PTTP), which is ongoing since 2006, tagging approximately 45,000 bigeye and with a recovery rate approaching 30%. For the PTTP, most bigeye tagging has occurred in the central Pacific, east of 180°. Bigeye tagged west and east of 180° show quite different patterns of time-at-liberty (higher attrition in the west) and displacement (more longer-distance displacements in the central Pacific). During the RTTP, bigeye were tagged mainly in the northwestern Coral Sea off Australia, in the Philippines and in the equatorial western Pacific. The Coral Sea releases are quite unique, with a significant number of very long-term recoveries (as long as 11 years), with approximately 80% of recoveries, many longer than five and some greater than ten years at liberty, being recorded by the small Australian longline fishery operating in the release area. However, a considerable number of fish also exhibited long-distance movement, some as far as the central Pacific. By contrast, recoveries of the Philippines releases occurred mainly within one year at liberty and mostly in the Philippines. The equatorial releases displayed longer-distance displacements over several years. Comparing across data sets, the PTTP Central Pacific releases showed the greatest median (approximately 800 nmi) and 95 percentile (approximately 3,000 nmi) displacements, followed by the RTTP and PTTP western equatorial releases. The Coral Sea and Philippines releases had median displacements of less than 100 nmi suggestive of greater site fidelity in these regions.

C. Connectivity of bigeye tuna throughout the Coral Sea region

Karen Evans[1], Robert Campbell[2], Toby Patterson[1], Uffe Hogsbro Thygesen[3], Rich Hillary[1], Jessica Farley[1], Craig Proctor[1].

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Commercial fishing for tunas and billfish in the waters of the Coral Sea commenced in 1952 when Japanese longliners first fished in the region. Commercial fishing expanded to include purse-seining and pole-and-line operations in the late 1960s and early 1970s. Over the past decade, catches of bigeye tuna by all fleets fishing in the region comprised ~1.5% of the total catch of bigeye tuna in the Western and Central Pacific Ocean. Catches taken within Australian waters of the Coral Sea across the Eastern Tuna and Billfish Fishery (ETBF) comprise around 7 % of total Coral Sea catches.

Bigeye tuna occurring within the ETBF are currently considered to form part of a wider western and central Pacific Ocean stock, with the Australian fishery considered to occur on the margins of the large equatorial Pacific fishery. Domestic harvest strategies for Commonwealth fisheries, including the ETBF, aim to provide a means by which assessments of target species can be produced and a Recommended Biological Commercial Catch (RBCC) determined from which total allowable commercial catches are set. Harvest strategies for highly migratory/straddling or joint authority fisheries stocks like bigeye tuna however are highly sensitive to a number of factors, including assumptions of connectivity. Implementing domestic harvest strategies that are complimentary to regional management measures are complicated as a result.

Fishery catch data, differences in age and growth of individuals and movements of individuals determined from tagging data raise some questions as to the origin of recruits caught in the ETBF and the degree of connectivity of fish in the Coral Sea with neighboring regions. Here, we detail current understanding of the movements, distributions, behavior and connectivity of bigeye tuna in the western Coral Sea region from fishery catch, tagging, age, growth and maturity data. We identify some of the current issues associated with connectivity understanding and research required to address these. Additionally, we discuss some regional efforts to improve current understanding of bigeye tuna throughout the Coral Sea and neighboring regions.

D. Movement and distribution of bigeye tuna in the Pacific Ocean based on Japanese tagging project

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Large scale bigeye tuna tagging was conducted by Japanese government in two tagging projects during 2000s. Tagging was conducted in the Nansei Islands area (southwestern part of Japan) and offshore central part of Japan, and the fish for tagging were mainly caught by pole-and-line, handline and troll. A total of 4,453 bigeye tuna were released that include 211 fish with archival tag, of which 465 fish (10.4 %) were recaptured including 35 fish with archival tag (a total of 2,890 days of data).

Many of the fish released at Nansei Islands area moved northeastward suggesting the relationship with Kuroshio Current, and the fish released at offshore central part of Japan moved to various directions. Difference of the movement among individuals was also seen. In most cases strong site fidelity was observed. More dispersion was observed for larger fish. Some seasonality of the movement was observed. There seems to be almost no relationship between movement or distribution and topography.

E. Hawaiian studies: Aggregative and Vertical Behavior of Bigeye Tuna

Kim Holland[1] and David Itano[2]
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Bigeye tuna behavior is strongly influenced by both natural and anthropogenic structure. Natural structures include seamounts and floating debris such as logs or dead whales. Anthropogenic structure includes floating debris and fish aggregating devices (FADs) - both drifting and anchored. These structures "hold" aggregations of both juvenile and adult bigeye although juvenile life stages appear to be particularly strongly influenced by floating objects. Tagging studies (both "spaghetti" and electronic – archival and acoustic) indicate that bigeye tuna can have 'residence' times at seamounts ranging from a few weeks to several months. There is also evidence that a proportion of these fish make long duration excursions – using the seamount as 'home base'. Stomach content analyses indicate that bigeye tuna gain a feeding advantage from associating with seamounts by exploiting deep scattering layer organisms (DSL) that become 'trapped' over the seamount summit. They appear to also gain a feeding advantage when associated with anchored FADs that are located far from shore but not when associated with near shore FADs. This may be related to the depths in which different FADs are anchored.

Tracking studies have revealed that bigeye tuna are capable of expanding their foraging range to include deep cold water where they can exploit DSL organisms in the daytime phase of their distribution. This foraging strategy is enabled by an ability to combine physiological and behavioral thermoregulation, which takes the form of periodic upward excursions into the surface mixed layer to warm up. Comparison of bigeye daytime depths in different parts of the ocean indicates that bigeye foraging depths are influenced by the warmth of the surface layer – warmer surface temperatures facilitate deeper daytime foraging excursions. Bigeye vertical distribution is radically influenced by floating objects – they abandon their typical daytime deep distribution and spend all of their time in the surface mixed layer. This shallow distribution when associated with FADs makes them more vulnerable to fishing gear – whether hook and line or purse seine. The distinctive daytime deep diving behavior of bigeye strongly influences which types of long line fishing gear are used in industrial fisheries.

The remarkable thermoregulatory ability of bigeye tuna also allows them to inhabit cool waters at the edges of their otherwise tropical core range. The cooler parts of their range are important parts of the commercial longline fishery and yet very little is known about bigeye behavior in these cooler regions - or where they go to when it is time for spawning behavior (which is thought to occur in tropical regions). This lack of information about movements in the higher latitude parts of their range, combined with low tag return rates from these areas, indicates that electronic tagging technologies (e.g., "electronic spaghetti tags") would be the appropriate strategy for advancing our knowledge of distribution and behaviors in these areas.

Appendix 7 Otolith stable isotope and micro-constituent analyses (abstracts)

Significance of local production and transboundary movements of bigeye tuna

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Defining the origin and stock structure of tropical tunas in the western and central Pacific Ocean (WCPO) is critical for their management, and here we examine movements and population connectivity of bigeye tuna (*Thunnus obesus*) in this region using chemical tags (stable isotopes and trace elements) in otoliths. Our approach is based on the premise that stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) and trace elements (Ba, Li, Mg, Mn, Sr) in otolith core material of bigeye are reflective of water masses occupied during early life stages, and therefore can be used to predict the nursery origin of individuals. Chemical signatures of age-0 BET from regional nurseries in the WCPO (far west equatorial, west equatorial, central equatorial, and Hawaii) were first examined and used to establish baseline or reference signatures for each region. Efforts focused on developing our baseline using otolith $\delta^{18}O$ and $\delta^{13}C$, and significant regional differences were detected with more depleted $\delta^{18}O$ values present for age-0 bigeye from far west equatorial (Philippines) and west equatorial (Marshall Islands, Solomon Islands) regions of the WCPO. Classification success of age-0 bigeye to the four regions was modest (60%) due to overlap in the otolith $\delta^{18}O$ values of individuals from the central equatorial and Hawaiian Islands, and improved markedly (79% to 91%) when samples from these two regions were combined, suggesting some degree of connectivity between Hawaii and central equatorial areas to the south of Hawaii. Trace elements in otoliths were also quantified in a limited number of individuals and certain elements (Mg, Mn, Ba) showed promise for distinguishing age-0 bigeye between regional nurseries, albeit overall classification success was lower than observed for otolith stable isotope. The nursery origin of age-1 to age-2+ bigeye collected in the Marshall Islands and the Hawaiian Islands was determined using otolith $\delta^{18}O$ and $\delta^{13}C$ values from age-0 bigeye collected in 2008 as our baseline. Mixed-stock analysis indicated that 100% of the age-1 to 2+ bigeye collected in the Marshall Islands originated from this nursery, highlighting the importance of local production for this region. For the Hawaiian Islands, the majority of the age-1 to age-2+ bigeye in our sample were of central equatorial origin (65%), with a smaller percentage matching the Hawaiian Islands signature (35%); no contribution from equatorial regions to the west were detected in the Hawaiian Islands sample.

Appendix 8 Fishery and climate mediated changes in distribution (abstracts)

Fishery and climate mediated changes in distribution of Pacific Bigeye tuna

P. Lehodey and I. Senina,
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The spatial ecosystems and population dynamics model (SEAPODYM) is used with a Pacific basin scale definition of fisheries to compute spatially explicit estimates of Pacific bigeye density by life stage, under the combined effects of climate-driven environmental variability and strong fishing pressure. The model with its recent new developments is presented. Limitations in both driving datasets, i.e. fishing data and environmental variables are discussed. The model optimization procedure is based on a Maximum Likelihood approach that can include catch or CPUE and size frequencies distributions of catch at different resolution, and also since recent development conventional tagging data. Results achieved using different model configurations in spatial resolution, source of environmental variables and combination of fishing data and tagging data are presented. The presentation will conclude with the preliminary results on the ongoing work to couple this model to a physical operational circulation model and a high-resolution regional model.

Appendix 9 Genetics studies (abstracts)

Bigeye Tuna – Genetics Perspective and Future Directions
Peter Grewe, CSIRO Marine and Atmospheric Research, Hobart, Australia

The Southern Bluefin Tuna (SBT) has been a test-bed for tuna genetic studies by CSIRO and its collaborators. A principal question that can be investigated by genetic sampling is where were fish born, and how many stocks of a particular tuna species are there in the ocean? With respect to bigeye tuna, there was a period of well-coordinated sampling between 1995 and 1998 in the Atlantic, Indian and Pacific Oceans. The analysis of samples used the most up-to-date technology, i.e. DNA microsatellites and mitochondrial DNA (mtDNA). This work did not demonstrate any stock structure but neither did it confirm a single gene pool. Yellowfin tuna was examined in the Pacific and again no stock structure was detected. It was concluded that migration was leading to homogenization of gene frequencies but the results cannot state that the populations are a single stock. Further, the populations are so big that mutation and differentiation are cancelling each other out.

A new approach was needed. A new statistical method was developed that required genetic techniques to underpin paternity analysis of southern bluefin tuna to estimate spawning stock biomass. This technique was originally developed for whale population estimates and is a gene-tagging mark-recapture technique where a juvenile carries two tags, one from each of its parents. This led to the SBT Close Kin Genetics project, which was successful and demonstrated proof of concept. This has led us to further develop general techniques for exploring applications in the other tuna species.

CSIRO is combining novel statistical approaches with the rapid advances being made in genetics, particularly in the area of genomics and next generation sequencing technology. This has opened up the use of genomics to underpin data acquisition to address fishery management questions. The use of fishery independent DNA markers or tags for species and stock identification was demonstrated with work on captive SBT. Results for yellowfin tuna are very positive, indicating population structure is present both within and between Indian and Pacific Oceans. This work is currently being prepared for publication. Results for bigeye tuna also show some structure in Pacific and Indian Oceans, though this is not as obvious as yellowfin tuna. The results are very preliminary at this stage and require a more sophisticated analysis. An important outcome of this work is that gene tagging could replace conventional tagging as the collection of genetic data becomes more economically competitive.

History of managing Pacific bigeye tuna

Paul Dalzell, Western Pacific Regional Fishery Management Council, Honolulu, Hawaii

Tuna fisheries in the Pacific Ocean are subject to conservation measures promulgated by to tuna regional fishery management organizations (tRFMOs), the Western and Central Pacific Fishery Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC). The IATTC has been developing resolutions for tuna management in the Eastern Pacific Ocean (EPO) since the late 1980s, with the most recent developed in 2013. The WCPFC is a newer tRFMO and has been developing conservation and management measures (CMMs) for tunas since 2005, with the most recent CMM also in 2013. The main focus of resolutions and CMMs developed by IATTC and WCPFC are the catches of bigeye tuna, which are about twice the maximum sustainable yield for this species. Bigeye has traditionally been one of the principle targets of longline fisheries but for the past three decades has been caught in equal or greater numbers by purse seine vessels operating around tethered and untethered fish aggregating devices (FADs). Bigeye catches continue to increase in the Western and Central Pacific Ocean (WCPO), driven largely by purse seining, while longline catches have declined. A wholesale decline of longline fishing in the EPO has occurred due to fleets from Japan and Chinese Taipei fishing well below their allocated limits as their fishing effort in the EPO has declined. In recent years, the Hawaii longline fishery has become increasingly active in the EPO, with one third of its 2013 annual catch coming from this area of the Pacific Ocean.

Bigeye Management: Developing Alternative Conservation and Management Measures

John Sibert, Joint Institute for Marine and Atmospheric Research, Honolulu, Hawaii

I present some of the milestones that lead to establishment of conservation and management measures adopted by the Western Pacific Fishery Commission and discuss how these measures relate to advice offered in scientific fora. The scientific advice, although well intended and soundly based in science, lacked practical insights that managers might have used to concoct alternate measures. I conclude by offering two examples of alternative ecosystem approaches to reducing catch.