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Nursery Origin of Yellowfin Tuna in the Hawaiian Islands

R.J. David Wells, Jay R. Rooker, and David G. Itano

Introduction

The existence of "resident" (locally produced) versus "transient" (arriving from distant areas) populations of yellowfin tuna (*‘ahi*) has been a contentious subject for Pacific Island nations since the beginning of industrialized fishing in the region. Conflict and management uncertainty result with distant-water or larger-scale fisheries claiming to target broadly mixed stocks while local fisheries are left to contemplate the possibility of reduced recruitment or local depletion of yellowfin tuna resources that may be more efficiently managed at sub-regional scales.

This is true in Hawai‘i where catch rates for nearshore troll and handline fisheries for yellowfin tuna have declined while offshore handline and longline fisheries and distant-water purse-seine fleets have developed and expanded. Data from large-scale tagging experiments have been incorporated into a complex, multi-fishery, length-based, spatial model that is used to manage the tuna resources of the western and central Pacific Ocean (WCPO). The model inputs assume that a significant proportion of the yellowfin tuna harvested by Hawai‘i-based fisheries originates from neighboring regions (Hampton and Fournier 2001). However the current model being used for stock assessment of the species primarily applies to the area in the core of the WCPO equatorial purse-seine fishery where the bulk of the biomass is harvested and where most of the tag-and-release data has been generated. The relative degree of local recruitment, residency, and movement of yellowfin tuna in Hawaiian waters remains unknown.

Resolving the issues of local recruitment and evaluating exchange rates of yellowfin tuna in Hawaiian waters and within the areas of the broader WCPO requires corroborative data from a variety of approaches including genetics, tagging, and other natural markers such as chemical signatures in the hard parts (e.g., otoliths, or "ear stones") of the fish. Recent studies using the chemical signatures in otoliths have shown that these natural markers can be of significant use in evaluating the origin and movement of tunas within the Pacific Ocean (Rooker et al. 2001, Wang et al. 2009, Shiao et al. 2010; Figure 1).

Figure 1. (left to right) Pepe Conley (boat captain) and authors Jay Rooker and David Itano with yellowfin tuna captured on the east coast of Kaua‘i and sampled for the study. (Photo: R.J. David Wells)

Principal assumptions underlying this approach are that otoliths continuously accrete material as a fish grows and that the chemical composition of these otoliths is related to the chemistry of the water mass inhabited. Therefore material deposited in an otolith during the first weeks-to-months of life can serve as a natural tag of an individual's place of origin. Previous studies have demonstrated that stable isotope ratios of carbon ($^{13}C/^{12}C$) and oxygen ($^{18}O/^{16}O$; hereafter carbon and oxygen) in otolith cores can be used to determine the origin of tropical and temperate tunas (Gunn and Ward 1994, Rooker et al. 2008). Such data may prove useful for determining contribution rates of yellowfin tuna

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recruits from different nursery areas throughout the WCPO.

The goal of this Pelagic Fisheries Research Program-funded project was to determine, using stable isotopes of carbon and oxygen in the otoliths, the nursery origin of sub-adult (1–2 year-old) yellowfin tuna collected in nearshore and offshore waters of the Hawaiian Islands. Of specific interest was determining whether the sub-adult yellowfin tuna that are targeted by domestic fisheries were derived locally or from distant nurseries in the equatorial Pacific.

Initially, spatial and temporal variability in stable carbon and oxygen isotopes in the otoliths of young-of-the-year (YOY; <1 year old) yellowfin tuna from Hawai‘i and different nurseries throughout the WCPO were assessed to develop baseline signatures for determining the nursery origin of larger yellowfin tuna. In the following year sub-adult (1–2 year-old) yellowfin tuna from the nearshore nursery and an offshore nursery within the Hawai‘i exclusive economic zone (EEZ) were targeted. Nursery origins of sub-adults were determined by examining stable isotope values in the otolith cores of these individuals. These cores represented material deposited during the first few months of their lives.

Methods

Using previous Pacific Ocean otolith-based ageing studies, yellowfin tuna ranging in size from 21–59 cm fork length (FL; the measured length from the tip of the snout to the fork of the tail) and 60–100 cm FL were classified as YOY and sub-adults, respectively.

YOY yellowfin tuna were collected from six nurseries in the WCPO: 1) the nearshore nursery (ca. ≤ 30 km from land) of the main Hawaiian Islands (i.e., coastal waters of Kaua‘i, Maui, O‘ahu, and the island of Hawai‘i), 2) an offshore nursery in the Hawai‘i EEZ (i.e., Cross Seamount, 300 km southwest of the main Hawaiian Islands), 3) the Line Islands of Kiribati, 4) the Marshall Islands, 5) the Solomon Islands, and 6) the southern Philippines (Figure 2). YOY yellowfin tuna were collected over a two-year period (late 2007 to early 2008 and late 2008 to early 2009; hereafter 2008 and 2009, respectively) using either hook-and-line or purse-seine gear.

Within each nursery, sub-samples from multiple collection locations and times were analyzed to ensure that otolith chemical signatures were representative of each. Sub-adult yellowfin tuna

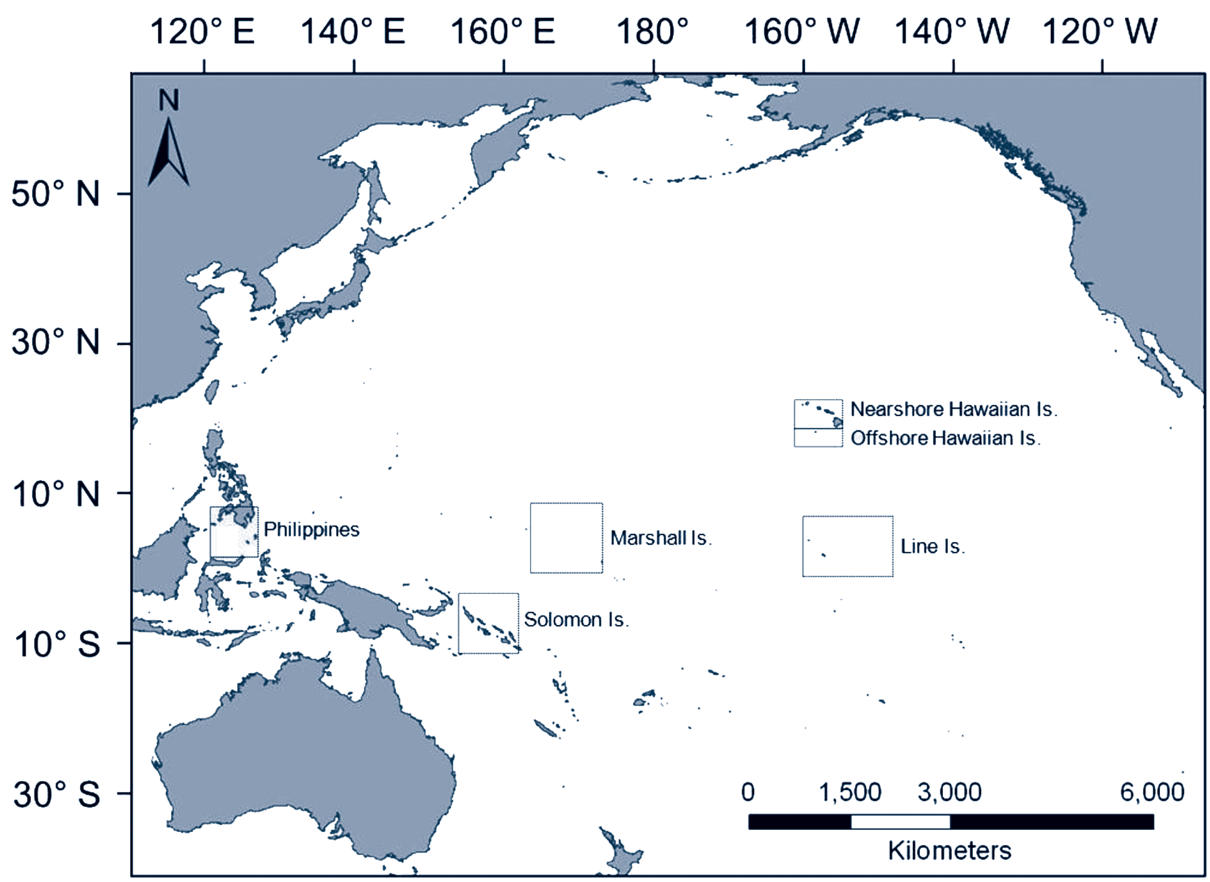

Figure 2. Locations of the six nurseries sampled in the western and central Pacific Ocean (WCPO). Nurseries include: 1) the nearshore nursery (ca. ≤30 km from land) of the main Hawaiian Islands (i.e., coastal waters of Kaua‘i, Maui, O‘ahu, and the island of Hawai‘i), 2) an offshore nursery in the Hawai‘i EEZ (i.e., Cross Seamount, 300 km southwest of the main Hawaiian Islands), 3) the Line Islands of Kiribati, 4) the Marshall Islands, 5) the Solomon Islands, and 6) the southern Philippines.

corresponding to the same year-class and cohort sampled in 2008 were collected in 2009 at nearshore sampling locations and in 2010 at the Cross Seamount nursery in the Hawai'i EEZ to investigate nursery-specific contribution rates. Similar to YOY fish, sub-adults were collected over a range of dates from the coastal areas of Kaua'i, Maui, O'ahu, and the island of Hawai'i.

Otoliths were embedded in Struers epoxy resin (Epofix™) and cut transversely to obtain 1.5 mm thin sections that included the core. The portion of the otolith core corresponding to approximately two months of age was milled with the resulting powdered material analyzed for stable carbon and oxygen isotopes.

Results and Conclusions

Stable carbon and oxygen isotope values from otolith cores of YOY yellowfin tuna differed significantly among nurseries while showing consistent trends during both years of sampling (Figure 3). Stable carbon isotope values in the otoliths of YOY fish were enriched for individuals collected from the Marshall Islands with mean values significantly enriched relative to other nurseries. The most enriched stable oxygen isotope values were observed for YOY yellowfin tuna from the nearshore main Hawaiian Island nursery with values decreasing from east to west across the locations sampled.

Stable carbon and oxygen isotopes in the otoliths of YOY yellowfin tuna proved useful in discriminating individuals from the six nurseries throughout the WCPO. Classification of individuals to specific nurseries was derived from differences in stable oxygen isotopes, which were linked to regional differences in seawater oxygen values. Patterns of stable isotope oxygen values in otoliths found in this study matched the decreasing seawater oxygen values from central to western study areas (Schmidt et al. 1999). Moreover, decreasing seawater and otolith oxygen were also observed north to south with surface seawater from the main Hawaiian Island nursery enriched relative to the central equatorial sampling sites at similar longitudes (Schmidt et al. 1999).

Otolith carbon and oxygen values of sub-adult yellowfin tuna (n=100) collected from the nearshore areas of the main Hawaiian Islands were compared to the YOY baseline samples collected during the previous year (age-class matching) to estimate their nursery origin. Results indicated that 91% of sub-adults in samples from the nearshore main Hawaiian Islands originated from the same nearshore nursery (Figure 4a), suggestive of local production and retention. Minor contributions were observed from the two closest nurseries south of the main Hawaiian Islands: the Line Islands (7%) and the Cross Seamount (2%), with no contribution from other investigated nurseries.

Nursery origin of sub-adult yellowfin tuna was also estimated for samples (n=25) collected from the Cross Seamount using otolith carbon and oxygen. Little-to-no contribution (<1%) from the Cross Seamount nursery was observed. Sub-adult recruits to the Cross Seamount nursery were primarily derived from the nearshore main Hawaiian Islands (90%) with the remaining contribution from the Line Islands (9%; Figure 4b).

Estimates of nursery origin using stable isotopes of carbon and oxygen in otoliths indicated that sub-adult yellowfin tuna collected in the areas close to the main Hawaiian Islands appear

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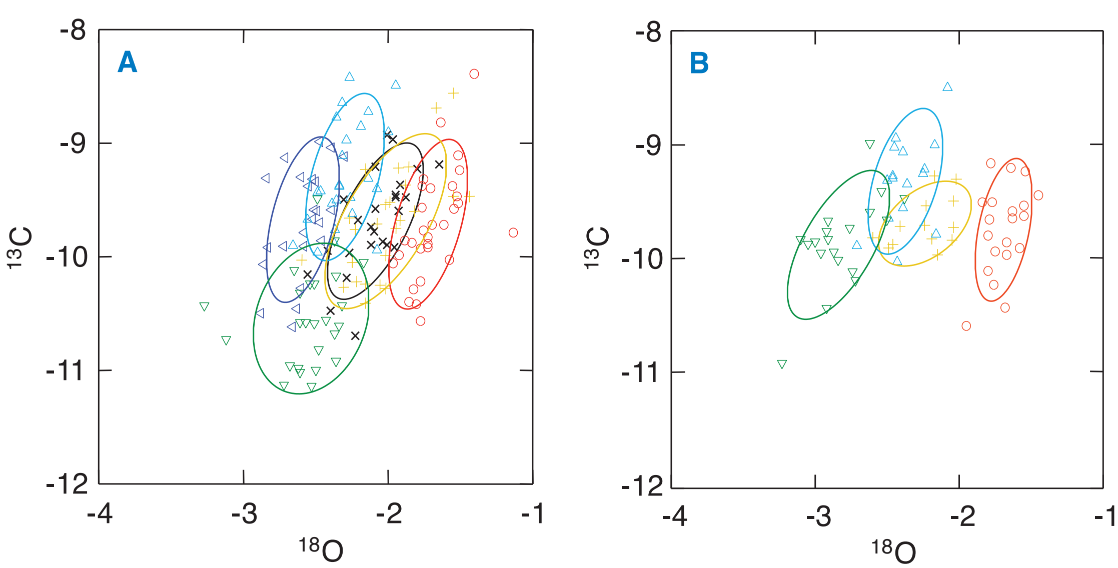

Figure 3. Otolith core carbon and oxygen of YOY (<1 year old) yellowfin tuna collected among nursery areas in 2008 (A) and 2009 (B). Confidence ellipses represent 1 standard deviation (SD) around the mean. Nurseries include 1) the nearshore nursery (ca. ≤30 km from land) of the main Hawaiian Islands (i.e., coastal waters of Kaua'i, Maui, O'ahu, and the island of Hawai'i; circles), 2) an offshore nursery in the Hawai'i EEZ (i.e., Cross Seamount, 300 km southwest of the main Hawaiian Islands; crosses), 3) the Line Islands of Kiribati (pluses), 4) the Marshall Islands (upright triangles), 5) the Solomon Islands (sideways triangles), and 6) the southern Philippines (upside-down triangles).

Nursery (continued from page 3)

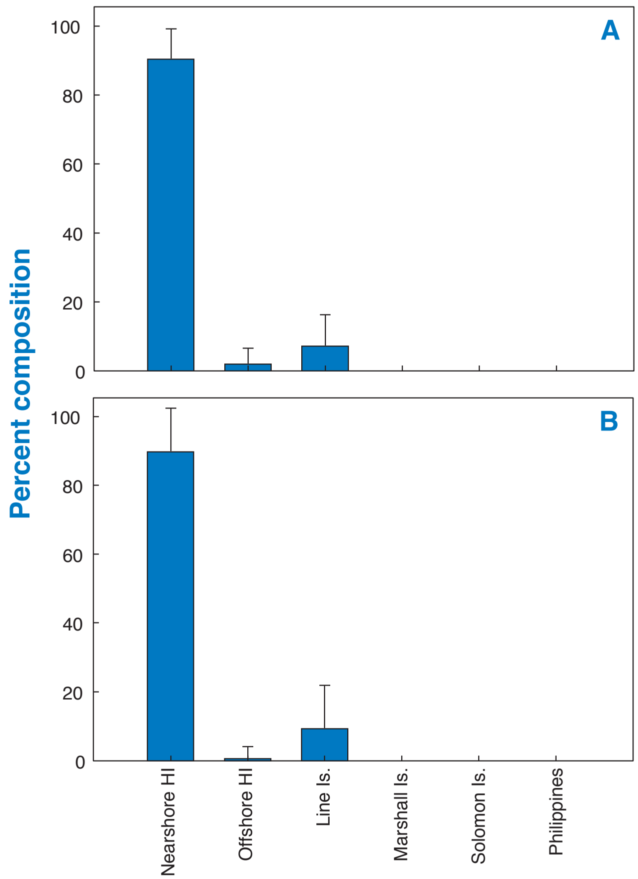

Figure 4. Nursery-specific contribution estimates (percent composition) of sub-adult yellowfin tuna collected from A) the nearshore nursery (ca. ≤30 km from land) of the main Hawaiian Islands (i.e., coastal waters of Kaua'i, Maui, O'ahu, and the island of Hawai'i) and B) an offshore nursery in the Hawai'i EEZ (i.e., Cross Seamount, 300 km southwest of the main Hawaiian Islands). Results were derived from mixed-stock analysis using baseline samples collected in 2008.

to be a product of local production with the majority of recruits originating from the nearshore waters of Hawai'i with minor contributions from nurseries directly south of Hawai'i.

These findings are in accord with earlier tagging studies that have demonstrated retention of yellowfin tuna tagged within the main Hawaiian Islands inclusive of the Cross Seamount (Holland et al. 1990, Itano and Holland 2000, Dagorn et al. 2007). Several studies have suggested that limited movement of tropical tunas is linked to the aggregative influence of natural bathymetric features (e.g., reef ledges or seamounts), nearshore fish aggregation devices (FADs), high biological productivity, and prey availability found around oceanic archipelagos such as the Hawaiian Islands (Holland et al. 1990, Kleiber and Hampton 1994, Brill et al. 1999, Itano and Holland 2000, Dagorn et al. 2007). Although otolith chemistry and tagging results support the importance of local production and retention of yellowfin tuna to the nearshore fisheries of Hawai'i, both also indicate the potential for lower levels of contribution from adjacent nurseries to the south.

Sub-adult yellowfin tuna collected in the areas close to the main Hawaiian Islands had minor contribution estimates from the Cross Seamount (2%) and the Line Islands (7%), approximately 300 and 1,000 km south, respectively. Sub-adult yellowfin tuna sampled from the Cross Seamount nursery appear to have originated primarily from the nearshore Hawaiian Islands. Nearshore to offshore movement of yellowfin tuna in the Hawaiian Islands has been documented with fish tagged nearshore to the main Hawaiian Islands later recaptured south at the Cross Seamount (Adam et al. 2003). Sibert et al. (2000) estimated that emigration accounted for 86% of yellowfin tuna losses from the Cross Seamount and postulated that yellowfin tuna recruit to this area from unknown sources, remain several days-to-weeks, and then leave. Findings from this study suggest the unknown source is primarily the main Hawaiian Islands, albeit such recruits may represent a transient population that visits the Cross Seamount area for short periods of time before moving to other locations (Holland et al. 1999).

In summary, these findings highlight the importance of local production and retention of yellowfin tuna to the nearshore and offshore areas and fisheries of the Hawai'i EEZ.

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UPCOMING EVENTS

Pelagic Fisheries Research Program, Principal Investigators Meeting

15–16 December 2011, Honolulu, Hawaiʻi, USA
http://www.soest.hawaii.edu/PFRP/

TOS/ASLO/AGU 2012 Ocean Sciences Meeting

20–24 February 2012, Salt Lake City, Utah, USA
Special sessions on "Early Life History" (CLIOTOP Working Group 1) and "Influences of Environmental Variability on Top Predator Distribution, Abundance, and Behavior" (CLIOTOP Working Group 2).
http://www.sgmeet.com/osm2012/

Planet Under Pressure: New Knowledge Towards Solutions

26–29 March 2012, London, England, UK
Special session on "Global Science for Governance of Oceanic Ecosystems and Fisheries" (IMBER-CLIOTOP).
http://www.planetunderpressure2012.net/session_maury.asp

Western Pacific Regional Fishery Management Council

19–21 March 2012, 109th SSC Meeting
26–30March 2012, 153rd Council Meeting
http://wpcouncil.org/meetings/

World Fisheries Congress

7–11 May 2012, Edinburgh, Scotland, UK
Edinburgh International Conference Centre
http://www.6thwfc2012.com/

Effect of Climate Change on the World's Oceans (IMBER)

15–19 May 2012, Yeosu, Republic of Korea
http://www.pices.int/meetings/international_symposia/2012/Yeosu/scope.aspx

Tuna Conference

21–24 May 2012, Lake Arrowhead, California, USA
http://www.tunaconference.org/

American Fisheries Society

19–23 August 2012, Minneapolis-Saint Paul, Minnesota, USA
http://www.afs2012.org/

Nursery (continued from page 5)

Wang, C.H., Y.T. Lin, J.C. Shiao, C.F. You, and W.N. Tzeng. 2009. Spatio-temporal variation in the elemental compositions of otoliths of southern bluefin tuna (*Thunnus maccoyii*) in the Indian Ocean and its ecological implication. *J. Fish Biol.* 75:1173–93.

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TUMAS: A Tool to Allow Analysis of Management Options using WCPFC Stock Assessments

Simon D. Hoyle, Fabrice Bouyé, and Shelton J. Harley

Introduction—Background to the Western and Central Pacific Tuna Fisheries

The tuna stocks in the western and central Pacific Ocean (WCPO) are the largest in the world, supporting annual catches of over two million metric tons since 2004 and providing around sixty percent of total world tuna catches (Williams and Terawasi 2010). These fisheries are managed under the Western and Central Pacific Fisheries Commission (WCPFC) with twenty-six members, seven participating territories, and nine cooperating non-members.[1] The membership comprises some of the world's largest countries but also some of the world's poorest countries. A unique feature of the tuna fisheries in the WCPO (compared to tuna fisheries in other ocean regions) is that a large proportion of catch is taken from within the two hundred mile exclusive economic zone (EEZ) boundaries surrounding various Pacific Island countries. Revenues gained from fees and taxes on activities related to tuna fishing can be a large proportion of total government revenues for some of these countries (Anon. 2011).

The four main tuna stocks considered by the WCPFC (South Pacific albacore—*Thunnus alalunga*, bigeye—*T. obesus*, skipjack—*Katsuwonus pelamis*, and yellowfin—*T. albacares*) are all estimated to be above the biomass level required to support the currently agreed-upon maximum allowable catch (Harley et al. 2011). Nevertheless, increasing catches and high level of fishing mortality on bigeye tuna and yellowfin tuna (in the western equatorial region) have led the WCPFC to introduce conservation and management measures (CMMs) with aims of reducing bigeye and not increasing yellowfin fishing mortality levels.

The assessments for these stocks are undertaken by the Secretariat of the Pacific Community—Oceanic Fisheries Programme (SPC-OFP) under a service agreement with the WCPFC. These assessments are some of the largest and most complex undertaken for any fishery stocks in the world—with the stock-assessment model incorporating large-scale movements within the waters of the WCPO, the characteristics of the many different fleets and fishing methods that are in operation, and the history of regional fishing dating back to the early 1950s. These assessments are undertaken using the stock-assessment package MULTIFAN-CL (Hampton and Fournier 2001), a package specifically developed in the context of Pacific tuna fisheries to incorporate the key dynamics of the stocks and the fisheries that operate in these waters.

In addition to the stock assessments, SPC-OFP has been increasingly called upon to undertake other analyses to help inform the WCPFC's development of CMMs, in particular undertaking "projections" whereby the abundance of stocks in the future is predicted for different management options (typically levels of catch or effort for fleets; OFP 2011). The results from these analyses are also provided in electronic form to all WCPFC participants.

Increased Transparency and Information for Fishery Managers

The software used to undertake these assessments—including the input data and output files—is publicly available to ensure transparency in the stock assessment process.[2] Theoretically, any person can use these files to replicate both the SPC-OFP assessments and the projection analyses that are conducted. In practice, however, MULTIFAN-CL presents a very steep learning curve and is used regularly by only a small handful of stock-assessment scientists worldwide.

So, although there is an institutional emphasis on transparency, it is also fair to ask whether decision makers from small, developing, island states are being provided appropriate information to confidently select management measures that will significantly affect the revenue available for their countries. On the same basis, can decision makers from those countries with economically significant distant-water fleets confidently estimate the likely impact of proposed measures on their industries?

Our experience working both within national fisheries administrations and within regional fisheries-management organizations

[1] www.wcpfc.int

[2] http://www.spc.int/oceanfish/en/ofpsection/sam/sam

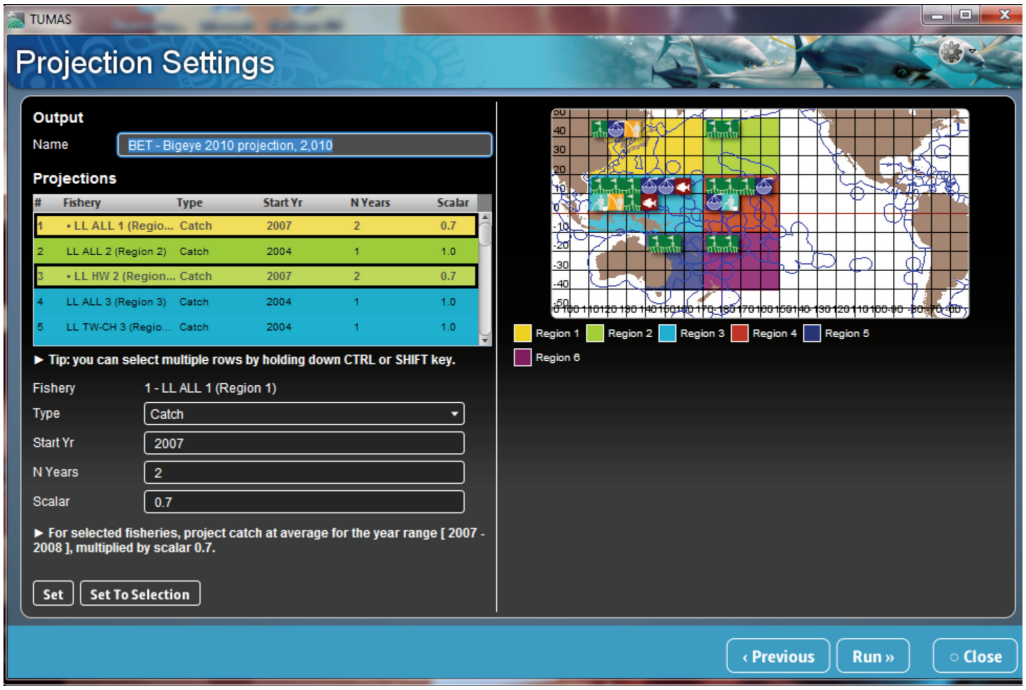

Figure 1.

such as the WCPFC, Inter-American Tropical Tuna Commission, and the Commission for the Conservation of Southern Bluefin Tuna, is that informed managers are more able to negotiate (with either industry representatives or other countries) when they have a more complete understanding of the science and potential implications of future management measures.

These concerns motivated a funding proposal to the Pelagic Fisheries Research Program (PFRP)[3] to develop a simple, user-friendly, interface allowing individuals to examine the results of fishery-stock assessments and analyze potential management options of particular interest to them. The new interface would not require knowledge or understanding of MULTIFAN-CL or any of the related programming packages. PFRP was able to provide partial funding supporting two years of development of the interface that became identified as TUMAS—the TUna MAnagement Simulator.[4]

The remainder of this paper first briefly describes the population/fisheries dynamics underlying MULTIFAN-CL, in particular the assumptions made in the projection analyses, before addressing the current features of TUMAS. A description of TUMAS, how it was developed, the software tools used, and other information of interest mostly to software developers follows. The approaches taken to testing TUMAS and the survey-based approach proposed to evaluate the success of TUMAS in leading to better-informed decision makers are detailed. Finally there is a discussion of proposed additional development to be undertaken with the existing PFRP funding, closing with a consideration of additional possibilities for the interface if further funding can be obtained.

All of this activity is taking place during a year when the WCPFC is seeking to renegotiate a revised CMM which will cover the three tropical tunas (bigeye, skipjack, and yellowfin)—a time when broad access to improved information will be critical.

TUMAS—the TUna MAnagement Simulator Stock Assessment and Projection Methodology

The underlying foundation of TUMAS is the stock assessment software MULTIFAN-CL, an age-structured statistical catch-at-length model capable of modeling movement between regions, characterizing the practices of various fishing fleets, and integrating mark-recapture data from large-scale tagging programs (Hampton and Fournier 2001). Recent and future proposed developments of the MULTIFAN-CL software can be found in papers produced annually for the WCPFC Scientific Committee (e.g., Hoyle et al. 2009, Davies et al. 2010). In recent years there has been a particular focus on MULTIFAN-CL development to increase the flexibility to examine the often-complex management measures most of interest to WCPFC members.

In the simplest terms, all that is really needed for a projection in MULTIFAN-CL is the stock assessment used to determine current stock status and a time series of either catch or effort for each fishery for some specified time into the future. As some fisheries are currently managed on output controls (e.g., catch limits) and others on input controls (e.g., effort limits and time/area closures),

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[3] http://www.soest.hawaii.edu/PFRP/
[4] http://www.tumas-project.org/

it is important to allow a fishery to be projected on either catch or effort. However it is not possible to have a mix of catch and effort measurements for a single future projection of a fishery.

There are two projection types currently implemented in MULTIFAN-CL: 1) deterministic projections and 2) stochastic projections. Only deterministic projections are implemented in TUMAS as stochastic projections are too computationally intensive to incorporate at present.

Under deterministic projections the population is projected forward from the state (i.e., numbers at age and, if appropriate, by region) at the end of the estimation model. It is assumed that fishery parameters such as selectivity and catchability (efficiency) remain constant into the future as do the key biological parameters of growth and natural mortality.

Possibly the most important assumption in any fisheries projection analysis is the likely level of recruitment of young fish into the fishery. Within MULTIFAN-CL there are two options: 1) that future recruitment will follow the prediction from the spawner-recruitment curve; or 2) that recruitment will remain at the average level previously estimated for some defined period within the estimation model.

To run projections in MULTIFAN-CL one needs to manipulate both the data input file to incorporate future catch or effort levels and the parameter file instructing MULTIFAN-CL when to start, how many years to project forward, and whether fisheries are projected in catch or effort. This second manipulation is more difficult than it may initially appear given the difficulty of manipulating complex file structures containing estimates for thousands of parameters. When the file parameters are established the MULTIFAN-CL program is run from either a DOS command line or from within LINUX and the results are viewed by running a set of purpose-built functions in R, the statistical software.

The TUMAS interface now incorporates all of the steps noted above. This saves the user from the need to access huge files and eliminates any requirement for the user to be able to manipulate complex software.

TUMAS Options and Functionality

The basic options and structure of TUMAS are briefly described below and Figures 1–3 provide a range of screenshots. The TUMAS user manual provides more detailed descriptions.[5]

TUMAS is designed to work by simply defining the parameters for a deterministic projection of a WCPFC stock-assessment model and then reviewing the results of that projection as a series of graphics.

Step 1: Setting up the projection

- Identify the species and the model (typically the base or a reference-case model)
- Select a future recruitment level:
  - the long-term average from the spawner-recruitment relationship; or
  - the recent average [default setting is "the past ten years"]
- Define the length of the projection [default setting is ten years]
- Choose whether or not to project forward the biomass estimated to occur in the absence of fishing. Choosing to project the biomass increases computation time by around thirty percent but does provide important information about the non-equilibrium conditions that exist if one projects with recent average recruitment rather than the long-term spawner-recruitment relationship levels.

Step 2: Setting up the fisheries-management scenario

- In MULTIFAN-CL fisheries are defined by characterizing a specific method of fishing in a particular region. When different fleets use similar fishing methods they can either be combined or, if they have different effects on the stock (e.g., they catch different-sized fish), split into separate fisheries. There are currently three parameters identified to define a fishery projection:
  - Catch or effort: it is possible to project forward a fishery based on either catch or effort. Typically catch is projected for longline fisheries and effort is projected for other fisheries.
  - Baseline levels: baseline levels of catch or effort are defined by the first year and the number of years over which the average is calculated. E.g., settings of 2004 and 3 would generate a baseline as the average for the period 2004–2006.
  - Scalar: this is the multiplier of the baseline level of effort. A value of 1 projects catch or effort at the baseline level.
- After the scenario has been defined it is then run using TUMAS to implement MULTIFAN-CL. TUMAS scripts convert the options entered using the TUMAS graphical interface into MULTIFAN-CL input files and command-line options and then execute MULTIFAN-CL. Projections take less than one minute to run on a relatively sophisticated computer with 4GB of random-access memory.

Step 3: Viewing the results

- Upon completion of the projection TUMAS displays results as series of graphics including the projected catches, catch rates, biomass, and fishing mortality (including comparing these indicators to the "Maximum Sustainable Yield" levels).
- Graphics may be exported as ".png" or ".pdf" formats or the data generating the graphics may be exported as an MS Excel file.

TUMAS, it should be noted, is designed only to provide management-option projection analyses for existing stock assessments. Users who want to run new stock assessments must use MULTIFAN-CL directly—TUMAS is not intended to be used for this purpose.

TUMAS Software Development

TUMAS uses a combination of Java and JavaFX Script code. As a more modern, "Rich Internet Application" type, web-enabled, software was originally desired, various other solutions (including "C# and Silverlight" and "Flash and ActionScript") were initially investigated.

[5] http://www.tumas-project.org/documents/TUMAS%20user%20 Manual.pdf

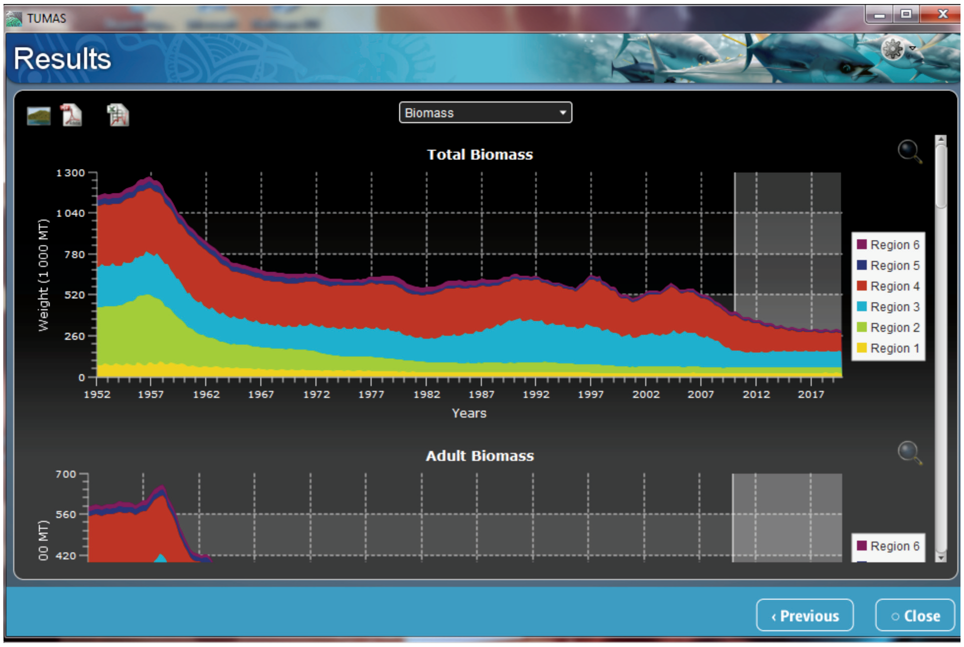

Figure 2.

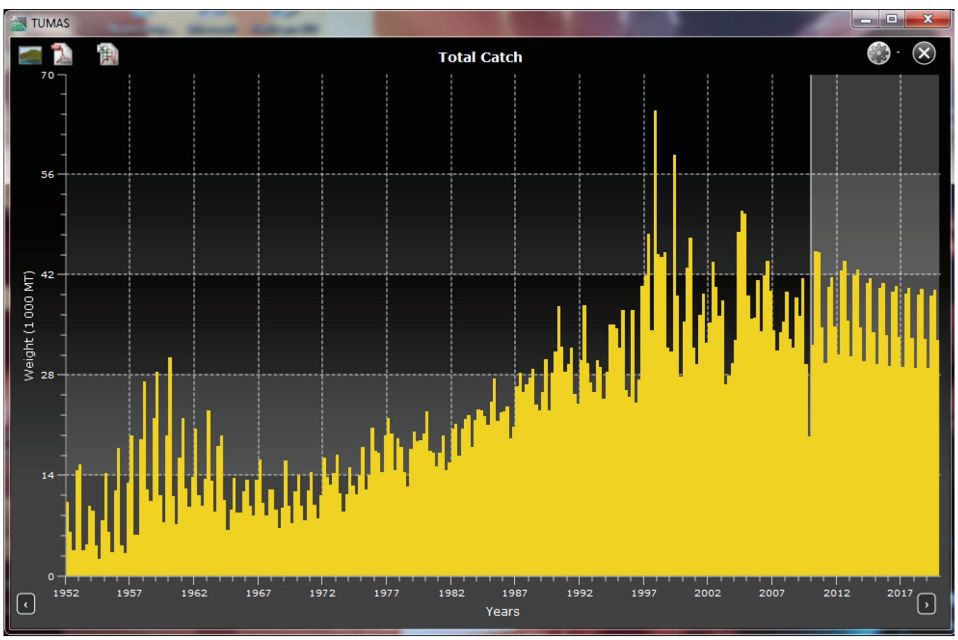

Figure 3.

After review, however, Java was selected to capitalize on existing Java input/output (I/O) code for reading and for writing MULTIFAN-CL output files developed for MULTIFAN-CL Viewer and other projects. Java allows the flexibility, without requiring extensive code rewriting, to provide TUMAS for the various platforms to which MULTIFAN-CL has previously been ported. In the current version of TUMAS the I/O operations and task-scheduling layers are written in Java while the graphical-user interface (GUI), charting, and launch scripts are written in JavaFX Script. The MULTIFAN-CL version provided is a native-executable (from

(continued on page 10)

C++ code) program that is the same program currently used for stock assessments.

Preplanning and prototyping lasted from the winter of 2009 to March 2010 and involved discussions concerning the feasibility of the projection algorithm, data packaging, and distribution as well as early discussions about the graphical interface. TUMAS comprises such independent entities as the GUI, a setup manager (which runs on the initial launch and then only during software updates), a CD-ROM installer, a scenario editor, a launch script (which runs multiple checks on the operating system), and other utilities.

Several programming challenges arose during the primary development, largely from the fact that the JavaFX API code and the JavaFX Script language were both then still in development at Sun (now Oracle). E.g., the release of JavaFX 1.3 led, in late August 2010, to substantial changes and simplifications in development of the TUMAS GUI.

Porting the projection algorithm from R to Java was, by and large, straightforward. Most of the existing MUTIFAN-CL–related code was ported from Java 4 to Java 6 (and 7) without difficulty. However significant care was required in the management of the various MULTIFAN-CL child processes needing to be spawned as external processes as well as in the ".frq" and ".par" file-reconstruction tasks required for a single simulation. Particular attention was also given to the file-decompression and packaging routines as well as the backup of the temporary-execution directory so as to be able to analyze and correct program crashes. Efforts continue toward optimizing the parameters and memory configuration fed to MULTIFAN-CL to try to minimize the memory requirements of the model (particularly to improve program performance on memory-limited computers).

Online installation and updates were elements of the original design of TUMAS. Unfortunately Java Web Start, the current distribution method, has proven to not be consistently reliable. The project has recently acquired a "digital certificate" that is expected to improve communications management between the software developers and the users.

Direct web-download of the program is now possible from the project website (http://www.tumas-project.org/). Updates will initially be distributed in new versions of TUMAS but later software versions will permit automatic web-based updates of the assessments from within TUMAS. Future plans include web-based support, a more detailed and comprehensive user manual, additional news feeds, release notes, and other communications. Further changes, optimizations, and bug repairs will be accomplished by upgrading to JavaFX 2.0 API and rewriting part of the existing JavaFX Script code into Java or another programming language supported by the Java Virtual Machine, if the project continues.

Testing of TUMAS

Software testing is an important aspect of all software development and, in the case of TUMAS testing, has been critical for addressing several issues:

1) Does the software actually work as intended—i.e., are their bugs?
2) Does the software provide the features required by the target audience?
3) Can the software functionally run on the computing resources available to the target audience?
4) Can the software be downloaded and updated with the levels of bandwidth available to the target audience?

TUMAS developers have addressed these concerns using multiple approaches. As an initial test of the project concept, early versions of TUMAS were demonstrated to fishery managers at several meetings including:

- Forum Fisheries Committee Management Options Consultation (November 2010)
- 31st Special Meeting of the Parties to the Nauru Agreement (November 2010)
- SPC Heads of Fisheries meeting (February 2011)
- SPC Pre-assessment workshop (April 2011)
- Forum Fisheries Committee Management Options Workshop (May 2011)

Substantive testing began when TUMAS was first supplied to users during the PRFP Principal Investigators meeting in December 2010.

In July 2011 TUMAS was the focus of a Stock Assessment Workshop (SAW) run by SPC. Over a period of three days eighteen fisheries officials, representing the governments of seventeen WCPFC member countries and territories, used TUMAS to evaluate management options formulated to achieve pre-specified objectives while, at the same time, examining the potential impact of these management options on their own fisheries. None of these officials had previous hands-on computing experience with MULTIFAN-CL. While they identified program bugs and suggested additional features, the officials were unanimously excited by the access to information provided by TUMAS.

Following the SAW testing the primary issue became reducing the computer-memory demand of TUMAS so that it would function on memory-limited computers. To address problems identified in the testing, a range of approaches to reduce the computational demands has been examined. The TUMAS version released after SAW now requires fifty percent less memory and has moderately reduced processing time. More significant improvements may be expected in the future to improve computing speeds when using the program on memory-limited computers.

The largest annual gathering of WCPFC member scientists is the Scientific Committee meeting which runs for ten days each August. The August 2011 meeting included a special session introducing TUMAS to the broader WCPFC membership.[6] At that time WCPFC membership was provided the most-current TUMAS

[6] http://www.wcpfc.int/doc/wcpfc-sc7-2011-13/provisional-agenda-tutorial-session-tumas

version and the templates to use the 2011 stock assessments (completed only days earlier).

This meeting not only generated further testing of TUMAS, it represented a significant step in assessing the true utility of TUMAS software in the WCPFC decision-making process. Follow up will be after the December 2011 WCPF Commission annual session. All participants from the SAW and the WCPFC Scientific Committee special TUMAS session will be contacted to see how useful TUMAS was in their preparation for, and negotiations at, the annual meeting. Of greatest interest will be responses from the participants who used TUMAS in one of the introductory sessions, particularly those who then later used TUMAS simulations to examine the results of differing management options to inform their country's negotiating positions.

The post-annual-session follow up will provide the final opportunity within the PFRP-funded project implementation to secure feedback and, potentially, implement minor improvements in the software.

TUMAS—Continuing Improvements

Continuing TUMAS development is currently funded by PFRP through early 2012. Working with this funding and the general support of the SPC membership, the following three program improvements are planned:

- *Time/area closures for purse-seine fishing effort:* In recent years time/area closures have been an important element of conservation and management measures used within the WCPO. A planned program improvement to TUMAS will provide an ability to examine the impact of seasonal closures of general areas within the equatorial region. Users will be able to input and then study the results of potential closures for designated regions and seasons. This feature will be effective for studying the management of the three tropical tuna species.
- *South Pacific albacore:* This species is of critical importance to many countries and territories in the South Pacific. Stock assessments of this species address both a large number of defined fisheries, to account for seasonal selectivity differences, and the modeling of the troll fishery in different time increments than those used by the longline fishery. Another planned program improvement, requiring modification to the algorithms currently used by TUMAS and MULTIFAN-CL, will address these parameters; and
- *Summaries of the size composition of projected catches:* For many species the value of the catch differs significantly depending on the size of the individual fish within the catch. MULTIFAN-CL currently predicts catch-at-age for each fishery in the projection period. The final currently planned improvement will seek to summarize this into broader categories to reduce the size of the prediction results.

In addition to these new features, general software issues including minimizing memory use, reducing run time for projections, and improving online updating capacity will continue to be addressed.

Beyond currently funded efforts there is clearly scope for further future development of TUMAS. MULTIFAN-CL is also used to assess tuna stocks in other oceans—with additional development TUMAS could support assessments in other locations.

Ideally projection outputs should enable detailed bioeconomic analysis. Additional work with fisheries economists would allow still further program improvements to better provide the information needed to evaluate the costs and benefits of alternative management options.

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PFRP

Socioeconomic Linkages of Hawai'i's Fishery Sector

Shawn Arita, Minling Pan, Justin Hospital, and PingSun Leung

Introduction

Quantitative assessment of Hawai'i's fishery sector's economic and social contribution is crucial for policymakers to properly assess the sector's importance and the potential impacts of policy changes. This article summarizes findings from a recently developed Social Accounting Matrix (SAM) model for the fishery.

Economic-impact models of commercial fisheries are typically based on Input-Output tables focusing exclusively on economic linkages among production sectors. Fishery managers, however, concern themselves not only with how much economic activity can be generated but also with which socioeconomic groups benefit from the fishery. A SAM identifies the distributional characteristics of the economic impact generated by the fishery industry and provides a useful tool to study the implications of existing and potential new fishery policies.

The Hawai'i Fishery SAM model was designed to:

1. Provide necessary information on the forward and backward linkages of the fishery sectors to other sectors of the economy and the household sector, and
2. Examine the distributional linkages of Hawai'i's production sectors to household income.

What is a SAM Model?

A SAM model is a detailed accounting of purchases of goods and services, mapping the flow of funds through the economy. It is both a data system and a conceptual tool for policy analysis. Beyond

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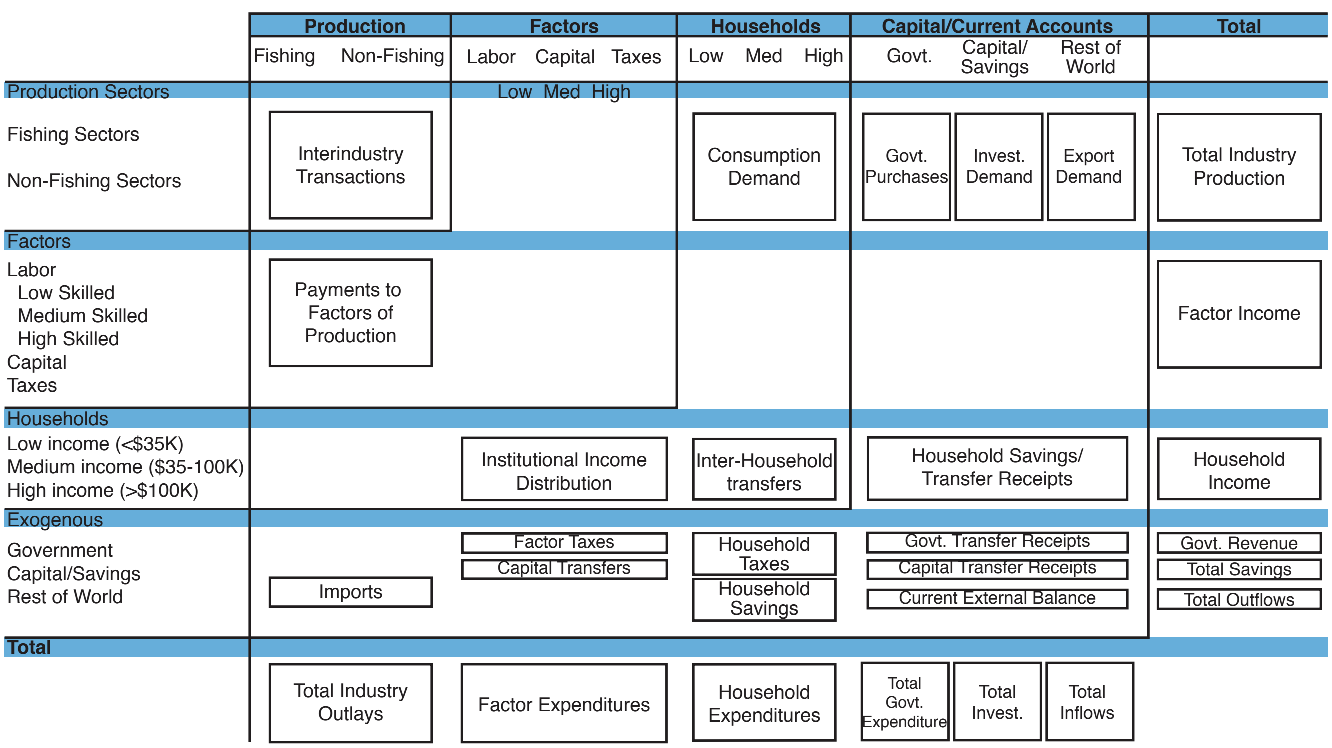

Figure 1. Layout of a Hawai'i Fishery SAM.

just delineating the traditional inter-industry linkages, by using household income and consumption patterns the SAM model provides information detailing the linkages between sectors. The explicit representation by SAM models of these linkages provide a more thorough picture of the circular flow of goods and money in the economy. Households, governments, and investments can be treated as endogenous variables in SAM models, expanding the analytical details to reflect the income-distribution process of the economy and increasing the precision of impact analysis.

If a number of conditions are met—in particular, the existence of excess production capacity and underemployed labor resources—the SAM framework may be used to estimate the effects of exogenous changes and injections on the entire aggregate economy.

Supply-side effects increase as endogenous accounts are estimated through the multiplier process. E.g., reductions in total-allowable-catch would result in decreased purchases of bait, ice, and other inputs. This would then decrease the amount of labor required by these sectors. In turn, a significant decrease in incomes earned by the groups providing this work will lead to declines of expenditures on items such as food. The subsequent decrease in food production to address this lost demand leads to further losses of employment and income for these groups, continuing the multiplier process until feedback effects dampen this decrease.

Construction of the Hawai'i Fishery SAM with Income-Distribution Linkages

The Hawai'i Fishery SAM model (developed for 2005 information) is based on multiple data sources. The Hawai'i State Input-Output table, generated by the Hawai'i Department of Business, Economic Development, and Tourism (DBEDT), served as the primary foundation of the SAM. It includes production activity information for sixty-eight accounts. Data for the additional SAM accounts—factors of production and institution accounts—were drawn from Hawai'i State IMPLAN (IMpact analysis for PLANning) data generated by MIG, Inc. Data to complete the income-distribution mapping from the industry sector to the household sector was identified in the Hawai'i State Industry Occupational Matrix generated by the Hawai'i Department of Labor and Industrial Relations.

Figure 1 shows the layout of the Hawai'i Fishery SAM model. SAM accounts are an extension of traditional input-output accounts whose basic structure follows from the System of National Accounts. Row entries represent receipts (income) to agents where total receipts must equal total expenditures. The main components of the SAM include production, factors, institutions, and exogenous accounts. These main accounts are broken into subaccounts and are disaggregated on the basis of availability of data and desired reporting categories.

SAM construction varies with the intended purpose of a given model. In developing the Hawai'i Fishery SAM special attention was given to disaggregating factor payments so that production

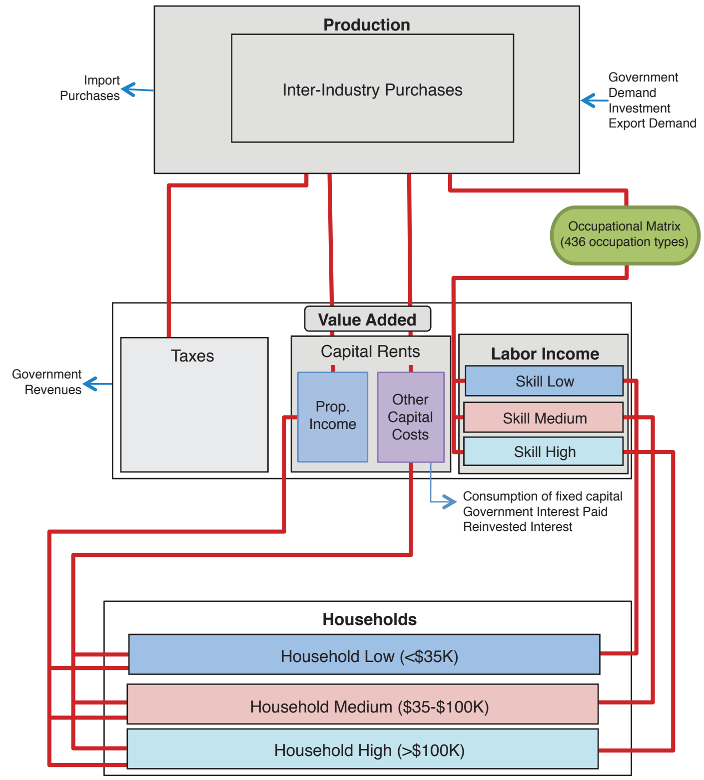

Figure 2. Income Distribution from Production Sectors to Households

activities could reasonably be linked to households. The state's Industry Occupational Matrix was used to disaggregate the industry-household linkage according to the composition of skill levels employed by each industry.

The mechanism of income flows can be seen more clearly in Figure 2. Here the production sector's labor payments are identified by individual occupations. Using the Industry Occupational Matrix, inputs are then mapped into appropriately defined skill levels based on the average salary of the occupation. The labor income is then mapped into the household sector where the distribution of skill levels is mapped to follow the distribution of household socioeconomic groups. Total labor compensation is then combined with capital income to generate total household income.

This mapping provides a high level of precision in identifying skill-intensive industries versus unskilled-intensive industries. It also provides explicit linkages between the distribution of income from the production sector to households.

SAM Multipliers and Distributional Analysis

The Hawai'i Fishery SAM output multipliers and distributional linkages are summarized in the figures below. Demand-driven multipliers reflect the impact effects of increasing a sector's final demand by one unit. The multipliers are broken down by total-industry impact and household income.

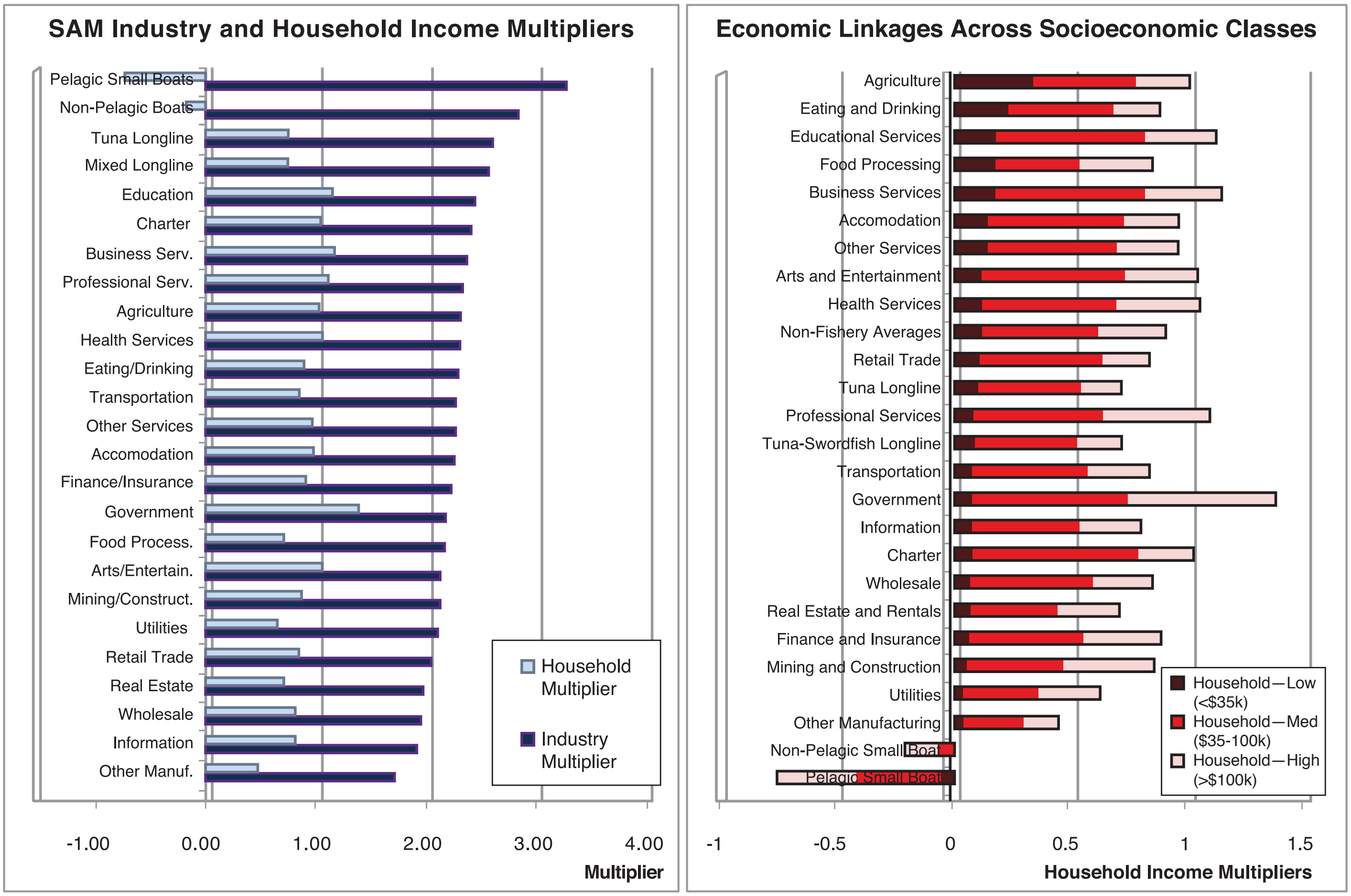

Figure 3. SAM Multipliers and Income-Distributional Linkages

The total-industry output multiplier for the longline tuna-fishing sector is approximately 2.6, suggesting that a $1.00 increase in final demand of longline tuna product may be expected to generate an additional $1.60 of economic activity in other production sectors of the economy. Comparing the industry-output multipliers shows that, on average, commercial-fishery sectors generate higher multipliers than non-fishery sectors. However the impacts on household income are generally much lower.

Compared to the non-fishery sector, the commercial-fishery sector has a smaller overall impact on household income, gaining only $0.70 for every additional $1.00 increase in demand (for both tuna and tuna/swordfish sectors). Most small boats incurred income losses generating a negative household-income multiplier on the economy because of the heavy additional use of such boats for recreational activities.

The SAM allows the tracking of income flows across different socioeconomic groups. The figure on the right presents the distributional impacts on high- (above $100,000), medium- ($35,000–$100,000), and low- (below $35,000) income households. These impacts reflect production linkages to household income stemming from increased production in the sector as well as from feedback effects between households and inter-industry transactions. Comparing the linkages across sectors indicates which sectors have higher linkages across different socioeconomic groups.

Examining the fishery sectors, the multipliers suggest that a demand increase in the longline-fishing sectors would primarily benefit middle-income groups—with lower- and higher-income groups receiving only modest levels of increased income. For the lower- and middle-income groups, the longline fishery sectors have a household income multiplier that is comparable-to-but-slightly-less-than the non-fishery sectors. Overall the fishery sector in general has a small household-income multiplier relative to the non-fishery sectors. Income from the fishery sector is largely distributed within the middle-income group while the lower-income group receives only a relatively small amount.

Conclusions

The present study, the first attempt to construct a Hawai‘i Fishery SAM, demonstrates the applicability of SAM models in assessing the socioeconomic impacts of the fishery sector. Policy

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Socioeconomic (continued from page 15)

applications of the model include generating socioeconomic-impact estimates for possible reductions in total allowable catch for the bigeye tuna sector and for fishery closures resulting from the fishery reaching the maximum allowed incidental sea-turtle take. Future studies of income distribution in Hawai‘i may also apply this modeling approach to study other industry sectors of economic interest, e.g., tourism and/or energy. Additional details regarding this research may be found in the *JIMAR Contribution Report* 11-373.

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