1. Purpose of the project and indicative results.
Stock assessment of bigeye tuna is generally based on longline catch-per-unit-effort (CPUE) as an index of abundance of stock assessment. Unfortunately, fishery-dependant CPUE does not necessarily reflect abundance of stock, but rather the catchability which is in turn dependant on variable oceanographic conditions. Preferential foraging habitat appears to be the 8-15 °C waters near the base of the thermocline so variability of thermocline depth could affect concentration. According to work by Boggs, Brill and others, bigeye tuna tend to remain in the upper 10-90m at night and repetitively during the day, migrating vertically between 350-500m and between 50-150m where their blood temperature increase in warmer waters after diving. However, a recent paper in the southern Pacific by Shaefer and Fuller (2002) suggests on rare occasions they can exceed 1000m in depth (and thus can not be physiologically oxygen limited to 350m in their dive profiles). This behavior suggests that at times when the thermal structure is depressed, bigeye tuna may be less aggregated and vice-versa. Likewise horizontal and vertical shears have a profound effect on catchabilities and we would like to consider whether wave activity could also be a factor effecting catchability.

After a lengthy recruitment process (12 months), Dr. Patrick Hyder joined the project as an oceanographer in November 2002 at which time there were two years of mooring data (from December 1999 to December 2000, and from December 2000 to December 2001) and CPUE data from twelve years from the region 0 to 40 N and 180 to 220 E. Although BIGEYE mooring was prepared for redeployment in November 2002, generator problems aboard the NOAA ship Ka'iminamoana resulted in a postponement of the year 3 deployment until July 2003. The delay in hiring Dr. Hyder and the postponement of the year 3 mooring have delayed the project by approximately one year.

Bigeye CPUE Data Analysis
Fishing effort for bigeye tuna in Hawaiian waters has increased steadily over the last decade resulting in a proportionally steady increase in catch (Figure 1). Over the 13 year record, the annual mean CPUE increased until 1997 to 1998 (an ENSO year), after which the increase appears to reduce despite increased effort. Interestingly, the seasonal signal indicates almost an order of magnitude difference between maximum catches (in winter) and minimum catches (in summer) and CPUE. Long-term monthly averages over the record reveal a clear seasonal cycle with a maximum CPUE during winter more than five times the minimum CPUE during summer. The effort also drops off during the summer, although only by ~50%, perhaps associated with boats switching target species. This trend in both catch and effort is evidenced in Hawaiian waters by Curran (1996) for several pelagic species such as albacore, bluefin, swordfish, striped marlin. Yellowfin tuna and blue marlin have more stable annual cycles and black marlin and mahi-mahi have maximum catches during winter. This implies that the summer months tuna longline boats switch species to target mahi-mahi and marlin, as well as possibly fishing outside Hawaiian waters.

For this analysis, the effort and catches have been split into regions to the northeast and southwest of the physical boundary of the Hawaiian Ridge. The analysis indicates seasonal migration in both fishing effort and catch, with a maximum in effort during winter to the southwest of the ridge (and in southern waters) and almost no fishing during late summer. By contrast, to the northeast of the ridge, the effort and catches are high during late summer and early winter. While much additional work remains to explain this apparent northeast-southwest migration or aggregation of bigeye tuna, the following hypotheses are being further explored: (i) a potential affinity of bigeye tuna or their prey for certain thermal ranges (i.e. an aggregation in more southerly tropical waters in spring in response to colder surface water conditions to the north with the migration of the subtropical front, or a possible migration away from surface waters which are too warm (in excess of 25°C in the upper 70m) in the southern region during late summer), or (ii) a migration of bigeye tuna or their prey in response to an annual variation in the northward extent of the region of enhanced productivity (indicated by high chlorophyll levels).

Further work is required to correlate these trends both with the local physical parameters and also with the larger scale changes in bigeye CPUE and migrations associated with the Pacific-wide circulation.

Hawaii Longline Logbook data were also used to study the interannual variability of bigeye and yellowfin tuna catch in the region from 167°W-158°W below 10°N, where the bulk of the fishery is associated with the area around Palmyra Atoll. Catch data for the span of the set was filtered to focus on deep sets to limit the effort used to sets that would be optimal for bigeye catch. Deep sets were defined by taking only sets that were reported to have used either more than 10 hooks per float or no light sticks. Beginning in 1998, increased effort at the Palmyra fishing grounds yielded high catches in yellowfin and bigeye tuna. In the years 1999 to 2001, yellowfin tuna accounted for 56% of all landings in the Palmyra area and make up 45% of all longline yellowfin catch. Bigeye
tuna landings accounted for 18% of the Palmyra catch and these landings equal 6% of all longline bigeye catch. In the El Nino years of 1998 and 2002, the species composition
Figure 1. The variation in the total number of fish caught, the total number of hooks (effort) and the C.P.U.E. in the full region covered by the data collection (0 to 40 N and 180 to 220 E).
of yellowfin and bigeye in the Palmyra catch appeared to invert with yellowfin tuna accounting for 46% of all landings and making up 34% of all longline yellowfin catch. Bigeye tuna landings accounted for 28% of the Palmyra catch and these landings equaled 14% of all longline bigeye catch. The highest catches for yellowfin tuna were found in August of 2001 with over 7,200 landings. March of both 1998 and 2001 yielded the highest catches for bigeye, with over 8,500 landings in 1998 and over 5,500 in 2002. These two time periods correspond roughly to the past two El Niño events.

Further work is required to investigate how CPUE with oceanographic conditions. It is thought that interannual variations in the equatorial current systems may result in short term eastward horizontal advection of mid- to higher level trophic organisms and also form mesoscale features around Palmyra Atoll. However, the observed increase in CPUE in spring could result from a similar seasonal concentration of fish in tropical waters by the larger annual cycle in temperature in subtropical waters, as suggested above.

**BIGEYE Mooring**

Data return is presented in previous reports. Very high data return was achieved for the seven Seabird SBE39 temperature recorders providing two years of vertical thermal structure data. During the first year deployment, the Aanderaa RCM 9 current meters malfunctioned resulted in good data for only the first 60 days at 4 depths. At 350m, good current, temperature, salinity and oxygen data were recovered for 250 days of the first year and for a full year in the second year. During, the second year, both Sontek Acoustic Doppler Profiler (ADPs) provided a full data return (though some data were lost due to interference between the instruments).

**Thermohaline Structure**

The thermal structure over the two year period indicates both the presence of strong internal tide (with vertical excursions in the pycnocline of well over one hundred meters) and a repeated seasonal cycle (Figure 2). The mooring data have been provided to other University of Hawaii investigators (Merrifield and Luther) to more fully examine the role of the internal tides in global mixing.

The annual cycle indicates periods of increased surface layer depth (at ~175m) during most of the year but periods of elevated pycnocline (at ~120m) during early summer (June to July) and autumn (October to November) separated by a period of unusually deep surface layer in September. These occur for longer than one would expect from mesoscale activity and at the same time during both annual cycles. Imposed on this cycle are shorted periods of pronounced surface layer depth reduction, probably associated with eddies or other mesoscale variability.

The direction of the mean flow between 80 and 220 indicates a mean drift to the northeast over the annual cycle between December 2000 and December 2001. The flow tended to be northward during the first part of the year (day 370 to 470), to oscillate with a mean
eastward drift during the summer (day 470 to 530) and then to flow northward to day 570
then southward for the remainder of the year to day 650. The event (day 450 to 560)
during the summer appears to have very interesting associated velocity structure and is
also evident in thermal structure at the same time during the previous year (Day 100 to
200).

Figure 2. The vertical thermal structure observed at the BIGEYE mooring during both deployments
(December 1999 to December 2001).
Further work is required to determine the dynamics and water masses associated with the annual thermal and velocity cycles, which are surprisingly distinct from the cycles to the northeast of the ridge discussed at the HOTS site (Bingham and Lukas, 1996). We also aim to collaborate with Rick Lumpkin to analyze the bigeye data in conjunction with drifter (and possibly OSCR) data from the Hawaiian Lee region, and to attempt to correlate the variation in pycnocline depth with changes in the strength and position of the North Equatorial Current to the south of the mooring location. We also aim to investigate the formation of eddies between the Islands and, in particular, a larger cross-ridge flow of surface waters across the ridge between the two northernmost islands.

In particular, the analysis of satellite imagery is required to put this mooring data into a spatial context to allow the investigation of the water masses or wave propagations associated with these changes. We are in the process of generating SST and SSH spatial image sequences for the region to facilitate the analysis of the mooring and CPUE data. Initial findings suggest there is a thermal front along the ridge for much of the annual cycle separating distinct water masses. At times during the annual cycle (November to January) conditions favored the formation of eddies between the southern islands apparently accompanied by a larger cross ridge flow of water between the two northern islands which may impinge on the BIGEYE mooring location. These eddies are
associated with increased bigeye tuna CPUE (which perhaps could also be associated with southward seasonal migration at this time).

There is an interesting heating-cooling cycle in this region with extreme seasonal variation in surface temperature (from 13 to 30 °C) at the region of the subtropical front. This transition zone migrates seasonally to the north in the summer and late summer (when sub-tropical waters are warm) and then south (right to the tropical boundary) in winter and early spring when the sub-tropical water masses are cool. A similar frontal migration is observed for chlorophyll as documented in (Leonard et al., 2001).

These annual cycles could potentially concentrate bigeye tuna (and other pelagics) in low latitudes in the respective winters since the fish are thought to return to warmer surface waters to warm up between dives (although they feed in the cooler (8-15 °C), deeper water where annual variations might be expected to be smaller). Conversely, during the late summer fish might be expected to migrate north when the surface waters are warmer (and possibly the surface waters become too warm to the south). This would be consistent with the observed minima in CPUE to the north in spring (when surface waters are coldest) and maximum to the north in late summer (when surface water temperatures are highest). This could also be consistent with the sharp reduction in CPUE to the south of the ridge between June and August. More work and comparisons between temperature at various depths and latitudes are required to investigate this.

From altimetry imagery there also appears to be a seasonal north-south shift in the region of maximum north-south SSH gradients associated with the NEC which could imply a seasonal shift in the location of this current. However, further analysis of imagery (perhaps the AVISO imagery) is required to confirm or disprove this. We plan for this work to be compared and analyzed in conjunction with a seasonal analysis of drifter data being undertaken by Flament and Lumpkin.

AVISO altimetry data sequences demonstrate the ability of carefully processed altimetry data to resolve features on the eddy scale (and track their westward propagation). We have calculated isotherm depth at the mooring location and plan to compare this with dynamic height to see if there is a way to approximately correct CPUE for isotherm depth using the expected correlation between altimetry derived sea surface height and dynamic height. However, since Bigeye dive to over 1000m at times and therefore appear not to be physiologically limited to this upper layer (Schaefer and Fuller, 2002), any such correction would be approximate.

Research Cruises

Another major component of the Bigeye Oceanography Program is a series of shipboard surveys to (1) expand the spatial representativeness of the BIGEYE mooring observations, (2) closely examine the vertical water column structure associated with oceanic variability; e.g., fronts, eddies and frontal meanders, and (3) obtain information of longline performance particularly in response to prevailing oceanographic conditions. Over the course of the project thus far, six research cruises (April 1999-2001, November 1999-2000, and July 2002) aboard the NOAA ship Townsend Cromwell (TC) have been
conducted and have focused on obtaining measurements of dynamic oceanographic variability and its influence on the biology. During these cruises, the primary activity included closely-spaced conductively-temperature-depth (CTD) casts conducted to observe water properties at very high vertical resolution. The July cruise conducted during FY 2003 occupied a transect coinciding with the overpass of the altimeter carrying Jason-1 satellite. The contoured vertical section of hydrographic properties clearly illustrate the contrasting thermohaline properties while traversing the North Equatorial Current region (Figure 4).

Figure 4. Vertical section of (a) temperature (°C), (b) salinity, (c) dissolved oxygen (ml L⁻¹), and (d) chloropigments (mg m⁻²) for oceanographic transect on TC 02-05.

In addition to the TC research surveys, three cooperative ventures (two of them in FY 2003) aboard commercial longline fishing trips have enabled sampling that otherwise would been less productive if attempted on the TC. On these trips, longline sets are instrumented with 3 to 6 time-depth-temperature recorders (TDRs) and hook timers per basket. A total of forty-two fish were caught on the instrumented sections, seventeen of which were bigeye tuna caught at depths ranging from 260-384 m. Additionally, 14 large viable bigeye tuna (ca. 70-110 lbs.) have been instrumented with Wildlife Computers
popup satellite archival tags (PATS) upon capture on these trips and released; these data are currently being analyzed. Information on core temperatures of bigeye tuna were also collected with internal temperature loggers inserted upon capture; these data are being examined in collaboration with John Kaneko, PacMar, Inc.

3. Plans for the next fiscal year.

During the next fiscal year, we request additional funds to continue analyzing the existing shipboard, mooring, and remote sensing data sets (and a similar mooring dataset in the Lee region being kindly provided as part of a collaboration with University of Hawaii) as well as to redeploy the BIGEYE mooring in July. Our specific aims include:

A) Analyze spatial and temporal CPUE variations.

(i) To compare temporal variations with temperature through depth at the mooring (and in the waters to the north and south) to try to see if fish might be concentrated seasonally by preferred thermal habitat (and hence to infer migrations). We also aim to compare the long-term changes in catch, effort and CPUE with oceanography and stock sizes.

(ii) To compare spatial variations in CPUE with satellite derived SST and SSH variations (using the AVISO dataset). As part of this analysis we would compare dynamic height and isotherm depth from the mooring data with SSH (and extend to the SSH spatial dataset if it appears worthwhile).

(iii) To investigate any detectable correlation between CPUE and current shear, weather and wave activity.

(iv) To investigate longer term temporal and larger scale spatial variations and how they compare with the findings in Hawaiian waters. We would hope to arrange collaboration with Fontenau’s group, in particular to determine whether they observe any long term concentration of fish along the tropical borders during spring by annual cooling of waters to the North and whether there are noticeable correlations between CPUE and the ENSO indices.

B) Physical analysis of BIGEYE mooring and satellite data

(i) Compare and contrast the annual cycles of thermal and velocity structure at BIGEYE with HOTS as they appear to be quite different (and perhaps use CTD data to compare intermediate and deep water masses).

(ii) To analyze the current regime at the BIGEYE location in conjunction with drifter data described by Flamant and Lumpkin, and AVISO imagery to estimate the strength and location of the NEC for comparison with variations at the mooring location.

(iii) Conduct analysis of the long-term current and thermal structure and try to compare with literature to estimate possible variations associated with ENSO (which are
documented by Lumpkin for the NEC to the south). For this analysis we are hoping to have access to thermal and velocity structure from a third years mooring data in the Lee region deployed by University of Hawaii.

(iv) The BIGEYE data set has been provided to University of Hawaii for analysis of the internal tide and mixing to be undertaken by the HOME group.

4. **List of papers published in refereed journals during FY 2003.**


5. **Other papers, technical reports, meeting presentations, etc.**


6. **Names of students graduating with MS or Ph.D. degrees during FY 2003.**
Include title of thesis or dissertation.

None