PFRP

Pelagic Fisheries Research Program

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Tagging and Tracking with Electronic Devices

John Sibert

The PFRP was host to "Tagging and Tracking Marine Fish with Electronic Devices," a major international symposium held at the East-West Center in Honolulu from February 7–11, 2000. More than 100 scientists and electronics manufacturers from a dozen countries assembled to share their findings and discuss the state-of-the-art in this rapidly developing field.

Results from all of earth's oceans were presented. Species discussed included tropical cephalopods (squids, octopii and cuttlefish), salmon, tunas, marlins, cod, reef fish, sea basses and sharks, from habitats ranging from shallow inshore waters to the deep ocean. Symposium proceedings will be published in 2000 as a book by Kluwer Press.

Enlightened participants post-conference, radiating new knowledge and insights about monitoring pelagic fish with electronic devices.

Why Marine? Which Devices?

The marine environment imposes severe constraints on the types of electronic tags that can be used to monitor fish behavior. Simply put, radio waves do not propagate well in media that conduct electricity, such as sea water, so marine biologists must devise more ingenious means of following their subjects. The Tagging and Tracking Symposium was intended to highlight solutions to the challenges of working in a conductive medium.

One solution is the use of ultrasonic "pingers" that emit a signal; these signals can be used to follow fish around in real time, or they can be recorded by an array of hydrophones for later analysis. Often, additional information is encoded in the pings, such as a unique identity code, ambient depth and temperature, body temperature, or swimming activity.

Another solution is geolocating archival tags. These devices record light intensity, time, and other information into a tiny embedded computer; the data then can be used to estimate the tags' daily longitude and latitude, which can accumulate for periods of up to 5 years.

Archival tags normally are implanted in the body cavity or musculature of fish, and data are recovered when the fish are recaptured. In contrast, "pop-up" devices are attached to fish externally and are programmed to detach on a specific date, float to the surface, and transmit data to an orbiting satellite. The first generation of pop-up tags merely transmitted a few temperature readings while the satellite determined the geographic position of the transmission. Newer devices incorporate archival technology and transmit a full suite of data to the satellite.

More recently, technology has come full circle with "chat" tags, archival tags that transmit data acoustically to listening stations on the sea floor. These various devices and the results obtained from them were the subjects of the Symposium.

Big Money Fish—Bluefin Tunas

The Symposium section devoted to pelagic fish was dominated by presentations on various species of tunas. Many of the papers reported research on the high-value bluefin tuna species. Scientists from both sides of the Atlantic presented results on northern bluefin tunas (ABT) (*Thunnus thynnus*) in the Atlantic. Most results are consistent with current knowledge and general thinking about bluefin tunas. These animals spend most of their time in the

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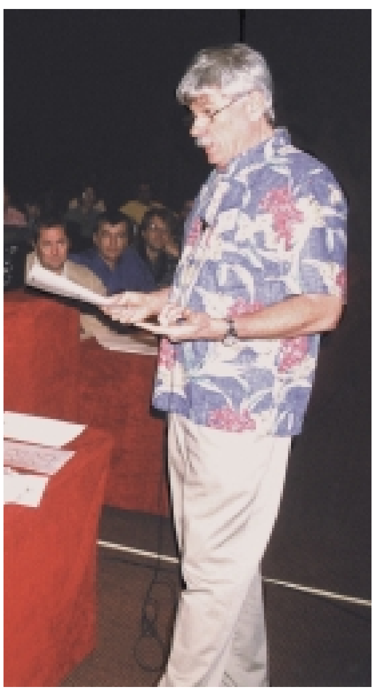
PFRP Administrative Assistant Dodie Lau finally exhales, in the wake of a hectic conference week.

warmer upper layer of the ocean and maintain high body temperatures (23-30˚ C) while swimming in waters of much wider temperature ranges (4-30˚ C). Other results are more surprising. ABT make regular deep dives at dawn and dusk, occasionally diving as deep as 800m, where the water temperature is very low.

Bluefin tuna appear to disperse widely throughout the Atlantic. Animals tagged in the western Atlantic with both pop-up and data-storage tags were reported at various places in the western and central Atlantic, as well as in the Mediterranean Sea. (Unfortunately, the devices were not returned from the Mediterranean, so information about these individual fishes is limited). Pop-up devices attached to animals in the Mediterranean reported positions in the eastern Atlantic, the Greenland Sea, and other sites in the Mediterranean. Comparison of the animals' tracks, estimated from tag data, with maps of oceanographic features in the western Atlantic, shows that bluefin often tend to remain near the frontal boundary between the warmer Gulf Stream and colder water surrounding it. Pop-off devices have been successfully used in bluefin on both sides of the Atlantic, but the reporting rate of the tags (supplied by the same manufacturer) is lower for eastern deployments than for western deployments. Whether this difference is due to differences in fish survival, attachment technique, or tag failure is not known.



PFRP Director and Conference Chair John Sibert makes a point in his closing presentation.

Similar results have been obtained for Pacific bluefin tuna (*Thunnus thynnus*), although fewer have been studied with electronic tags. The Pacific variety also maintains body temperatures above ambient, prefers the surface layer of the ocean, often remaining within 20m of the surface, and makes dawn and dusk dives, occasionally to depths of 300m.

A break in presentations allowed time for participants to talk story.

Some of the first large-scale deployments of archival tags were on southern bluefin tuna (*Thunnus maccoyii*) around Australia. The results have shown cyclic excursions from southern Australian coastal waters westward across the southern Indian Ocean and back, requiring reinterpretation of data from conventional tags. Archival tag data also enable researchers to monitor feeding behavior and estimate daily food intake in different parts of the animals' range at different times of the year.

Bigeye Tuna

Bigeye tunas have been extensively studied with both geolocating archival tags and acoustic telemetry in Hawai'i and French Polynesia. Telemetry data, sonar estimates of forage abundance, and analyses of longline performance indicate a preference for the surface layer during the night and deep foraging during the day. Archival tag results confirm this behavior over much longer periods, and extend the foraging depth. Bigeye regularly occupy depths below 500m, where the temperature is less than 5˚C and the oxygen content is around 1 ml/liter. This tolerance for scant oxy-

Symposium participants learn about the potential for combining tracking data with conventional tagging data.

gen is an unsuspected physiological ability in tunas, and appears to be related to the unique properties of bigeye tuna blood.

Stay-at-Home Tunas?

Aggregation and site fidelity are critical aspects of tuna behavior, and both archival tag and acoustic telemetry have provided useful information for yellowfin and bigeye tunas. When these animals are monitored near fish aggregation devices (FADs), both species appear to remain close to the FAD at night, and make longer excursions during the day. Results from archival tags indicate that bigeye tuna do not move very extensively during periods of several months, a result that is consistent with data from conventional tags.

Marlin

A few marlin in the Atlantic and Pacific oceans have been tagged with pop-up devices. Although some long distance movements have been documented, the reporting rate is much lower (around 50%) than for the same devices used on tunas. Again, it is not known whether this difference is due to differences in fish survival, attachment technique, or tag failure.

Conclusions

Most of the work presented at the Symposium, not merely the work on pelagic species, was strongly motivated by management concerns and has immediate applications in management. Accurate monitoring of fish movement and activity is perhaps the most important application of these studies, as it makes precise definition of habitat possible. Understanding of environmental preferences of bigeye tuna and blue marlin has already been used to refine some stock assessment methods (see PFRP V4: #s 4, 3, 1 and previous). Furthermore, legislation guiding management of U.S. domestic fisheries requires definition of "essential fish habitat," and electronic tagging data will almost certainly be used to establish these definitions.

Kim Holland notes that the last great frontier in biology is explaining navigation by animals, and suggests experiments should be designed to elucidate navigational organs and processes.

Keith Stoodley says extensive collaboration between scientists and manufacturers will be required to develop instruments that can push the boundaries of remote sensing of physiological conditions.

Additional work is needed in several areas. Improvement is needed to the method of attachment for pop-up devices before the devices can be used confidently with many species. The durability of fish hide, effects of chafing, and interference with movement and fins are other details that need to be addressed. Similarly, pop-up tags need to be smarter so they don't fail if carrying fish die and sink to depths that damage the tags.

Symposium participants also discussed improvements for future electronic devices, including incorporation of sensors that can record ambient oxygen, blood pressure, tail beat, jaw muscle activity and other physiological indicators.

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The author is Director of the Pelagic Fisheries Research Program, SOEST, University of Hawai'i at Manoa.

The Substitution Effect of Area Closures

Ujjayant Chakravorty

Area closures are fast becoming a popular and low-administrative-cost management tool that can be used to rebuild depleted fish stocks. However, the economics of area closures is still in its infancy. Relative to more traditional analysis of Individual Transferable Quotas (ITO) and harvest quotas, there is very little theoretical or empirical work on this important topic. For instance, most traditional models in fisheries economics neglect the element of spatial heterogeneity in fishing, which I think is a serious limitation, especially in the economic analysis of pelagic fisheries. It is obvious that fish not only move in response to climatic factors (such as temperature and seasonal migration patterns) but also in response to density variations caused by a spatially heterogenous distribution of effort. In a perfect-information world, effort, in turn, is allocated according to the calculation of profits from fishing in a certain location, and the choice of fishing location based on maximum profit.

Significance of Displacement

Analysis of area closures in a spatial continuum allows for the evaluation of substitution effects that may be significant. For instance, closure of fishing grounds in the northern latitudes in the Hawaiian ocean would cause longliners to move into inshore locations. This would result not only in increased catches in these areas, but also in a reduction of catches by competing handline and troll boats. Modeling closure without the resulting substitution effects may result in an overestimation of the negative effects on the longliner fleet and an underestimation of the effects of interaction on handliners and trollers.

More empirical studies of the precise nature of these interactions need to be made, although there is evidence that substitution effects may be significant. Closure of inshore fishing areas in the Gulf of Mexico shrimp fishery is reported to have led to an increased allocation of effort to offshore fishing grounds.

The importance of substitution can be seen in simulated closures in the north Hawaiian longline fishery done by Chakravorty and Nemoto (2000). As shown in Table 1, the year-round closure of two five-by-five-degree squares (20º N, 155º W and 15º N, 155º W) near the main Hawaiian islands results in an increase in fishing effort in “Other Areas,” i.e., those not affected by closure. Compared to the Base Case, these areas register an increase in activity as shown in column C-B. However, the increase in fishing in the open areas does not fully compensate for the decline in the closed area, leading to a net decline in aggregate effort. However, for some months in the year, the substitution effect is quite significant. For example, in October, substitution resulted in an increase in effort from 53 trips to 91 trips, more than a 70% increase. This substantial increase in trip allocation could have serious short-term impacts on fish stocks, as well as on competing fleets.

Table 1. Trip Allocation with and without Area Closure: Closure of Two Five-degree Squares 20º N, 155º W and 15º N, 155º W

	Base Case			Area Closure		
Month	Closed areas (A)	Other areas (B)	All areas (A+B)	Other areas[a] (C)	Change in other areas (C-B)	Change in all areas (C-A-B)
Jan.	23	77	100	94	+17	-6
Feb.	21	80	101	95	+15	-6
Mar.	2	84	86	85	+1	-1
Apr.	5	89	94	92	+3	-2
May	33	74	107	92	+18	-15
Jun.	27	88	115	106	+18	-9
Jul.	20	67	87	79	+12	-8
Aug.	36	31	67	43	+12	-24
Sep.	25	62	87	75	+13	-12
Oct.	63	55	118	87	+32	-31
Nov.	65	53	118	91	+38	-27
Dec.	2	111	113	112	+1	-1
Total	322	871	1193	1051	+180	-142

[a]The number of trips allocated to "closest areas" is zero.

Aggregated over the year, fishing trips in the areas not subject to closure increased by about 20% (180 trips). This is significantly less than the decline in trips in the closed areas (322), so when substitution is accounted for, the net decrease is about 44% of the initial effort in the closed areas. Although these results are based on simulation models, they suggest that substitution effects may be significant.

These results may need to be modified with information on the effects on adjacent open areas of stock rebuilding in closed areas. It is possible with area closures that there is a positive spillover effect that causes an increase in stocks radially from closed areas. In that case, the effect of additional fishing vessels in the open fishing grounds may be less than predicted by the above scenario, at least in the fishing grounds adjoining the closed areas.

Profitability & Vessel Mobility

In terms of profitability, it is clear that fishing trips into closed areas were based on maximum profit; the fact that trips shift into areas previously not selected implies that profits will be lower than before. However, a mass exodus of boats from the closed areas will mean congestion externalities and adverse local effects on stock. Another consideration is the heterogeneity of fishing vessels, which prevents substitution into newer areas, or targeting of different species of fish. For instance, Chakravorty and Nemoto found that the above closure of two squares in the main Hawaiian islands reduced catches of inshore species such as bigeye, yellowfin and striped marlin by about 10–20%, but swordfish catches increased only by 3.4%. This implies that inshore fishing boats cannot easily substitute into swordfish boats and begin operating in distant northern locations rich in swordfish stocks.

However, a simulated closure of all squares north of 30º N that are predominantly swordfish locations revealed much higher substitution possibilities, as shown in Table 2.

Notice that there was a net increase in the number of trips, from a reduction of 165 trips in the closed areas to an addition of 233 in the open areas, which are primarily inshore. This is partly

Table 2. Trip Allocation with and without Area Closure: Closure of All Five-Degree Squares North of 30° N

	Base Case			Area Closure		
Month	Closed areas (A)	Other areas (B)	All areas (A+B)	Other areas[a] (C)	Change in other areas (C-B)	Change in all areas (C-A-B)
Jan.	29	71	100	115	+44	+15
Feb.	29	72	101	114	+42	+13
Mar.	22	64	86	90	+26	+4
Apr.	9	84	94	97	+12	+3
May	0	107	107	107	0	0
Jun.	1	114	115	116	+2	+1
Jul.	24	63	87	98	+35	+11
Aug.	22	45	67	72	+27	+5
Sep.	6	81	87	90	+9	+3
Oct.	7	111	118	121	+10	+3
Nov.	1	117	118	119	+2	+1
Dec.	15	98	113	122	+24	+9
Total	165	1028	1193	1261	+233	+68

[a]The number of trips allocated to "closest areas" is zero.

a result of the fact that inshore trips require less travel time and therefore can be made more often within the same period. The impacts of this closure policy are quite different in magnitude from the one discussed first. Here, swordfish catches declined by 40% while catches of inshore species bigeye, yellowfin and striped marlin increased by 10–15%. The substitution effect is stronger here, possibly because it is easier for swordfish boats to target other species than vice versa.

Income Effects

Economic effects follow the substitution effects. The inshore area closure reduces fleet profit by 11% with only a 5% decline for the ban on swordfish fishing. However, there is an asymmetry in impacts on boat owners and crew. The prevalence of profit-sharing arrangements suggests that boat owners and crew split net revenues from each trip. So boat owners' incomes mimic fleet profits. However, crews benefit when the fleet spends more time fishing and less time travelling; inshore closure policies thus lead to more long-distance trips and a larger negative impact on crew profits, while closures in offshore areas induce shorter trips and thus minimize impacts on crew. To the extent that the objective function of the regulatory agency puts additional weight on the welfare of crew members, who tend to be from poorer segments of society, offshore closures may be less harmful.

While the effect of substitution effects is only beginning to be understood, it is important to develop models that incorporate information on stock dynamics in a model of endogenous substitution of effort. This will allow for a realistic assessment of the economic effects of area closure policies.

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The author is an Associate Professor of Economics at Emory University in Atlanta.

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Editor Chris Anderson, John Sibert
Writers John Sibert, Ujjayant Chakravorty, Matthew Parry, Richard Young, and Jed Hirota
Layout May Izumi
Printing Fisher & Pioneer Printers, Honolulu, HI 96817

For more information

Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai‘i at Mānoa
1000 Pope Road, MSB 313
Honolulu, HI 96822
TEL (808) 956-4109 FAX (808) 956-4104
E-MAIL jsibert@soest.hawaii.edu
WWW http://www.soest.hawaii.edu/PFRP

Upcoming Events

May 8–12, 2000

2nd International Conference on the Biology and Conservation of Albatrosses and Other Petrels
U.S. Fish & Wildlife Service; U.S. National Park Service Pacific Cooperative Studies Unit; Environment Hawai‘i, and the Packard Foundation
Ilikai Hotel, Honolulu, HI
Contact Katie Swift at (808) 541-1201; fax (808) 541-1216

May 22–25, 2000

Lake Arrowhead Tuna Conference, Lake Arrowhead, CA
NMFS and IATTC
Contact Dave Holts or Michelle DeLaFuente at (858) 546-7186 or 546-7175; e-mail: David.Holts@noaa.gov or Michelle.DeLaFuente@noaa.gov
web site: http://www.swtsc.ucsd.edu/tunaconf.html

June 10–14, 2000

IIFET 2000 International Conference: "Microbehavior and Macroresults"
Oregon State University; Corvallis, OR
Dr. Richard S. Johnston (conference organizer)
OSU Dept. of Agricultural and Resource Economics
213 Ballard Extension Hall

July 5–12, 2000

13th Meeting of the Standing Committee on Tuna and Billfish
Secretariat of the Pacific Community, Nouméa, New Caledonia
Contact Tony Lewis at +687 26.20.00; fax +687 26.38.18
e-mail: spc@spc.org.nc

The Trophic Ecology of Two Hawaiian *Ommastrephid* Squids

Matthew Parry, Richard Young and Jed Hirota

The red squid, *Ommastrephes bartramii*, occupies the subtropical and temperate regions of the world's oceans (Roper et al., 1984). This antitropical distribution divides the species into a number of separate populations. Members of the North Pacific population have mantle lengths (ML; the length of the squid excluding the head and arms) that range up to 380 mm for males and up to 650 mm for females. At the latter size the squid weighs roughly 6 kg, making it an attractive commercial target.

Range, Populations & Catch

Like many members of the nekton in the north Pacific, the red squid migrates southward seasonally from summer feeding grounds in the north (roughly at 40-45° N) to spawn in tropical or subtropical latitudes at about 28-20° N. This winter migration takes the red squid into Hawaiian waters occupied by a closely related squid *Sthenoteuthis oualaniensis* (the purpleback flying squid), which is the target of a small, local fishery.

The purpleback squid is about half the length of the red squid, and therefore is a potential prey as well as a potential competitor of the red squid. The purpleback ranges throughout the tropical Indopacific, although it may be comprised of genetically distinct populations (Nesis, 1993). Hawaiian waters are at the northern distributional range of this species in the Central Pacific, and one of the few areas where the red and purpleback squid populations overlap. Around the main Hawaiian Islands, the purpleback is abundant and spawning is common, but abundance declines rapidly north of the Hawaiian Islands, and females found there usually fail to mature (Young and Hirota, 1998).

A female Purpleback Squid (*Sthenoteuthis oualaniensis*) in an aquarium.

Before the moratorium on driftnet fishing in 1992, the commercial catch of red squid in the North Pacific peaked at around 350,000 metric tons (mt), rivaling the *Illex argentinus* fishery off the southwestern coast of South America as the dominant squid fishery in the world (Yatsu et al., 1993). In 1989, the ex-vessel price of the catch was approximately one billion U.S. dollars (Sonu, 1993). The primary fishery was for subadults, but large mesh driftnets targeting billfish and tuna caught adult red squid as by-catch. A summary of this by-catch by the U. S. National Marine Fisheries Service (NMFS) indicated that adult red squid are very abundant on the winter swordfish (*Xiphias gladius*) fishing grounds around 30-35° N; this observation was a major impetus for the present research.

Squid & Swordfish

The red squid appears to be a dominant prey item for adult swordfish in this area, occurring in 20% of stomachs sampled, and comprising 39% of prey weight (Mundy et al., NMFS report 1997). Our initial results and those of NMFS indicate high red squid abundance at the southern front (about 19°C) of the subtropical frontal zone (STFZ); this corresponds with higher catch rates of swordfish along the same front. In the spring, however, swordfish are thought to migrate farther south to spawn and the proportion of red squid in their diet decreases (Seki et al., 1999). The distribution and trophic ecology of the red squid (the objective of our research) clearly is important in understanding the ecology of the swordfish, as well as the ecology of nekton in the high North Pacific, as the red squid is one of the dominant members.

A female Red Squid (*Ommastrephes bartramii*) on deck.

Our work is based mostly on five cruises between February 1996 and February 2000 aboard the Japanese FTS *Hokusei Maru* through a joint research agreement between the University of Hokkaido and the University of Hawai'i at Manoa. Adult squid were caught using pole and line, automatic jigging machines, and a deep driftline. Paralarvae were obtained using a 1m ring with a 505 µm mesh plankton net.

Red Squid

Roughly half of the red squid males (158 individuals) we caught were at or north of the 19°C isotherm, while the rest (154) were caught well south of the front. In contrast to males, sexually mature females are rarely caught south of the front. Adult female red squid (43 individuals) were caught almost entirely at or just north of the 19°C isotherm, while only three were caught south of the isotherm.

This also differs sharply from the distribution of red-squid paralarvae (recently hatched squid), which we found only well south of the STFZ. The temperature where the paralarvae have been caught in greatest abundance was within a tenth of a degree of 22°C during our first four cruises. Our results therefore agree well with previous work by Bower (1995) that suggested a spawning preference between 21 and 24°C; this temperature generally is found between latitudes of 22 to 28°N in Hawaiian waters during the winter. However, our year 2000 cruise partially contradicted the trend established in our first four cruises. During the 2000 cruise, the front was further north than we have ever seen it in February (31°06' N) yet paralarvae were abundant further south than we have ever recorded (off the windward coast of Hawai'i Island at 19°57'N). The sea-surface temperature there (23.4°C), surprisingly, was still within the range observed by Bower.

We suspect that the apparent absence of females in southern waters is simply due to an increase in their nighttime depth distribution. Squid swimming deeper than about 100 m at night would not be easily caught by the methods we employ.

Squid Diet

Analyses of stomach contents of squid caught in the Hawaiian region have begun to reveal some trends. Most of the contents are fishes and cephalopods. Otoliths from red squid stomachs belong to 20 families of mesopelagic fishes. Roughly 10% of the otoliths are unidentifiable at this time. Fishes from the family Myctophidae account for half of the total otoliths. This contrasts with otoliths taken from the purpleback squid, where an even higher percent (about 80%) belong to the Myctophidae. Within the Myctophidae, the red squid feeds on a wide variety of species while the purpleback squid feeds heavily on just three species, *Symbolophorus evermanni*, *Ceratoscopelus warmingii* and *Hygophum rheinhardti*. *Symbolophorus evermanni* otoliths alone comprise roughly 35% of the total otoliths in purpleback squid stomachs.

Cephalopods in the diet of the red squid come from 14 families and 20 genera of epipelagic and mesopelagic species. The dominant cephalopod prey in the stomach of both the red and purpleback squid are squids of the genus *Onychoteuthis*. Three species of *Onychoteuthis* occur in these waters but species identification of beaks is not yet possible. Contrary to our expectations, the purpleback squid, apparently, is not being preyed upon by the red squid, and competition between them does not seem to be severe, with the red squid being more of a generalist or opportunistic feeder.

Isotopic Analysis

The relative abundance of stable isotopes of carbon and nitrogen (^{15}N and ^{13}C) can provide valuable information on trophic levels (Sholto-Douglas et al., 1991; Abend and Smith, 1997). This technique is attractive because it yields an objective numerical value of relative trophic position. This value represents trophic information integrated over a considerable time span, unlike the isolated feeding events revealed by stomach analyses. The standard delta notation for stable isotope ratios is used here. A roughly 3.4 parts-per-thousand (‰) enrichment of $\delta^{15}N$ generally defines the difference between trophic levels (Minagawa and Wada, 1984; Fry, 1988). In contrast, $\delta^{13}C$ has shown a less reliable and lower enrichment that is usually <1‰ (Tiezen et al., 1983). Because of the low change per trophic level, $\delta^{13}C$ values more closely resemble those of the initial primary producers and therefore better reflect the general isotopic composition of the geographic location and its food web.

Our first set of isotopic data show that in the red and purpleback squid, both $\delta^{13}C$ and $\delta^{15}N$ vary as a function of mantle

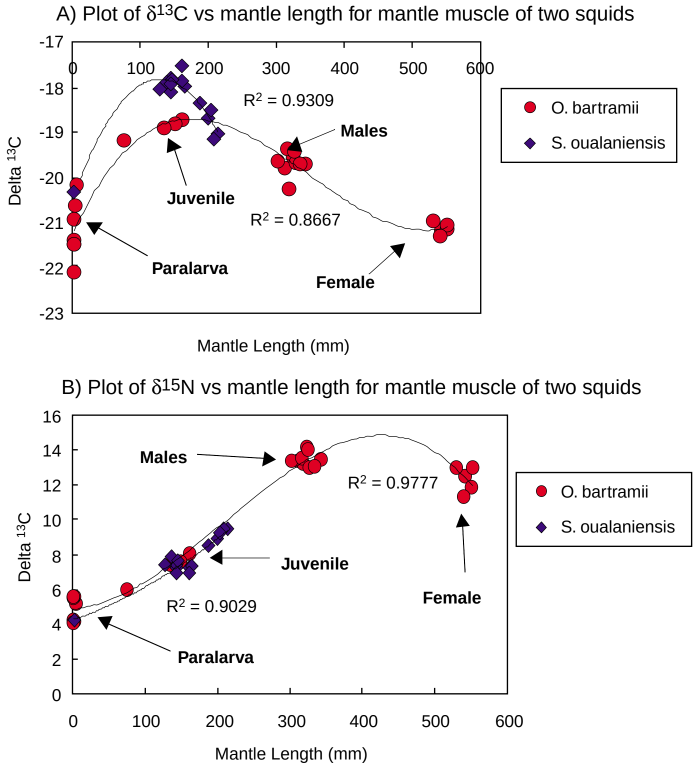

Figure 1. A) Plot of $\delta^{13}C$ versus mantle length for two oceanic squids showing four classifications for Ommastrephes bartramii. B) Plot of $\delta^{15}N$ versus mantle length for two oceanic squids showing four classifications for *Ommastrephes bartramii*.

length, but in unexpected ways (Fig. 1). For both squids, $\delta^{13}C$ is low in the paralarvae, higher in juveniles, then low again in adults, but the absolute differences are low (between 2 and 3‰) (Fig. 1a). In contrast, $\delta^{15}N$ in the purpleback squid shows increasing values with increasing size throughout the size range sampled. In red squid, the same trend seems to hold for mantle lengths up to 350 mm. For larger males values do not seem to increase, and for females around 550 mm, values may even decline (Fig. 1b). These analyses indicate that adult red squid are well over one trophic level above the purpleback squid (male red squid: 13.45‰; female red squid: 12.33‰; subadult red squid: 7.66‰; female purple squid: 7.97‰). The female red squid have a $\delta^{15}N$ that averages 4.36‰ greater than the purpleback squid, while the male red squid are about 5.48‰ greater. This difference is not readily apparent from stomach content data, and suggests that, among other possibilities, trophic differences of prey between the species and locality of capture may be important.

Future work will examine C and N isotopic ratios in different squid tissues, in predators, prey and lower trophic levels. This, combined with further dietary analyses, should resolve these problems and provide a clearer picture of the trophic ecology of these important squids.

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The Trophic Ecology (continued from page 7)

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The authors work in the Department of Oceanography at the University of Hawai'i at Manoa: Matthew Parry is a graduate assistant with a master of science, Richard Young is a professor, and Jed Hirota an associate professor.

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Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai'i at Mānoa
1000 Pope Road, MSB 313
Honolulu, HI 96822