Different residence times of yellowfin tuna, *Thunnus albacares*, and bigeye tuna, *T. obesus*, found in mixed aggregations over a seamount

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Aggregations of tuna can be found in association with seamounts throughout all the tropical oceans and these aggregations are often exploited by tuna fishing fleets (Fonteneau, 1991). In Hawaii, a fishery has developed over the last decade that targets the mixed species aggregations of predominantly subadult tuna found in association with the Cross Seamount located approximately 160 nmi south of Honolulu and Oahu and 150 miles east of South Point on the island of Hawaii (Fig. 1). Its shallowest depth is about 330 meters.

The Cross Seamount fishery is a hybrid troll, jig, and handline fishery that augments slow trolling methods by using frozen, cut and whole bait to induce feeding behavior around the fishing boat. Initially described as a yellowfin tuna (*Thunnus albacares*) fishery, closer scrutiny has revealed that the catch is dominated by juvenile bigeye tuna (*T. obesus*). Schools of skipjack tuna (*Katsuwonus pelamis*) are also found over the seamount but these are avoided by fishermen and, when skipjack tuna occur in mixed schools with the other species, the quite large size of the baits deters the capture of skipjack tuna. The fishery occurs year-round but fishing effort tends to subside periodically when larger tuna become available closer to shore—primarily during summer months.

Two concerns have arisen within the fishing community. First, fishermen exploiting the Cross Seamount resource were concerned that increasing fishing effort at the seamount by additional vessels entering the fishery would overexploit the schools of tuna associated with the seamount. Second, there was concern among the broader community that heavy fishing effort at the seamount might reduce the number of fish that were available to other gear types operating closer to shore. That is, the seamount might be a major "staging point" for fish that subsequently move into the coastal handline and troll fisheries. In response to these concerns, a tag-and-recapture program was conducted to elucidate the dynamics of the tuna populations associated with the seamount and to document the movements of individual fish forming those aggregations.

Materials and methods

Tag-and-release operations were conducted by trained tagging technicians placed onboard collaborating commercial vessels. Tuna were caught by crew members using handlines and pole-and-line methods, and the fish were then passed to the tagging technician for evaluation, identification, measurement, and tagging. Standard, serially numbered 11-cm nylon-tipped dart tags (Hallprint Pty, Australia) carried a message (stating a reward) and a toll-free phone number for reporting recaptured fish. Also, because the commercial fishing fleet in the seamount fishery consists of fewer than ten boats, close liaison was established with these boats to ensure maximum reporting of fish recaptured at the release site.

Residence times for tuna at the seamount were calculated by constructing tag-recapture attrition curves (Kleiber et al., 1987) that plotted the number of tagged fish recaptured against time at liberty. The elapsed time at which 50% of the releases had been recaptured at the point of release (Cross Seamount) represents the "half-life" of resident tuna within that area. That is, for a group of animals tagged at Cross Seamount, the residence time was defined as the elapsed time at which only half those animals remained at that location. In order to avoid disproportionate influence of fish recaptured immediately after release and be-

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Table 1
Fish tagged and released at Cross Seamount.

	Released at Cross	Recaptured at Cross		Recaptured elsewhere		Combined recaptures	
Yellowfin	458	86	(18.7%)	9	(1.9%)	95	(20.7%)
Bigeye	835	61	(7.3%)	12	(1.4%)	73	(8.7%)
Total	1293	147	(11.4%)	21	(1.6%)	168	(12.9%)

cause nighttime is when tuna often make significant horizontal movements away from their daytime haunts (Holland et al, 1990; Marsac et al., 1995), attrition curves were constructed only for fish recaptured for time at liberty >24 h.

Results

Between August 1995 and November 1996, 835 bigeye and 458 yellowfin tuna were released at Cross Seamount. The tagged bigeye tuna were between 40 and 105 cm FL; yellowfin released were between 40 and 90 cm FL. There were no significant differences between the two species in the size distribution of fish tagged and released (Fig. 2) or in size distribution of the recaptures. Because no effort was made to preferentially tag a particular species, the ratio of releases (65% bigeye, 35% yellowfin) reflected the ratio of species actually caught. Release and recapture data are summarized in Table 1.

The numbers of yellowfin and bigeye tuna recaptured at Cross Seamount were aggregated into 30-day periods of time at liberty and plotted as percentages of total number of fish recaptured. The resultant regression curves for the recapture of each species are shown in Figure 3. An analysis of covariance indicated that the slopes of the attrition curves for the two species are significantly different (P=0.013). The attrition rate (slope of the regression line) for yellowfin tuna is approximately twice the rate for bigeye tuna, and the slopes indicate a residence time (50% recaptured) of 15 days for yellowfin tuna and 32 days for bigeye tuna. By contrast, the tag attrition

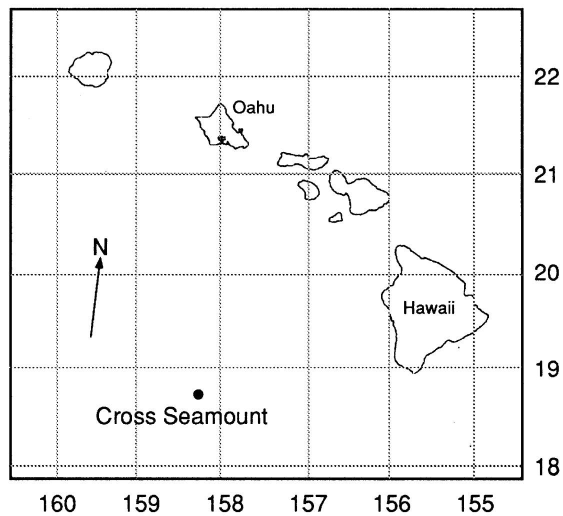

Figure 1
Chart of the study area showing position of Cross Seamount in relation to the main Hawaiian Islands.

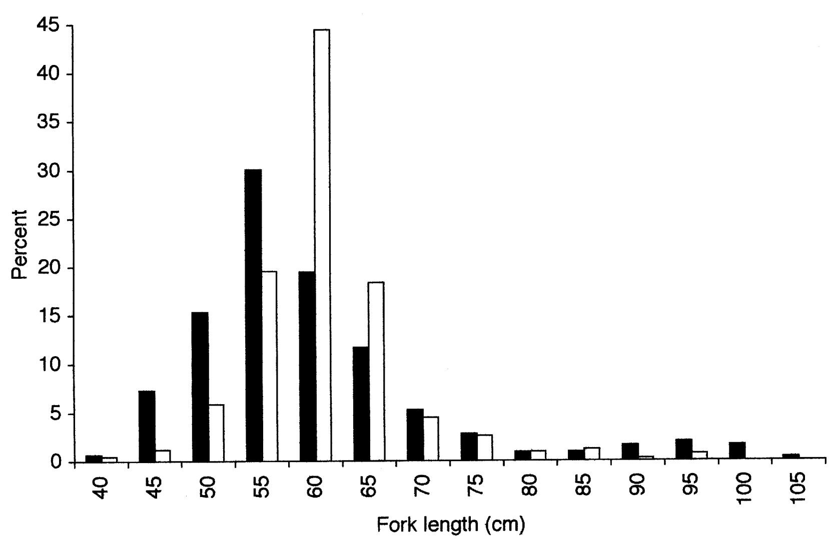

Figure 2
Size distribution of bigeye tuna and yellowfin tuna tagged and released at Cross Seamount. Solid bars = bigeye tuna; open bars = yellowfin tuna.

curves for statewide returns (that is, time at liberty for all recaptured Cross Seamount yellowfin and bigeye tuna, regardless of recapture location) were not significantly different (P=0.45, Fig. 3).

In addition, there were more recaptures of bigeye tuna with longer periods at liberty than of yellowfin tuna at the seamount and the longest time at liberty was 169 days for bigeye tuna compared with the longest point-of-release recapture of 93 days for yellowfin tuna.

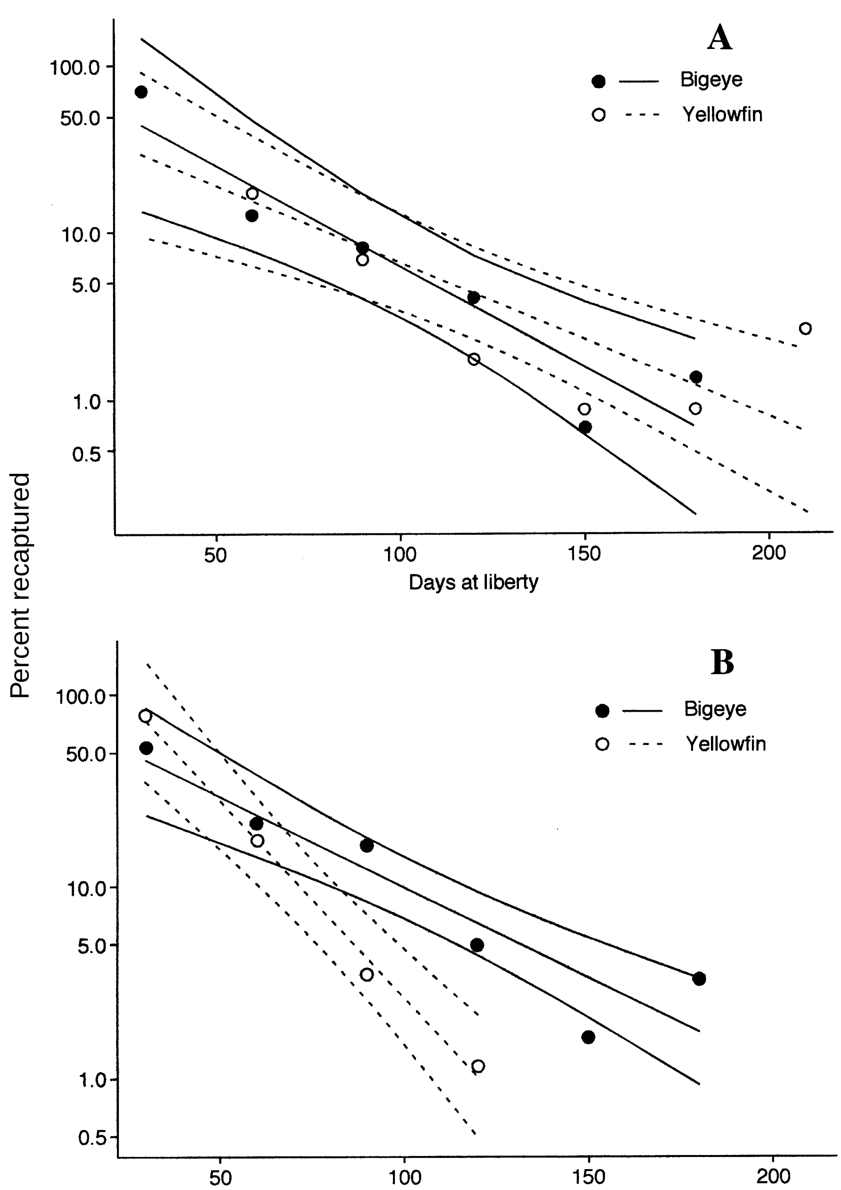

Figure 3

Tag recapture attrition curves (semi-log plots with 95% confidence contours) for bigeye and yellowfin tuna tagged and released at Cross Seamount. **(A)** All recaptures from all locations; **(B)** Recaptured at Cross Seamount.

Discussion

The main thrust of this analysis was to compare the residence times of the two tuna species at Cross Seamount. Consequently, many complicating factors often associated with analysis of tag-and-recapture data could be avoided (especially the impact of variability of fishing effort on the temporal pattern of recaptures) because effort could be assumed to be equal for both species. Therefore, the difference in the tag attrition curves, and the resultant difference in residence times ("half-life"), probably reflect real differences in the behavior of these two species at Cross Seamount. The similarity of the recapture curves for the entire area (Fig. 3) further suggests that methodological or experimental biases are not responsible for the differences in attrition curves obtained for these two species at Cross Seamount.

These results differ from those of Fonteneau (1991) who observed no differences in the temporal characteristics of recaptures of tagged bigeye, yellowfin, and skipjack tunas released at a seamount in the tropical Atlantic.

Fisheries data (Hanamoto, 1976, 1987) and acoustic tracking (Holland et al., 1990) both indicate that the open ocean behavior of bigeye and yellowfin tuna is different. Bigeye tuna select colder waters and are therefore usually found deeper than yellowfin tuna, which orient principally to the top of the thermocline and the mixed surface layer. However, this vertical separation breaks down around fish aggregating devices (FADs, Holland et al., 1990) and floating objects where bigeye tuna move closer to the surface and overlap in vertical distribution with yellowfin tuna. This same effect occurs at Cross Seamount where both species are caught in surface schools and bigeye tuna outnumber yellowfin tuna in the fishery. Similarly, mixed aggregations of yellowfin tuna, bigeye tuna, and skipjack tuna have been reported at seamounts in the Atlantic (Fonteneau, 1991).

Although the vertical behavior of yellowfin and bigeye tuna seems to merge at Cross Seamount, the current data indicate that the duration of horizontal orientation to the seamount (as measured by residence time ["half-life"]) is different.

The underlying advantage of seamounts to tuna biology is not well understood. Although seamounts can cause geographically stable regions of planktonic enrichment, it is not known if this enrichment persists long enough to move through the trophic chain to the level of the tuna forage base (Boehlert and Genin, 1987). We do know that Cross Seamount is situated in a very dynamic part of the ocean characterized by vortices created on the downcurrent side of the main Hawaiian islands (Flament et al.[1]). As these eddies spin off from the islands, current direction over the seamount can change frequently.

If an enriched area of prey does exist, and feeding is the principal underlying reason for tuna aggregations, it is difficult to understand why residence times are different for the two species and quite brief for both. The feeding advantage should impact both species equally and their residence times at the seamount should be similar. A comparison of the stomach contents of the two species when caught in seamount aggregations would be instructive. It is possible that, rather than acting as feeding stations, seamounts act as orientation points in the larger-scale movement patterns of these fish. Even though they may be too deep for visual detection, seamounts may be recognized by tuna through their ability to detect the effect of seamounts on the earth's magnetic field (Walker, 1984; Walker et al., 1984; Klimley et al., 1988). The seamounts may act as midocean reference points that may also occasionally harbor increased prey densities, the periodicity and persistence of which are driven by events in the surrounding oceanographic conditions.

A navigational role might explain why remote seamounts aggregate more tuna than seamounts located closer to land masses (Fonteneau, 1991) and why, in our study, the residence times were quite brief for both yellowfin and bigeye tuna species. The differences in the duration of orientation to the seamount might be explained if the navigational importance of seamounts is different in the broader behavioral repertoires of the two species.

Certainly, the current data indicate that Cross Seamount hosts transient populations of both tuna species rather than long-term populations. This brevity of residence at the seamount for both species probably reduces the chances of excessive fishing exploitation.

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Literature cited

Boehlert, G.W., and A. Genin.
1987. A review of the effects of seamounts on biological processes. *In* B. H. Keating, P. Fryer, R. Batiza, and G.W. Boehlert (eds.), Seamounts, islands and atolls. Geophys. Monogr. ser. 43, 405 p.

Fonteneau, A.
1991. Seamounts and tuna in the tropical Atlantic. Aquat. Living Resour. 4:13–25

Hanamoto, E.
1976. The swimming layer of bigeye tuna. Bull. Jpn. Soc. Fish. Oceanogr. 29:41–44. [Engl. Transl. 21 by T. Otsu, 1977, 7 p. Honolulu Lab. SWFC-NMFS, NOAA.]

Hanamoto, E.
1987. Effect of oceanographic environment on bigeye tuna distribution. Bull. Jpn. Soc. Fish. Oceanogr. 51:203–216.

Holland, K.N., R. W. Brill, and R. K. C. Chang.
1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull. 88:493–507.

Kleiber, P., A. W. Argue, and R. E Kearney.
1987. Assessment of Pacific skipjack tuna *Katsuwanus pelamis* resources by estimating standing stock and components of population turnover from tagging data. Can. J. Aquat. Sci. 44:1122–1134.

Klimley, A. P., S. B. Butler, D. R. Nelson, and A. T. Stull.
1988. Diel Movements of hammerhead sharks *Sphyrna lewini* Griffith and Smith, to and from a seamount in the Gulf of California. J. Fish Biol. 33:751–761.

Marsac, F., P. Cayre, and F. Conand.
1995. Analysis of small scale movements of yellowfin tuna around fish aggregating devices (FADs) using sonic tagging. Sixth expert consultation on Indian Ocean tunas, Colombo, Sri Lanka, 25-29/09/95, 20 p.

Walker, M. M.
1984. Learned magnetic field discrimination in yellowfin tuna, *Thunnus albacares*. J. Comp. Physiol. 155:673–679.

Walker, M. M., Kirschvink, J. L, R. K. C.Chang, and A. E. Dizon.
1984. A candidate magnetic sense organ in the yellowfin tuna *Thunnus albacares*. Science (Wash. D.C.) 224:751–753.

[1] Flament, P. J., C. Lumpkin, J. Tournadre, P. Kloosterziel, and L. Armi. 1997. Period doubling and vortex pairing in an anticyclonic shear flow in the ocean. Manuscript in review.