Effects of entanglement and escape from high-seas driftnets on rates of natural mortality of North Pacific albacore, *Thunnus alalunga*

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North Pacific albacore (*Thunnus alalunga*) are heavily fished and may have experienced recent reductions in recruitment (NOAA, 1991). U.S. troll fishery landings and catch per unit of effort (CPUE) have been decreasing since the 1960's and are currently at only about 50% of their peak levels (Kleiber and Perrin, 1991; NOAA, 1991). Landings and CPUE by the Japanese pole-and-line fishery have also been falling continuously since the late 1970's[1]. North Pacific albacore are additionally targeted by longline fleets, and considerable numbers are taken by high-seas large- and small-mesh driftnet fleets. The small-mesh fleets of Japan, Taiwan, and Korea target neon flying squid (*Ommastrephes bartramii*) and incidentally capture albacore. The large-mesh fleets of Japan and Taiwan target albacore, skipjack tuna (*Katsuwonus pelamis*), and various billfishes (*Istiophoridae* and *Xiphiidae*).

Foreign driftnet fleets and U.S. trollers taking albacore overlap geographically (Fig. 1). They also target a common stock even when fishing in widely separated areas because of the trans-Pacific migration of albacore (Otsu and Uchida, 1963). Albacore that encounter drift nets, and escape to survive long enough to be recaptured by another fishery can bear some external marks[2,3]. These marks provide direct evidence of interactions among fisheries. U.S. trollers operating in the North Pacific have reported an increased frequency of net-marked fish with the expansion of the Taiwanese, Korean, and Japanese high-seas driftnet fleets (NOAA, 1991;[2,3]).

Albacore that become entangled in drift nets face a number of possible fates (Fig. 2). The fraction that become entangled and subsequently drop out (alive or dead) is not known. If it is significant, the North Pacific albacore stock could be affected more seriously by high-seas drift nets than landings alone indicate. Our study, part of a larger effort to determine the impacts of drift nets on the North Pacific albacore stock, was undertaken to determine whether albacore that encounter drift nets, and subsequently escape alive, suffer higher than normal rates of natural mortality.

Our strategy was to look for differences in measures of fitness, and differences in short-term and long-term growth rates between net-marked (i.e., fish that have encountered drift nets and escaped) and unmarked albacore. We also looked for indications of bacterial infection and long-term stress in net-marked albacore. These parameters could evince, although not quantify, differences in rates of natural mortality. We had to use indirect measures because rates of natural mortality (or physiological changes) could not be directly observed in albacore encountering simulated drift nets in shoreside tanks. Unlike skipjack and yellowfin tuna (*Thunnus albacares*) (Brill, 1992), albacore have yet to be successfully maintained in captivity.

Selection of specific parameters was constrained by the necessity of collecting measurements and samples at sea aboard small commercial fishing vessels. We could acquire only measurements and samples that could be obtained under difficult conditions and that did not interfere with normal fishing operations. We were further limited to collecting samples that could be stored for later processing in the laboratory and that would not reduce the market value of the catch. Given these constraints, we chose the following parameters. Weight to length and maximum girth to length ratios were used as indicators of general fitness (Bolger and

[1]Tsuji, S., H. Nakano, and N. Bartoo. 1992. Report of the Twelfth North Pacific Albacore Workshop. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038. Admin. Rep. LJ-92-04, 15 p.

[2]Bartoo, N., D. B. Holts, and C. Brown. 1991. Report of the 1990 cooperative albacore observer project. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., NOAA, Southwest Fish. Sci. Cent., B.O. Box 271, La Jolla, CA 92038. Admin. Rep. LJ-91-09, 16 p.

[3]Bartoo, N., D. B.. Holts, and L. Halko. 1992. Report of the 1991 cooperative North Pacific albacore observer project. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., P.O. Box 271, La Jolla, CA 92038. Admin. Rep. LJ-92-07.

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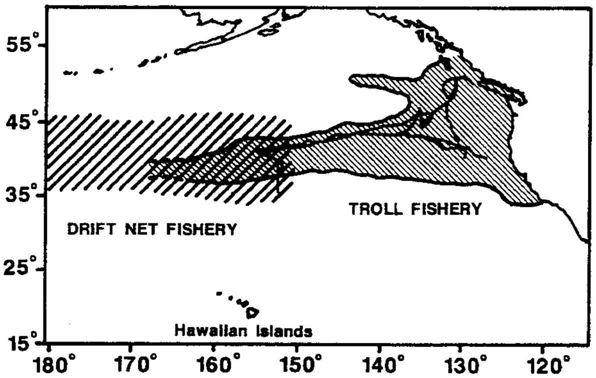

Figure 1
Area of operation of the U.S. troll fishery (light cross-hatching) catching albacore. Track lines of U.S. vessels carrying National Marine Fisheries Service observers in 1991 are shown by the solid line. Area of operation of foreign drift net fleets (heavy cross-hatching) extends west to approximately 140°W.

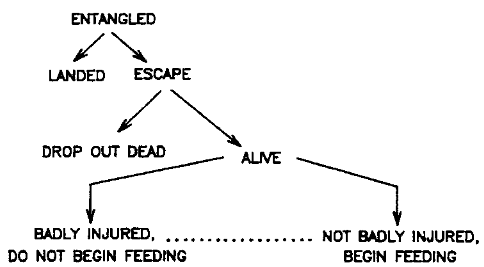

Figure 2
The possible fates of albacore that become entangled in high-seas drift nets. Note that the condition of fish which escape drift nets alive probably form a continuum from those that are so badly injured that they succumb quickly, to those that are only slightly injured and resume feeding immediately.

Connolly, 1989; Cone, 1989, 1990; Murphy et al., 1991). Relative otolith weight (i.e., the ratio of otolith weight to body weight) was used as an indicator of long-term growth rate (Boehlert, 1985; Pawson, 1990; Fletcher, 1991). (Because otolith weight is proportional to fish age rather than to body size, slower-growing fish have larger otoliths at a given body size because they have taken longer to reach that body size.) RNA:DNA ratio of white muscle was measured because it is an established indicator of short-term (days to weeks) growth rates (Bulow, 1970; Bulow et al., 1981; Ferguson and Danzmann, 1990; Mustafa et al., 1991). Relative leukocyte abundance (i.e., the ratio of leukocytes to red blood cells) was assessed as an indicator of bacterial infection and long term stress (Blaxhall, 1972; Anderson, 1990; Goede and Barton, 1990). Although muscle lipid content can be used as a measure of recent feeding history (Dotson, 1978), it was not used in this study. The lipid content of tuna muscle is dependent on sampling site (Dotson, 1978; Vileg et al., 1983; Boggs and Kitchell, 1991) and this factor could not be rigorously controlled.

Materials and methods

During 1990 and 1991, observers were placed aboard ten U.S. trollers by the Southwest Fisheries Science Center (NMFS, NOAA), in cooperation with the Western Fishboat Owners Association. Observers documented the number of net-marked albacore landed and collected data and samples for our study. Boats operated in an area of the North Pacific shown in Figure 1. Albacore were classified according to the severity of net damage with a scheme (Table 1) developed by Bartoo et al.[2]. Fork length, maximum girth (both to the nearest centimeter), and body weight (to the nearest kilogram) were measured. Dried blood smears, sagittae (otoliths), and white-muscle samples (frozen in sealed tubes in the boats' commercial fish freezers) were also obtained from a subsample of landed fish selected by the observers. Muscle samples (taken from the small amount of muscle remaining near the skull following decapitation) and otoliths could be obtained only on vessels that processed (i.e., "gilled and gutted") their catches. Complete sets of samples were not, therefore, obtained from every fish.

In the laboratory, otoliths were dried, cleaned, and weighed to the nearest 0.1 mg on a Sartorius 1207 MP2 electronic balance. RNA and DNA were extracted from the frozen muscle samples by standard procedures (Hutchison and Munro, 1961; Munro and Fleck, 1966; Wilder and Stanley, 1983). The only modifications were that the RNA was extracted with 1.0 N NaOH, and the DNA with 1.2 N perchloric acid, both at 37°C for 60 minutes. RNA, DNA, and protein concentrations were measured with a Beckman model 35 UV spectrophotometer using the dual wave length method (Tsanev and Markov, 1960) and standard extinction coefficients (Wilder and Stanley, 1983). Red cells and leukocytes were counted in Geimsa-stained blood smears with the aid of light microscopy (oil immersion lens) in a minimum of three microscope fields, or until at least 200 red cells were counted. Eosinophils could be easily differentiated from the remainder

Table 1

Net damage classification scheme (Bartoo et al.[2]) used to assess severity of injury to albacore caused by entanglement and escape from drift nets, and the number fish in each damage code category examined for our study.

Damage code	Damage description	Number of fish
0	No damage or scarring.	217
1	Minor damage along side(s) of fish, pattern of stripes due to minor scale loss where fish forced its way through or along the net.	39
2	Minor damage to head, chiefly forward of pectoral fins, brush-like pattern of scale loss.	5
3	Severe damage from bruising or scraping away of parts of the skin, primarily in area of greatest girth and mostly on dorsal surface.	10
4	Damage of any degree that was partially or completely healed.	60

of the leukocyte population and were excluded from the total leukocyte count. Although Alexander et al. (1980) described the distinguishing features of albacore blood cells, we were only able to differentiate eosinophils clearly from the remainder of the leukocytes. Leukocytes were, therefore, not further classified.

By using data from unmarked fish only, regressions of body weight on fork length, maximum girth on fork length, and otolith weight on body weight were fitted by a least squares procedure (Statgraf Statistical Software) to the exponential equation:

$$Y = a \cdot x^b.$$

Regression parameters a and b were estimated for each case.

Relative condition factor, relative girth, and relative otolith weight for individual fish were then calculated with the regression parameters:

$$K = W/(a \cdot X^b).$$

When K = relative condition factor, W = body weight and X = fork length; when K = relative girth, W = maximum girth and X = fork length; and when K = relative otolith weight, W = otolith weight and X = body weight.

Relative condition factor, relative girth, and relative otolith weight were calculated to permit direct comparison of groups containing individuals of different body sizes (Pollard, 1972; Brill et al., 1987).

The standard condition factor (C) was calculated separately for unmarked and net-marked fish:

$$C = W / FL^3$$

where W = body weight and FL = fork length.

Fish were grouped only as net-marked (damage codes 1-4, Table 1) and unmarked (damage code 0). Differences in mean values for unmarked and net-marked fish were evaluated by unpaired Student's t-tests with $P < 0.05$ taken as the maximum level for statistical significance.

Results and discussion

The only significant differences between net-marked and unmarked fish were in measures of absolute size (mean fork length, body weight, and maximum girth), which were greater for unmarked albacore (Table 2). These data suggest that smaller fish escape drift nets, survive, and are recaptured by the troll fleet more frequently than large fish. This appears to be confirmed by size-frequency distributions for the 217 net-marked and 114 unmarked fish included in this study (Fig. 3A). The two peaks in Figure 3A (at approximately 65 and 80 cm) represent 3- and 4-year-old fish, respectively[2] and imply that 4-year-old individuals predominate the unmarked group. In the net-marked group, 3- and 4-year-old fish are approximately equally represented. This result is, however, more likely due to either a sampling bias of the observers when choosing fish for inclusion in this study, or to time-area variations in fish size composition and the percentage of net-marked fish. The size-frequency distributions of

Table 2

Parameters measured to evaluate the effects of escapement from drift nets on the natural mortality of albacore *Thunnus alalunga*. *N* equals the number of observations.

	Unmarked fish		Net-marked fish	
Parameters	Mean ± SD	*N*	Mean ± SD	*N*
Body weight* (kg)	10.6 ± 2.4	182	8.6 ± 2.6	83
Fork length* (cm)	79.1 ± 7.4	215	73.5 ± 7.9	114
Maximum girth* (cm)	56.1 ± 5.7	214	51.8 ± 6.2	113
Condition factor (kg/cm^3)	0.0208 ± 0.0015	182	0.0210 ± 0.0017	83
Relative girth	1.00 ± 0.02	214	1.00 ± 0.03	113
Relative condition factor	1.00 ± 0.07	182	1.00 ± 0.07	83
RNA to DNA ratio	6.99 ± 0.97	34	6.90 ± 1.49	36
Relative otolith weight	1.00 ± 0.09	175	0.99 ± 0.11	47
Leukocytes/200 red cells	7.26 ± 5.30	15	6.44 ± 3.59	35

*$P \leq 0.05$.

a much larger number of albacore (12,085 unmarked and 381 net-marked individuals[4]; and from which the fish used in this study are a subsample, show that the frequency distributions of 3- and 4-year-old net-marked and unmarked fish are more nearly identical (Fig. 3B); 3-year-old fish were found to be only slightly dominant in both groups.

Our objective in calculating condition factor, relative girth, and relative condition factor (also referred to as relative weight) was to determine if there was any indication of differences in fitness between unmarked and net-marked fish. No differences were found (Table 2). The use and misuse of condition factor and relative condition factor have received much recent attention (Bolger and Connolly, 1989; Cone, 1989; Murphy et al., 1991). The use of such indices in groups of fishes with different mean lengths and size-frequency distributions may not be justified because disparities may be due to differences in body size, rather than to physiological fitness (Cone, 1989, 1990). Because indices of fitness were not different for unmarked and net-marked fish, we considered the question of suitability moot.

No differences were found either in measures of short-term (RNA:DNA ratio) or long-term (relative otolith weight) growth rates (Table 2). The RNA:DNA ratio can be affected by the age of the fish (Haines, 1973); however, it was not corrected for body size (i.e., age) because we found no correlation between it and body weight.

The relative leukocyte counts also did not differ between unmarked and net-marked albacore (Table 2). We assumed that net-marked albacore could show either elevated or reduced leukocyte counts. Acute bacterial infection has been shown to increase leukocyte counts in fish (Wedemeyer et al., 1990). Conversely, reduced leukocyte counts can be caused by elevated circulating corticosteroid levels (an acute stress response) or by chronic bacterial infection causing leukocytolysis (Shreck, 1981; Wedemeyer et al., 1983). The lack of difference between unmarked and net-marked albacore suggests that none of the processes that can affect relative leukocyte counts was occurring in the latter.

We were hampered in interpreting our results because we could not determine precisely how long the fish were at liberty following escapement from drift nets. Based on observations of skipjack and yellowfin tuna held in shoreside tanks at the Kewalo Research Facility (described in Brill, 1992), skin damage resulting from capture generally heals completely within weeks in feeding fish (R. W. Brill, unpubl. observations). Fish with damage codes 1–3 (Table 1), therefore, probably encountered drift nets within one month of recapture. It was impossible to estimate how long fish with damage code 4 had been at liberty or how long net damage remains visible, although Bartoo et al.[2] speculated that fish with damage code 4 may have been at liberty more than a year since encountering a

[4] N. Bartoo, D. Holts, C. Brown, and L. Halko. La Jolla Laboratory, Southwest Fish. Sci. Cent., unpubl. data.

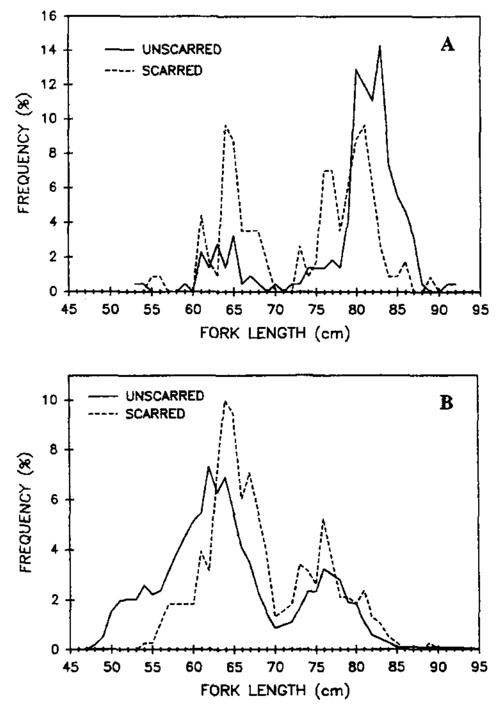

Figure 3

Size-frequency distribution of the unmarked and net-marked albacore sampled for our study (**A**) (215 unmarked and 114 net-marked fish) and much larger data set (**B**) (12085 unmarked and 318 net-marked fish) from which the fish used in our study are a subset (N. Bartoo, D. Holts, C. Brown, and L. Halko, SWFSC, La Jolla Laboratory, unpubl. data).

drift net. It is unknown if this is sufficient time for differences in relative otolith weight to become measurable. Boggs and Kitchell (1991) showed that significant weight loss occurs in tunas within one week of starvation. Therefore, it was likely that net-marked fish were at liberty long enough for measures of physiological fitness to become apparent, assuming net-marked albacore had not been feeding prior to recapture. The rate at which relative leukocyte abundance changes in albacore following stress or infection is not known, but in coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*O. mykiss*) leukocyte abundance changes within 96 hours of imposition of stressful conditions (McLeay and Gordon, 1977). Leukocyte abundance should be a good measure of differences in the health of net-marked and unmarked albacore, but the large standard deviation (Table 2) may limit its usefulness in this species.

Failure to detect differences (Table 2) between unmarked and net-marked albacore suggests that the fish escaping from drift nets, and living long enough to become vulnerable to recapture by U.S. trollers, do not suffer increased natural mortality. Most of the fish however, recaptured by trollers are found to be only minimally damaged or to have healed scars (Table 1), which may explain the lack of differences between net-marked and unmarked fish. As shown in Figure 2, there is most likely a spectrum of damage caused during encounters with drift nets. We do not know if the distribution of damage severity in the population of albacore vulnerable to the troll fishery is the same as that of all the albacore that escape drift nets alive. Also, the number of albacore falling out dead, or escaping so badly injured that they succumb before becoming vulnerable to recapture by troll vessels, may well be significant but remains to be determined.

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