EARLY LIFE HISTORY AND SPAWNING OF THE ALBACORE, *THUNNUS ALALUNGA*, IN HAWAIIAN WATERS

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ABSTRACT

Thirty-five juvenile albacore were found in the stomachs of 4,568 billfishes captured in Hawaiian waters between July 1962 and April 1966.

Regressions of standard length on lengths of various segments of the vertebral column, determined from measurements made on 21 intact specimens caught in the Pacific Ocean, were used to estimate the lengths of the fragmentary specimens. A linear regression was used to describe the first year's growth of albacore. By use of the regression, expected lengths for various ages, in days, up to 1 year were obtained. One-year-old albacore were estimated to be 38 cm. in standard length. The spawning season for albacore in Hawaiian waters peaks in May and probably extends from March to September.

The albacore (*Thunnus alalunga*) in the North Pacific are believed to constitute a single subpopulation, the adults of which support fisheries off the coasts of North America and Japan. The age and growth of adult albacore have been estimated and hypotheses have been developed on their migrations among the fisheries (Otsu, 1960; Clemens, 1961; Otsu and Uchida, 1963).

Basic information on young albacore before they are recruited into the commercial fisheries is sketchy, however. Descriptions of larval albacore appear in the literature, but they need verification. Matsumoto's (1962) description of larval albacore differs significantly from that of Yabe and Ueyanagi (1962). Yabe, Ueyanagi, Kikawa, and Watanabe (1958) and Yoshida (1965) published descriptions of the anatomy of juvenile albacore, and Asano (1964) published observations on the morphology. The present report treats aspects of the early life history of albacore before their recruitment into the commercial fisheries. Growth in the first year of life is estimated and inferences are made on the spawning habits of the adults.

The juvenile albacore for this study came from the stomachs of billfishes, which are good collectors of juvenile tunas (Yabe et al., 1958; Yoshida, 1965). The Honolulu fish markets were an excellent source of billfishes from which stomachs could be sampled with relatively little difficulty. Although the abundance of billfishes varied seasonally, stomachs were available from every month in a 46-month period between 1962 and 1966. The billfish stomachs yielded 35 juvenile albacore. Skipjack tuna (*Katsuwonus pelamis*), the most numerous juvenile tuna, was about 24 times more numerous than albacore. Smaller numbers of juvenile yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), and other tunas and tunalike fishes were found.

COLLECTION AND EXAMINATION OF STOMACHS

Stomachs of 4,568 billfishes were examined from July 1962 to April 1966—3,751 striped marlin (*Tetrapturus audax*), 477 blue marlin (*Makaira nigricans*), 268 shortbill spearfish (*Tetrapturus angustirostris*), 34 black marlin (*Makaira indica*), 31 sailfish (*Istiophorus orientalis*), and 7 unidentified billfishes. The stomachs of striped marlin, blue marlin, and shortbill spearfish contained juvenile albacore.

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Most of the stomachs came from billfishes captured by vessels of the Hawaiian longline fishery. Otsu (1954) and Shomura (1959) gave detailed descriptions of that fishery. The catches are landed at the United Fishing Agency and the Fishing Co-Op of Hawaii in Honolulu, where the fish are sold at auction. The stomachs and information on the date of landing, locality of capture, weight, and sex for each fish were made available by the fish market personnel or the purchasers of the fish.

The vessels usually fished within sight of land. Thus, most of the stomachs came from billfishes captured within about 37 km. of the main Hawaiian islands. A few of the stomachs, however, came from billfishes caught as far as 644 km. from Oahu.

From 1962 to 1965, stomach samples were also collected from billfishes captured in the Hawaiian International Billfish Tournament, held annually since 1959 at Kona, Hawaii. The rules of the tournament limited the fishing area to the lee of the island of Hawaii.

The striped marlin were 4 to 148 kg.; the size distribution showed modes between 16 and 20 kg. and between 36 and 40 kg. The blue marlin were 16 to 364 kg.; a prominent mode was present between 60 and 70 kg. The shortbill spearfish were 14 to 38 kg.; a mode was present between 12 and 16 kg. The sailfish were 14 to 38 kg.; black marlin, from 36 to 290 kg.

The stomach samples from the Honolulu markets were taken to the laboratory and either examined immediately or preserved in 10 percent Formalin[1] for later examination. The samples from the billfish tournaments were shipped to the laboratory after preservation in 10 percent Formalin. In the laboratory, the stomach contents were initially sorted for tuna and tunalike specimens, which were later identified to species. The tuna specimens, which were affected in varying degrees by digestion, could be identified by their skeletons (Yabe et al., 1958; Matsumoto, 1963; Yoshida, 1965).

LENGTH OF JUVENILE ALBACORE

Few juvenile albacore from the billfish stomachs were intact. To estimate the SL (standard length) of the fragmentary specimens, which usually included part of the vertebrae, I determined the relation between the standard length and the lengths of various vertebral segments. On 21[2] relatively undamaged specimens (table 1) I measured the standard length, lengths of the vertebral column (39 vertebrae), precaudal vertebrae (1st–18th vertebrae), caudal vertebrae (19th–39th vertebrae), 1st to 9th vertebrae, and 19th to 28th vertebrae. The data indicated that all the relations were linear. The regressions describing the relations are:

Standard length on length of:

(1) vertebral column, $l = -0.2825 + 1.2762L$ $(s = 0.218)$,

(2) precaudal vertebrae, $l = 0.0634 + 2.8843L$ $(s = 0.429)$,

(3) caudal vertebrae, $l = -0.4370 + 2.2744L$ $(s = 0.298)$,

(4) 1st–9th vertebrae, $l = 0.3200 + 6.3963L$ $(s = 0.788)$,

(5) 19th–28th vertebrae, $l = -0.4579 + 4.4282L$ $(s = 0.289)$,

where l is the standard length (cm.), L is the length (cm.) of the vertebral fragments, and s is the standard deviation from regression.

TABLE 1.—*Measurements of standard length and various vertebral column lengths of 21 juvenile albacore found in stomachs of billfish caught in Pacific Ocean*

Specimen No.	Standard length	Length vertebral column	Length precaudal vertebrae	Length caudal vertebrae	Length 1st–9th vertebrae	Length 19th–28th vertebrae
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
1	85	68	30	38	13	20
2	88	69	29	39	13	20
3	74	61	25	35	10	18
4	257	200	86	114	38	58
5	354	281	122	159	54	81
6	105	85	35	50	17	25
7	184	147	65	83	29	43
8	143	116	50	66	19	34
9	78	62	25	37	11	18
10	119	97	43	54	19	28
11	118	94	41	53	18	28
12	113	90	38	52	19	27
13	113	92	40	52	18	27
14	121	99	42	57	19	29
15	99	80	34	46	15	24
16	53	41	17	23	8	12
17	86	71	31	40	14	20
18	328	257	112	145	53	75
19	230	182	80	102	35	53
20	230	184	83	101	35	52
21	185	149	64	85	27	44

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

[2] These specimens were from stomachs of predators captured not only in Hawaiian waters but in various localities in the North and South Pacific. I believe this fact should not affect the results. A covariance analysis applied to the relation between standard length and vertebral column length for North and South Pacific juvenile skipjack tuna showed no significant differences between the samples in the mean vertebral column length and slope of the lines.

I estimated the lengths of 26 of the 35 specimens with the regressions. The longest vertebral fragment available was always used to estimate the lengths. For example, if the vertebral column was intact, the regression with the length of all vertebrae as the variable was used rather than any of the other regressions. Pertinent data on the juvenile albacore are in table 2.

TABLE 2.—*Record of juvenile albacore from stomachs of billfishes caught in Pacific Ocean, 1962–66*

Date	Albacore: Standard length	Predator: Species	Predator: Weight	Predator: Location of capture (off the coast of)
	Cm.		*Kg.*	
August 1, 1962 [1]	18.4	Blue marlin	132.4	Kona, Hawaii.
August 13, 1962 [1]	[2] 13.0	Striped marlin	29.5	Waianae, Oahu.
September 13, 1962. [1]	[2] 18.1	Blue marlin	93.9	Do.
November 2, 1962 [1]	25.7	Striped marlin	29.9	Do.
Do	[2] 28.0	do	32.2	Do.
August 16, 1963	[2] 11.1	do	19.5	Do.
September 16, 1963	[2] 14.2	Blue marlin	65.8	Kalapana, Hawaii.
November 4, 1963	[2] 16.0	Shortbill spearfish.	15.9	Do.
November 7, 1963	[2] 11.9 [2] 11.4	Blue marlin	59.4	Do.
February 6, 1964	[2] 31.0	Striped marlin	19.5	Napoopoo, Hawaii.
February 20, 1964	35.4	do	147.9	241 km. south of Oahu.
February 25, 1964	[2] 33.6 [2] 35.5	do	17.2	161 km. south of Oahu.
March 4, 1964	[2] 34.6	do	26.8	West Lanai.
March 17, 1964	[2] 35.0	do	20.9	Waianae, Oahu.
June 29, 1964	[2] 9.5	Shortbill spearfish.	10.9	Do.
July 17, 1964	[2] 11.0	do	12.7	483 km. south of Oahu.
July 27, 1964	[2] 9.0	Striped marlin	12.7	Waianae, Oahu.
August 3, 1964	[2] 12.8	Shortbill spearfish.	10.9	483 km. south of Oahu.
September 15, 1964	[2] 9.5	do	13.6	Upolu Pt., Hawaii.
November 3, 1964	[2] 14.5	Striped marlin	39.9	Waianae, Oahu.
August 24, 1965	[2] 12.0	Blue marlin	52.2	Do.
Do	[2] 7.8	Shortbill spearfish.	15.0	Cape Kumukahi, Hawaii.
August 26, 1965	[2] 12.2	do	13.2	Waianae, Oahu.
Do	13.1	Blue marlin	72.6	Do.
October 6, 1965	17.8	do	49.4	Do.
October 18, 1965	[2] 19.8	Striped marlin	36.7	Ilio Pt., Molokai.
October 28, 1965	16.7	do	22.2	Cape Kumukahi, Hawaii.
November 4, 1965	[2] 12.1	Shortbill spearfish.	5.4	Do.
November 8, 1965	17.4	Striped marlin	33.6	Do.
November 10, 1965	25.0	do	36.7	483 km. south of Oahu.
November 12, 1965	[2] 16.4	do	29.0	Waianae, Oahu.
December 20, 1965	[2] 18.1	Blue marlin	42.6	Do.
January 20, 1966	28.9	Striped marlin	39.0	Do.

[1] Data from Yoshida (1965).
[2] Estimated from regressions.

AGE AND GROWTH

Because the juvenile albacore were collected from the stomachs of billfishes, any size selectivity by the billfishes could affect the analysis of the growth rate of the juveniles. Bias could be introduced by interspecific and intraspecific differences in the size of juveniles eaten by billfishes (e. g., larger billfish preying on larger juveniles). It is possible that billfishes do not feed on small juveniles. Fish shorter than 7 cm. SL were not found in the stomachs of the billfishes.

Other factors that may affect the estimation of growth are (1) changes in spawning season from year to year (the data for all years were pooled), (2) individual variation in growth, and (3) size-associated differences in schooling behavior and distribution of juvenile albacore so that the entire size range of juvenile fish would not be available to the predators. These factors are probably only a few of the many that may affect the data. I assume that all these factors have not seriously biased the data and that the juveniles eaten by billfishes are fairly representative of the population.

The standard length of the juvenile albacore is plotted against sampling date in figure 1. As would be expected, a considerable amount of variation in the size of juveniles is evident, particularly between August and November. Despite the scatter of the points, an increase in size with time is evident. A test showed that a second-degree polynomial provided a better fit to the data than a linear regression ($\underline{F}=7.491^*$; $d.f.=1, 32$). It was decided, however, to use the simpler linear regression because of the possible heterogeneity of the data, as discussed above. For example, most of the larger juveniles were found in striped marlin stomachs.

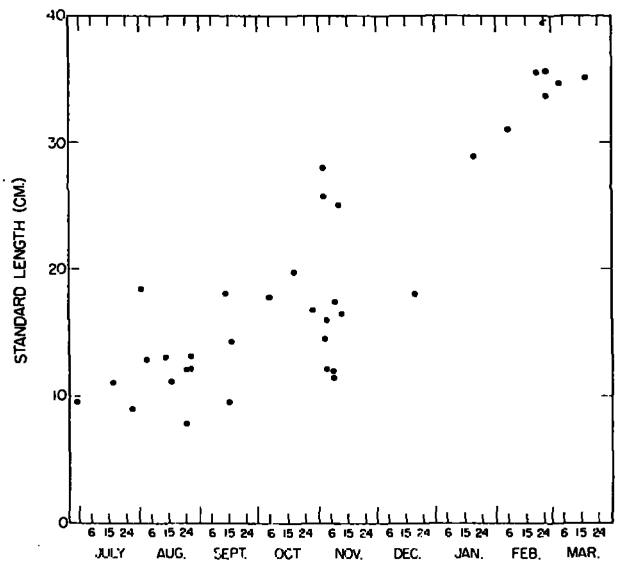

FIGURE 1.—The size and sampling date of juvenile albacore found in billfish stomachs.

For an initial approximation of the growth of the juveniles, a linear regression was fitted to the data with the hatching date set arbitrarily on April 1. Then, assuming a hatching size of 3 mm.,[3] I extrapolated the regression to obtain a better estimate of the hatching date, which proved to be in early May. The regression was then recalculated with May 1 as the hatching date. The linear growth is represented by

$$l=0.349248+0.104184T$$

where l is standard length (cm.) and T is age in days. Figure 2 shows the regression and the observed data. Table 3 gives estimated lengths at various ages.

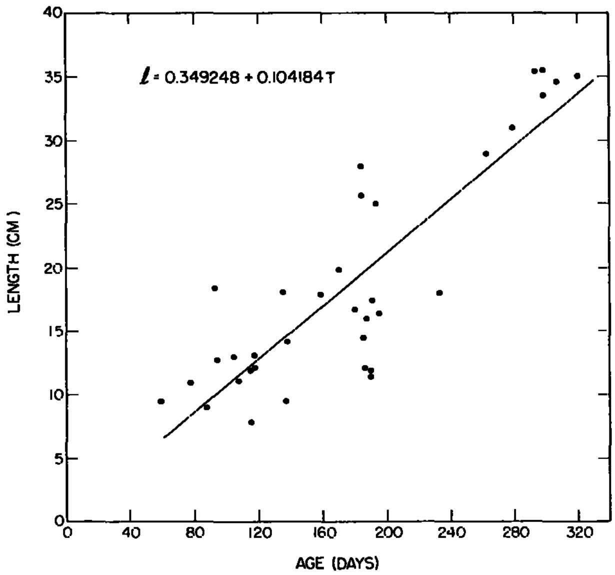

FIGURE 2.—Growth of juvenile albacore found in billfish stomachs.

TABLE 3.—*Expected lengths (derived from the linear regression) at various ages of juvenile albacore from billfish stomachs*

Age*	Standard length	Age*	Standard length
	Linear regression		Linear regression
Days	*Cm.*	*Days*	*Cm.*
60	6.6	240	25.3
90	9.7	270	28.5
120	12.8	300	31.6
150	16.0	330	34.7
180	19.1	360	37.8
210	22.2	365	38.4

*The age is based on an estimated hatching date of May 1 and should be considered only tentative.

[3] Matsumoto's (1958) observations suggest that tuna larvae are about 2 to 3 mm. long at hatching.

The data from this study have a bearing on an unresolved problem in the biology of albacore—that of determining the absolute age of the fish. Various investigators, using scales and vertebrae for aging, have reported conflicting results in determining the absolute age of albacore. Others attempted to estimate the age of groups of albacore that appear regularly in the commercial catch. Investigators now generally agree that the modal groups in the Pacific albacore fisheries represent year classes, but disagree on the ages assigned to the year classes (Clemens, 1961; Otsu and Uchida, 1963).

The expected length that I estimated for 1-year-old fish is most similar to that given by Aikawa and Katō (1938), who made one of the earlier studies on the age and growth of albacore. Their results, however, were not generally accepted because they postulated rectilinear growth. Otsu (1960) was not entirely satisfied with the results of fitting a Gompertz curve to his growth data, which indicated that albacore required 3 years to grow about 30 cm. TL[4] (total length). In a later study Otsu and Uchida (1963) speculated that albacore 30 to 35 cm. TL, which sometimes appear in the commercial catches, were probably 1-year-old fish, and albacore 50 to 55 cm. TL were 2-year olds. Clemens (1961) and Bell (1962), on the other hand, assigned lengths of 52 cm. and 57.3 cm. TL, respectively, to 1-year-old albacore.

SEASONAL AND LENGTH DISTRIBUTION OF JUVENILE ALBACORE

Catch per unit of effort is often used to assess apparent abundance of fishes. For this study I used the number of juveniles per 100 billfishes as an index of apparent abundance. Juvenile albacore were found in stomachs of only three (striped marlin, blue marlin, and shortbill spearfish) of the five billfish species examined. In calculating the monthly apparent abundance of juveniles, however, I used the total of all billfish species for each month. I assumed that (1) no differences exist among the billfish species in relative efficiency in capturing prey and the apparent abundance of all the billfish species did not greatly change over the years and that (2) billfishes will feed on juvenile albacore when they are available, not selecting

[4] Total length as defined by Marr and Schaefer (1949).

other prey in preference to juvenile albacore, or vice versa.

Serious error may result if my first assumption was not valid. Figure 3 shows the monthly distribution of striped marlin, blue marlin, and shortbill spearfish used in this study. These numbers generally reflect the seasonal abundance of these billfishes around Hawaii. Striped marlin are almost always more abundant than blue marlin and shortbill spearfish. Seasonally, striped marlin are most abundant from November to June and blue marlin are most abundant from June to September. Although the distribution of shortbill spearfish in figure 3 shows peaks in April and August, the seasonal abundance of this species is not well defined around Hawaii. Because of interspecific and intraspecific differences in seasonal abundance, differences in catching efficiency among the billfish species may affect estimates of juvenile albacore abundance. No attempt was made to test whether differences did exist in catching efficiency because the data were inadequate.

The second assumption is probably justified; studies on the food habits of billfishes indicate that they are broadly carnivorous (Royce, 1957).

Because of the small number of juveniles, the apparent abundance on a seasonal basis is shown in figure 4, for all years combined. Juvenile albacore occurred in billfish stomachs in all months except April and May; they were most numerous between August and November. The juveniles were generally larger in the winter than in the summer and fall. The large juveniles that were collected between January and March were most likely the progeny of spawning the previous spring.

My observations are consonant with the hypothesis of Otsu and Uchida (1963) that albacore spend their larval and early juvenile stages in subtropical waters and that the older juveniles then migrate into temperate waters. Otsu and Uchida also speculated that small albacore are probably abundant generally throughout temperate waters, but are not available to the commercial fisheries until they are 2 or 3 years old. Occasionally, small albacore (about 35 cm. TL) appear in the catches of the United States west coast and Japanese pole-and-line fisheries.

No attempt was made to find differences in abundance among areas, for example around the various islands, in Hawaiian waters. It is not realistic to do so because longline fishing is not random throughout the islands (Otsu, 1954). Because billfishes are fast-moving and can probably travel many miles in a single day, the location of their capture may not necessarily coincide with that at which they preyed on the juveniles.

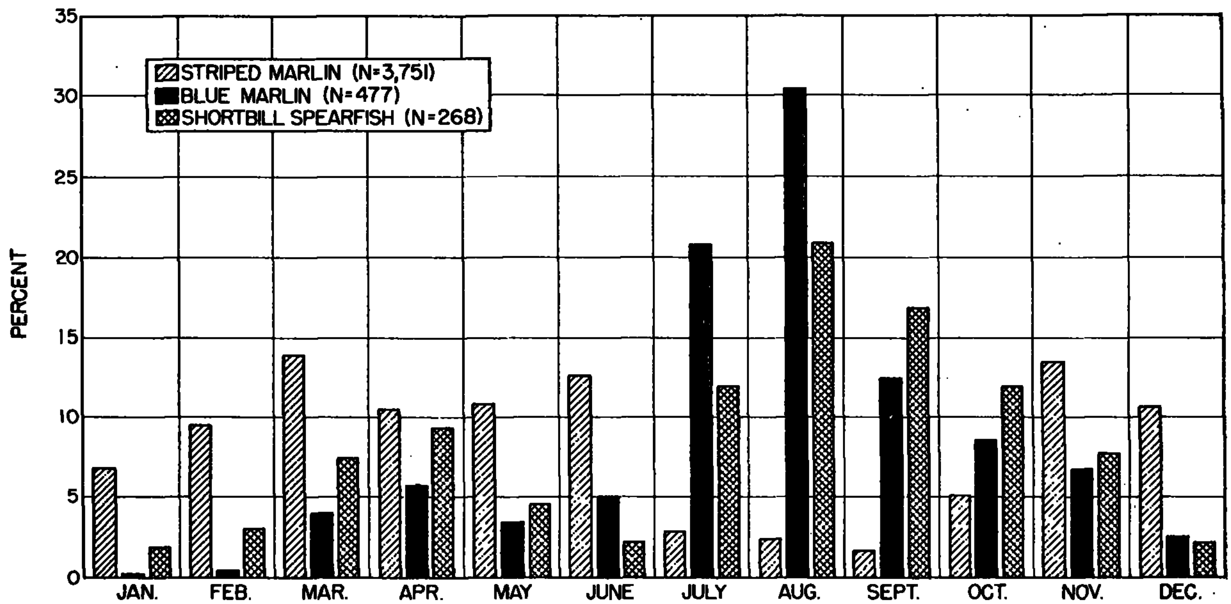

Figure 3.—Seasonal distribution of catches of striped marlin, blue marlin, and shortbill spearfish off Hawaii, 1962–65.

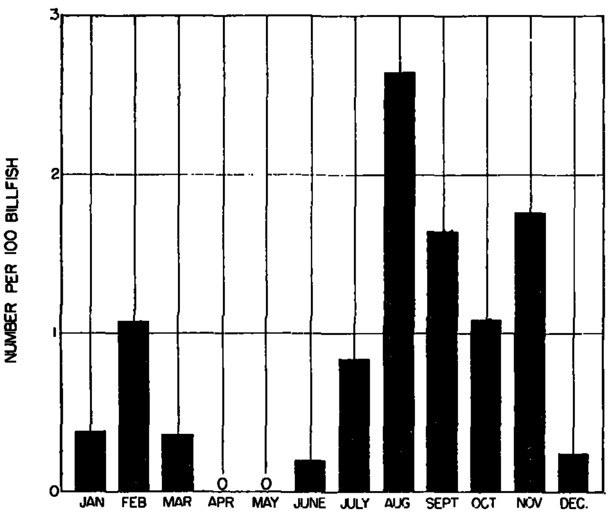

FIGURE 4.—Apparent seasonal abundance of juvenile albacore in Hawaiian waters, 1962–65.

SPAWNING

Yoshida (1965) reported that juvenile albacore occur near the Hawaiian Islands and tacitly assumed that albacore spawned in these waters. The most direct method of determining the spawning habits of fishes is to observe the spawning activity, where possible. Another method is to determine the seasonal and areal distribution of freshly fertilized ova and newly hatched larvae. Because these observations are not available, however, inferences on spawning must be made on indirect evidence.

Otsu and Uchida (1959), who examined albacore ovaries, indicated that albacore in the central and eastern North Pacific (between lat. 30° to 50° N. and the 180th meridian to the U.S. west coast) were either sexually immature fish or were adults that did not show signs of being near spawning. Adult albacore caught near Hawaii, however, showed evidence of active spawning during the summer. Furthermore, the northern limits of the distribution of all tuna larvae in the longitudes of the Hawaiian Islands are lat. 30° N. in the summer and 25° N. in the winter (Walter M. Matsumoto, personal communication). Finally, the wide size range of the juveniles around Hawaii suggests that they probably do not move great distances. I conclude, therefore, that albacore do spawn in Hawaiian waters and that the resulting juveniles spend at least part of their early life in these waters.

As noted earlier, the growth curve provided an estimate of early May as the time albacore larvae hatched. For all practical purposes the hatching and spawning periods can be considered coincident; Matsumoto (1958) estimated that the incubation period of fertilized tuna ova was not more than 4 days. The 5-percent confidence limits for the extrapolated hatching date suggest that albacore may spawn from March to September. I can conclude that albacore spawning around Hawaii peaks in May and may extend from March to September. These observations are not unlike that of Otsu and Uchida (1959), who postulated summer spawning for albacore in Hawaiian waters.

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