Diving Behaviour of Hawaiian Skipjack Tuna

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Introduction

The principal commercial fishery in Hawaii is for oceanic skipjack, *Katsuwonus pelamis* (Linnaeus), a surface-schooling tuna 40–90 cm in length which is captured exclusively by day using pole-and-line with live-bait as chum. In an attempt to increase the catch per unit of effort, the Honolulu Biological Laboratory (HBL), U.S. Bureau of Commercial Fisheries, has begun studies of skipjack behaviour. Major aspects of this subject have been investigated from an underwater observation chamber mounted on the research vessel "Charles H. Gilbert". This blister-like structure, which has been described by STRASBURG and YUEN (1960), is located two metres below the surface in the fishing area at the ship's stern. From this vantage point it is possible to study skipjack behaviour during fishing and at other times.

During July–September 1959, the "Charles H. Gilbert" was engaged in experimental skipjack fishing in Hawaiian waters. Experiments consisted of varying certain fishing conditions such as kind and amount of bait, bait supplements, etc., and in addition to such tests, collecting general information on the behaviour of skipjack. One conspicuous behaviour pattern observed during skipjack fishing was an abrupt vertical movement which we have called "diving". Diving consisted of skipjack vanishing from view in a nearly vertical direction, the fish disappearing at 30–60 m depths. This is of practical importance to the fisherman, for a school which dives frequently requires more bait and yields a smaller catch than a school which remains at the surface.

This report describes a possible cause of skipjack diving. Attention was focused on prey organisms because preliminary observations indicated a relation between prey and behaviour. For example, the fishermen believe that skipjack are conditioned to their natural food, and are difficult to catch with baits differing greatly from this food. In order to evaluate the feasibility of fishing a particular school they examine the spewings of the first few fish caught. The results of their examinations may be used to determine fishing procedure

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or to rationalize a poor catch. If the regurgitated material contains numerous postlarval synodontid fish, the fishermen believe that few skipjack will be caught and extensive bait expenditure is unwarranted.

Methods

Test fishing on the "Charles H. Gilbert" consisted of alternate periods of normal and experimental routine which allowed observers to compare skipjack behaviour under constrasting conditions. Although frequently affecting catch and catch rate, none of the tests caused the tuna to dive, and test effects are therefore ignored in the following account. Records of tuna activity consisted of underwater motion pictures, recorded oral comments by underwater and surface observers, and records of time and catch. Echo-sounders were not used to record skipjack activity primarily because these fish lack a swim-bladder and thus give poor echoes. After fishing, meteorological and water temperature data were obtained, and a sample of the catch was examined for length, sex, and food consumed.

Stomach contents were usually determined for a sample of ten skipjack, but a larger number was examined when an unusual diet was indicated. Dietary items were counted and a rough attempt made to judge their volumes. Excluding bait, 42 food items were encountered, but only ten of these occurred frequently. One of these, unidentified fish remains, was not considered further, but an idea of the importance of the others can be obtained from Table 1.

Identification of the more important food items was necessarily based on the specimens in best condition, and there is a possibility that other species occurred in the damaged material. Fish being eaten were postlarval *Acanthurus* spp. (Acanthuridae), postlarval *Chaetodon corallicola* Snyder (Chaetodontidae), juvenile *Holocentrus lacteoguttatus* Cuvier and Valenciennes (Holocentridae), juvenile *Parupeneus* sp. (Mullidae), and postlarval *Synodus variegatus* (Lacepède) (Synodontidae). Because these fish are littoral as adults, some interest is attached to the fact that their larval and juvenile stages are pelagic. It is thus desirable to explain the procedures used in identification and to briefly describe the specimens.

Acronurus-stage Acanthuridae were identified with the aid of RANDALL's publications (1955, 1956). Meristic characters were used to determine the silvery 25–33 mm chaetodontid postlarvae. Their formulae of dorsal rays XIII, 21 to 23 (usually 22); anal rays III, 18 or 19; pectoral rays 15; and scale rows 31 to 33 are referable only to *Chaetodon corallicola* among the Hawaiian butterfly fishes (GOSLINE and BROCK, 1960; WOODS, in SCHULTZ, *et al.*, 1953; and personal examination of specimens). The squirrel fish were all *Holocentrus lacteoguttatus* (WOODS, in SCHULTZ, *et al.*, 1953; GOSLINE and BROCK, 1960); they were 54–58 mm in standard length, deep blue dorsally, silvery ventrally, and with a bright violet stripe separating these colours. The mullids were also blue and silver, and 53–58 mm in standard length. Four preserved mullids had a single row of caniniform teeth in each jaw and $2\frac{1}{2}$ scale rows between the lateral line and the dorsal fin interspace. According to GOSLINE and BROCK (1960) they are therefore a species of *Parupeneus*. The descriptions by GIBBS (1959), GOSLINE and BROCK (1960), and SCHULTZ (in SCHULTZ, *et al.*, 1953) were used to identify synodontid postlarvae. The deep-lying dark spots as well as the

Table 1

Diet versus dive-frequency in skipjack

Station number	Number of dives: Dives ≥ 1 min.	Number of dives: All dives	Number of skipjack eating item (adjusted to sample size 10): Acanthuridae	Chaetodontidae	Holocentridae	Mullidae	Synodontidae	Crab megalops	Squid	Stomatopods	Empty
45– 2	0	0	0	0	0	7	0	0	1	0	0
– 3	3	5	0	5·4	0	10	0	4·6	2·3	0·8	0
– 7	1	4	2	10	1	6	0	9	1	1	0
– 8	0	2	1	2	0	0	0	0	5	2	2
– 9	0	0	2	6	0	1	0	0	1	0	0
–23	3	3	0	5	0	0	0	0	0	1	2
–32	1	4	2	1	0	6	1	0	0	0	2
–33	1	2	6	9	1	1	2	1	9	4	1
–34	0	2	2	5	0	4	0	1	2	0	0
–35	1	3	6	10	3	6	2	0	6	4	0
–37	0	1	0	10	0	0	0	2	1·3	0·7	0
–38	1	1	0	10	0	0	1	0	0	1	0
–39	1	5	1	10	0	0	0	3	2	2	0
–44	1	2	1	5	0	2	0	1	3	1	2
–46	2	3	0	3·1	0·8	0	3·8	0	4·6	0·8	0·8
–47	1	1	0	0	0	4	0	0	3	0	5
–49	0	1	0	5	2	0	0	0	4	4	1
–50	5	7	0	2	3	0	4	0	8	0	0
–54	1	1	1	2	2	10	1	0	4	3	0
–57	0	1	1·2	0	0	0·6	0·6	5	1·9	8·8	0
–58	3	5	1	1	2	0	0	1	1	5	1
–59	1	3	0	0·7	3	9·3	0	0	0·7	0	0·7
46– 7	1	1	1·7	0	0	0	0	0	3·3	0·6	4·4
–10	6	8	2	0	9	1	2	0	5	1	0
r, all dives			0·036	−0·061	0·622[2]	−0·020	0·426[1]	0·160	0·242	−0·093	−0·228
r, dives ≥ 1 min..			−0·089	−0·233	0·681[2]	−0·101	0·518[2]	−0·089	0·294	−0·046	−0·087
% of stomachs containing item (305 stomachs examined)			10·5	36·7	9·8	27·5	6·6	10·8	27·9	17·4	12·1
% of schools eating item (27 schools sampled)			51·9	74·1	44·4	55·6	37·0	33·3	85·2	70·4	48·1

[1] Indicates a *p*-value between 0·05 and 0·01. [2] Indicates a *p*-value less than 0·01.

dentition of tongue and jaws showed the 12 preserved specimens to be *Synodus*; one specimen, at least, had the dorsal fin formula of *S. variegatus*. These postlarval lizardfish were large, 55–62 mm in standard length, and were eaten by skipjack captured 3–16 km from shore.

No attempt was made to identify the crabs megalops or stomatopods, but the squid were examined by Robert T. B. Iversen of HBL and identified as *Symplectoteuthis oualaniensis* (Lesson) and *Ommastrephes* sp., both of the family Ommastrephidae.

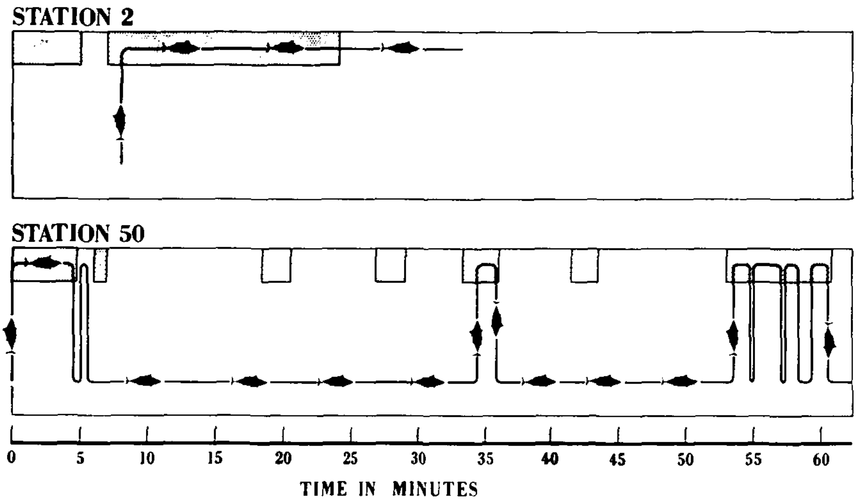

Figure 1. Activity of non-diving and diving schools of skipjack during fishing. Shaded blocks represent chumming intervals, fish figures indicate skipjack activity (surfacing or diving) during this period.

Relation of Diet to Diving

In the most desirable fishing situation a school of skipjack was attracted to the stern with live-bait (attracting fish with live-bait is locally known as chumming) and held there continuously for varying periods of time, usually about 20–30 minutes. With a diving school, the tuna were not only difficult to attract, but after fishing had begun it was periodically interrupted by the fish disappearing into the depths. Diagrammatic representations of extreme cases of these patterns of activity are given in Figure 1. Similar diagrams were prepared for all 24 schools observed in detail, and from these the number of dives per school was determined. A school which remained at the surface until the end of fishing was not considered to have dived, even though it departed in a dive after chumming stopped. Schools leaving the fishing area horizontally were also not considered to have dived, even if they emerged from the depths when re-engaged.

It was evident that diving was the rule rather than the exception (Figure 2). The number of dives per school ranged from 0 to 8, with a mean of 2·7. The tuna were away from the surface as briefly as 3 seconds or as long as 28 minutes. In the case of prolonged dives it was impossible to be certain that only one school was involved. It was felt, however, that only one was present, for the ship remained in the same spot and there were no indications (by birds or surface disturbance) of the approach of other fish. Thirty-three of the 65 dives observed resulted in a surface absence of one minute or more. Most dives were vertical or nearly so, and frequently the fish passed beneath the vessel as they descended. In nearly all cases diving was simultaneous among the hundred or more skipjack visible from the observation chamber.

As explained above, a sample of ten stomachs per school was examined for food. A few larger samples were proportionately reduced to ten for the sake of

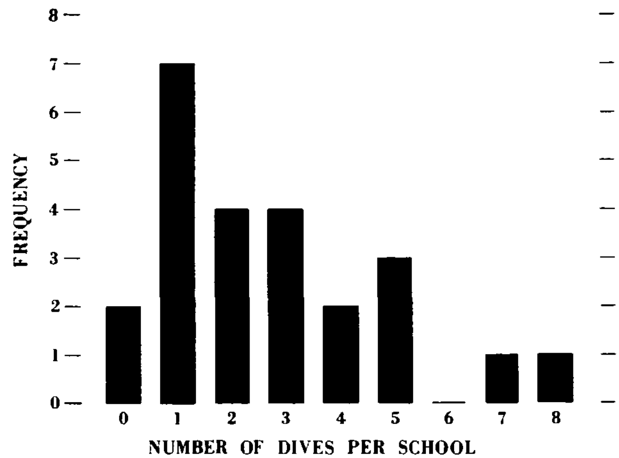

Figure 2. Frequency of diving in Hawaiian skipjack schools.

uniformity. The basic data, together with the results of the correlation analyses used to relate diet and dive-frequency are presented in Table 1. From this it is clear that the consumption of two foods, postlarval *Synodus variegatus* and juvenile *Holocentrus lacteoguttatus*, was significantly related to diving frequency. The correlation analyses treat each food item as if only it had been eaten, and therefore no particular account is taken of those cases, indicated in Table 1, in which *Synodus* and *Holocentrus* occurred together in skipjack stomachs.

Discussion

The food habits of Hawaiian skipjack have been discussed by WELSH (1949) and YUEN (1959), and are generally the same as those of skipjack of Japan (SUYEHIRO, 1938; HOTTA and OGAWA, 1955) and the Philippines (RONQUILLO, 1953). Wherever they occur, skipjack prey on small fish, squid, and crustaceans, taking a wide variety of species but also gorging on a few abundant forms. The heterogeneity of their diet has prompted RONQUILLO (1953) to state: "These pelagic fishes are seemingly nonselective, that is, they are voracious eaters. They would eat any living organism available."

With such proclivities it is perhaps surprising to find skipjack behaviour influenced by a particular kind of prey. One example of this phenomenon is YUEN's observation (1959) that skipjack feeding on nomeids, thunnids, carangids, and gempylids (all relatively fast swimmers) are caught at a greater rate than skipjack preying on slower-swimming chaetodontids, scorpaenids, molids, and acanthurids. Similarly, skipjack feeding on nomeids, thunnids, and gempylids, but not carangids, are caught for a longer time interval than those eating the slower species.

Other observations on the susceptibility to capture of skipjack schools in relation to their natural food are less clear-cut with respect to diet-induced behaviour. SUYEHIRO (1938) found that skipjack preying on neritic organisms (mackerel, horse mackerel, spotted shrimp, amphipods, and crab larvae) were relatively difficult to capture, whereas those taking oceanic food (flying fish, squid, and schizopods) were more easily caught. He surmised that this difference resulted from the relative abundance of food in neritic versus oceanic situations, rather than from a differential response to the food organisms.

It is unlikely that the consumption, *per se*, of *Synodus* or *Holocentrus* produces dyspepsia causing skipjack to flee the surface. Instead it is reasonable to think of them as diving in pursuit of deep-swimming prey whose attractiveness is greater than that of the chum. Thus, a school which is difficult to engage initially could be feeding on an enticing natural food, and one which dives after fishing has begun might be responding to natural food, or to other feeding skipjack, beneath it.

If better use is to be made of chum it is worthwhile to examine the characteristics of attractive natural food. In gross aspect there is little to distinguish *Holocentrus* from *Parupeneus*, the specimens recovered being of the same size, shape, and colour. They seem to have been equally available in 1959 (roughly half of the schools sampled had eaten each), although this is not always the case. YUEN (1959) found over three times as many schools eating holocentrids as mullids in 1956–57. Neither food seems to be preferred over the other, for although YUEN (unpublished data) found holocentrids in six times as many stomachs as mullids, the present data show holocentrids in one-third as many as mullids. Despite these vagaries, the fact remains that consumption of *Holocentrus* was associated with diving whereas consumption of *Parupeneus* was not. In addition to such possibilities as nonrandom sampling or a difference in the depth of occurrence of these two species, there is another possible explanation for this condition. This relates to prey behaviour, about which little is known, yet conceivably the "action" of *Holocentrus* might be attractive to skipjack whereas that of *Parupeneus* might not.

The other fish associated with diving, *Synodus variegatus*, is one of the few skipjack prey species having a prominent colour pattern. Whereas the other food organisms are inconspicuously colourless, blue, or silver, living *Synodus* postlarvae bear a series of large blackish spots on an otherwise unpigmented body. These markings are conspicuous to the human eye but do not suggest a fish-like form owing to the transparency of the intervening flesh. Instead an impression is given of an advancing file of disassociated spots. Judging from the dive data, skipjack detect and react to *Synodus* at distances on the order of 30 m. The immediacy of their response suggests triggering by some releaser, perhaps the spotted pattern of the prey. Apparently only a few *Synodus* are available to a skipjack school, for only 6·6 % of the stomachs examined in this study contained them, and YUEN (unpublished data) found them in only 10 of 573 stomachs. If these fish are as desirable skipjack food as they seem to be, then perhaps their characteristics can be put to human use. Mr. John C. MARR of HBL is presently examining the efficacy of skipjack lures having the shape and pattern of postlarval *Synodus*.

Summary

Observations from an underwater chamber showed that schools of skipjack commonly dive during fishing, leaving the surface for a minute or more on many occasions. Stomach analyses showed that the presence of two prey fish,

Synodus variegatus and *Holocentrus lacteoguttatus*, was significantly related to diving frequency. It was hypothesized that these two species were more attractive than the live-bait used by the fishermen, and that the skipjack dived in pursuit of them. A study of the characteristics of attractive natural food may lead to the development of better bait and lures for catching skipjack.

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