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A Contribution to the Trophic Biology of the Blue Marlin (*Makaira nigricans* Lacépède, 1802) in Hawaii[1]

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ABSTRACT: A study of the trophic biology of 87 blue marlin caught in Hawaiian waters indicates that these opportunistic predators consume a diverse array of prey. The data suggest that the diet of blue marlin is influenced by the locality of capture. Thus, surface (troll)-caught blue marlin from near the Hawaiian Islands consume numerous larvae, postlarvae, and juveniles of inshore species, prey relatively rare in marlin taken on the high seas. Volumetrically, these inshore forms are of little consequence and probably contribute little to the energy requirements of blue marlin. As shown in other studies, small tunas are the single most important component of Hawaiian blue marlin diets.

THERE HAS BEEN CONSIDERABLE interest in the feeding habits of the blue marlin (*Makaira nigricans*). This is probably due to its large size (to 800 kg), game qualities, reputed pugnacity, and its position as a terminal predator in the ocean. Most trophic studies of this species have simply identified and determined the relative importance of food items consumed in a given geographic region. Usually there has been little other concurrent ecological information available to the investigator, and sample sizes are often small. These difficulties have resulted in a situation where some information is available on what is consumed by blue marlin from a number of geographical localities but little else is known of their trophic biology.

This paper reports on the food and feeding habits of 87 blue marlin taken off Hawaii during one-week tournaments in each of two consecutive summers utilizing concomitant ecological information (size, location, and time of catch) to obtain a better understanding of their trophic biology.

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MATERIALS AND METHODS

Stomachs for analysis were obtained from blue marlin caught in the 27–29 July 1981 and 16–20 August 1982 Hawaiian International Billfish Tournaments (HIBT). In these tournaments fish are taken off the Kona, Hawaii, coast in an area from Upolu Point (20°18′N lat.) to South Point (19°00′N lat.) and from the shore westward to 156°20′W long. The HIBT rules require records of catch location, time of hookup, fight time, and gear used. Effort in both years was similar with 75 boats each fishing an 8-hour day. Small variations in effort expended could be due to differences in the number of lines fished per boat, the method of fishing (live bait or plastic lures), or due to the time spent fighting an individual fish. These differences are probably small, however, thus allowing direct comparison of catches. Once landed all fish were weighed, length measurements taken, sex determined, stomach removed and cut open and the contents labeled and placed in 0.5 mm mesh bags which were immersed in 10 percent formalin. All stomachs were sampled on the day of capture. At the time of sampling care was taken not to confuse any bait with other stomach

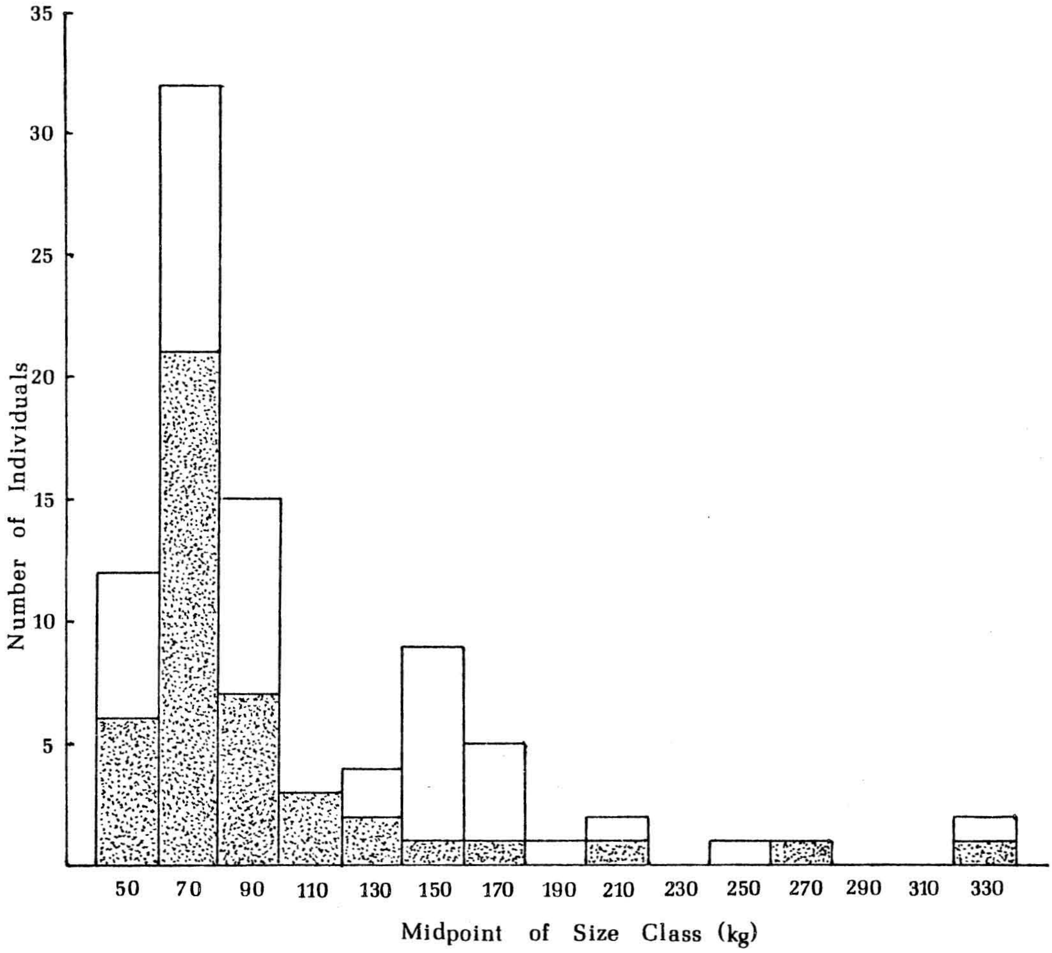

FIGURE 1. Frequency distribution of size classes (by 20 kg intervals) of blue marlin sampled in this study (fish caught in 1981 = shaded, 1982 = unshaded).

materials. Small tunas were the usual bait and were readily discerned as such by the presence of bridles or wounds caused by hooks. All bait was discarded.

In the laboratory all material was rinsed in fresh water and identified to the lowest taxonomic category possible. Taxonomic works consulted include Berry (1914) for cephalopods, Townsley (1953) and Barnes (1974) for crustaceans, and for fish Gilbert (1905), Weber and De Beaufort (1913–1936), De Beaufort (1940), De Beaufort and Chapman (1951), Gosline and Brock (1960), Fritzsche (1978), Hardy (1978*a*, 1978*b*), Johnson (1978), Jones, Martin, and Hardy (1978), Martin and Drewry (1978), and Miller, Watson, and Leis (1979). Following identification, a volumetric determination was made on all taxonomic categories. All material was labeled and preserved in isopropyl alcohol for later reference.

RESULTS

Most blue marlin sampled in this study were relatively small. The average size in 1981 was 95 kg and in 1982, 114 kg. The size frequency distribution of sampled fish by year is given in Figure 1.

In total 108 fish were sampled, 52 from the 1981 tournament and 56 from the 1982 tournament. In 1981 eight fish had everted stomachs and were not considered in any further analysis. Of the remaining 44, seventeen (39 percent) had empty stomachs and with the remainder the average volume of food per fish was 418 ml. In 1982 thirteen blue marlin had everted stomachs leaving 43 fish for further analysis. Of the 43 marlin (12 percent), 5 had empty stomachs, and in the remaining fish, the average volume of food present was 403 ml per fish.

Representatives of 23 fish families and four major invertebrate groups were found in the stomach contents of 65 blue marlin (Table 1). Fish comprised 99.4 percent of the total volume of food remains in 1981 and 98.5 percent in 1982. The remaining material was made up of arthropods and molluscs (particularly squids of the Family Ommastrephidae).

The scombrids were the most important identifiable fishes by volume of material (86.4 percent in 1981, 67.8 percent in 1982). By count of individuals or entities, the unidentified fish remains were the most important group followed by the scombrids. Again by number, squids were the most important invertebrate taxon, probably due to the retention of their nondigestible radulae.

A wide range of fish species was consumed including the larvae and juveniles of a number of inshore forms. These juveniles were in the families Fistulariidae, Holocentridae, Priacanthidae, Mullidae, Chaetodontidae, Pomacentridae, Acanthuridae, Balistidae, and Tetraodontidae. These fishes contributed heavily to the number of identifiable individuals consumed, occurring in 78 percent of the blue marlin examined, but added little to the total volume of prey material (Table 1).

Few postlarvae of pelagic species were encountered in the stomach contents of the blue marlin. Exceptions were postlarvae of the ocean sunfishes (Family Molidae) and juvenile scombrids and coryphaenids. In both years a number of juvenile istiophorids were found in the stomachs of adults. Thus, cannibalism at the family level accounted for 1.8 percent of the total volume of food found in marlin stomachs in 1981, and in 1982, 3.6 percent.

Table 2 presents the distribution of stomach content volumes. The large percentage of low food volume stomachs (near empty) in blue marlin may be related to the rate of digestion/or infrequent feeding. The weight of individual fish bears little relationship to the volume of food present; it is best described by a logarithmic function, however, the correlation coefficient is low ($r = 0.33$). There is a wide variation in the stomach volumes among fish of the same size, which masks any relationship between fish size and the amount of food consumed. This variation is related to the fact that large blue marlin eat organisms of greater dimensions than those consumed by smaller marlin, but that both groups feed on the same minute organisms, such as crab and fish larvae.

There was no discernible relationship between the hour of capture (i.e., time of hookup), the average volume of food present, and the number of blue marlin caught (Table 3). These data suggest that blue marlin are in the surface waters taking food during all hours of the day. More blue marlin were caught, however, near low ebb tide (about 47 percent of the total) than during any other part of the tidal cycle (Table 4). Similarly, good catches (about 25 percent of the total) were made during the period of near peak high tide. Collectively, the low slack tide period represents 38 percent of the total time (and effort) available for fishing during 1981 and 1982 tournaments, but these data are not statistically significant. The volume of food present in marlin stomachs was not related to the state of the tide (Table 4). This is because the material in stomachs may have been consumed at any time from many hours before to just prior to capture.

DISCUSSION

There are many uncontrollable variables in any study of the food habits of fishes. However, food items that rank large in number and volume, as well as in frequency of occurrence, are foods important at the time

TABLE 1

CHECKLIST OF FOOD ORGANISMS IN THE STOMACHS OF 65 BLUE MARLIN TAKEN IN THE HAWAIIAN INTERNATIONAL BILLFISH TOURNAMENT (27 INDIVIDUALS FROM 1981 AND 38 FROM 1982)

FOOD ORGANISMS	NUMBER OF ORGANISMS 1981	NUMBER OF ORGANISMS 1982	STOMACHS IN WHICH OCCURRED NUMBER 1981	STOMACHS IN WHICH OCCURRED NUMBER 1982	STOMACHS IN WHICH OCCURRED PERCENT 1981	STOMACHS IN WHICH OCCURRED PERCENT 1982	AGGREGATE TOTAL VOLUME ml 1981	AGGREGATE TOTAL VOLUME ml 1982	AGGREGATE TOTAL VOLUME PERCENT 1981	AGGREGATE TOTAL VOLUME PERCENT 1982
ARTHROPODA					4.4	2.1			0.1	0.1
Stomatopoda										
Squillidae										
Pseudosquilla ciliata		1		1				0.5		
Odondactylus hanseni		1		1				0.5		
Decapoda										
Unidentified Crab Megalops or Zoea	3	52	2	1			1.2	6.5		
MOLLUSCA					17.4	23.5			0.5	1.4
Decapoda	3	49	1	11			5.9	57.2		
Ommastrephidae	4	41	3	10			23.6	13.6		
Symplectoteuthis oualaniensis	3	7	2	2			13.5	70		
Symplectoteuthis sp.		7		4				43.1		
Hyaloteuthis pelagicus	2	6	2	3			8.7	24		
Octopoda		9		4				0.9		
CHORDATA (Pisces)										
Alepisauridae						0.7				0.6
Alepisaurus borealis		1		1				87		
Belonidae						0.7				5.9
Strongylura gigantea		1		1				900		
Fistulariidae						0.7				0.1
Fistularia commersonii		1		1					12	
Holocentridae	1	5	1	2	2.2	2.1	5.5	13	0.1	0.1
Myripristis sp.		1		1				9		
Sphyraenidae					2.2				0.1	
Sphyraena barracuda	1		1				16.1			
Priacanthidae					4.4	4.8			0.2	0.6
Priacanthus cruentatus	2	4	1	3			10	59		
Priacanthus sp.	1	4	1	4			12.5	35.5		
Carangidae	1	2	1	2	4.4	3.5	45	84	0.8	4.6
Decapterus pinnulatus	12	1	1	1			45.5	238		
Selar crumenophthalmus		4		2				382		
Coryphaenidae						1.4				3.7
Coryphaena hippurus		4		1				261		
Coryphaena equisetis		2		1				310		
Mullidae		6		3		2.1		57		0.4
Chaetodontidae		2		2		1.4		5.8		
Pomacentridae	2		1		2.2		7.8		0.1	
Acanthuridae		3		3	2.2	2.8		15.5		0.1
Ctenochaetus sp.	1		1				4			
Naso sp.		1		1				5		
Gempylidae						0.7				0.4
Gempylus serpens		1		1				56		
Scombridae	3	38	3	15	17.4	15.2	1,144	1,941.5	86.4	67.8
Acanthocybium solandri	1	1	1	1			4,200	160		
Scomber japonicus		4		1				215		
Auxis sp.		1		1				175		
Katsuwonus pelamis	5	5	3	4			2,100	7,900		
Thunnus albacares	1		1				2,300			
Istiophoridae	1	1	1	1	6.5	3.5	35	10	1.8	3.6
Tetrapterus angustirostris		1		1				116		
Istiophorus orientalis	2	3	2	3			173	427		

TABLE 1 (*continued*)

FOOD ORGANISMS	NUMBER OF ORGANISMS		STOMACHS IN WHICH OCCURRED				AGGREGATE TOTAL VOLUME			
			NUMBER		PERCENT		ml		PERCENT	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
Chiasmodontidae					2.2	2.1			0.2	0.2
Pseudoscopelus sp.	1	3	1	3			23.5	29		
Tetragonuridae		1		1		0.7		4		—
Dactylopteridae										—
Dactyloptena orientalis		1		1		0.7		6.5		
Balistidae	1	3	1	2	4.4	5.5	1.8	28	0.2	0.8
Canthidermis maculatus		1		1				11		
Xanthichthys auromarginatus	1		1				20			
Melichthys vidua		5		4				69.4		
Melichthys sp.		1		1				20.5		
Monacanthidae		1		1		4.1		1		0.3
Pervagor melanocephalus		2		2				13.5		
Cantherhines sandwichiensis		1		1				18		
Cantherhines sp.		2		2				14.5		
Tetraodontidae		10		6		6.9		238		5.6
Lagocephalus sp.		6		4				623		
Diodontidae						0.7				0.2
Diodon sp.		1		1				26		
Molidae										—
Ranzania laevis	2		1		2.2	0.7	38		0.3	
Masturus lanceolatus		3	1					4		
Unidentified fish and fish remains	36	81	13	20	28.3	13.8	1,044.6	531.5	9.3	3.6
TOTAL	90	392								

TABLE 2

DISTRIBUTION OF THE VOLUME OF TOTAL STOMACH CONTENTS FROM 87 BLUE MARLIN CAUGHT IN THE 1981 AND 1982 HIBT (data combined)

VOLUME OF STOMACH CONTENTS (ml)	NUMBER OF FISH	%	ACCUMULATED %
Empty	21	24	24
0.1–10	3	4	28
11–20	4	5	33
21–50	10	11	44
51–100	8	9	53
101–200	11	13	66
201–300	6	7	73
301–400	6	7	80
401–500	5	6	86
501–600	3	4	90
601–800	1	1	91
801–1,000	1	1	92
1,001–1,500	2	2	94
1,501–2,000	1	1	95
2,001–3,000	3	4	99
3,001–4,000			
4,001–5,000	1	1	100

TABLE 3

NUMBERS OF BLUE MARLIN CAPTURED BY THE HOUR DURING THE HIBT AND STOMACH CONTENTS DATA (1981 and 1982 data combined)

TIME	NUMBER OF MARLIN CAUGHT	AVERAGE AGGREGATE FOOD VOLUME (ml) PER STOMACH	AVERAGE VOLUME (ml) PER kg OF BODY WEIGHT
0800–0900	7	306	2.6
0901–1,000	13	459	7.4
1,001–1,100	14	157	1.5
1,101–1,200	7	584	5.8
1,201–1,300	12	133	3.5
1,301–1,400	9	356	3.0
1,401–1,500	4	243	3.0
1,501–1,600	7	35	0.4

TABLE 4

NUMBERS OF BLUE MARLIN CAPTURED AT DIFFERENT TIDE HEIGHTS DURING THE 1981 AND 1982 HIBT, EXPECTED CATCH, AND FOOD VOLUME DATA

TIDE HEIGHT (m)	NUMBERS OF BLUE MARLIN CAUGHT	EXPECTED CATCH OF BLUE MARLIN (corrected for effort)	AVERAGE AGGREGATE FOOD VOLUME (ml) PER STOMACH	AVERAGE FOOD VOLUME (ml) PER kg OF BODY WEIGHT
−0.11–0.0	1	1.7	320	4.4
0.01–0.10	21	17.0	519	3.7
0.11–0.20	12	8.9	247	2.2
0.21–0.30	2	5.8	8	3.4
0.31–0.40	4	5.3	591	3.2
0.41–0.50	10	5.8	84	0.9
0.51–0.60	5	6.0	108	6.7
0.61–0.70	9	9.7	126	1.9
0.71–0.80	9	12.7	124	1.4

and locality of sampling (Reintjes and King 1953). Scombrids are the most important component in the diet of Hawaiian blue marlin sampled in this study. In other central Pacific marlin studies (Royce 1957, Strasburg 1970, Eldridge and Wares 1974) tuna are an important dietary component; in New Zealand waters (Baker 1966) and in the Caribbean (Krumholz and DeSylva 1958, Erdman 1962, DeSylva 1963, cited in Rivas 1975, Nakamura and Rivas 1972, cited in Rivas 1975) this importance has been similarly established. Tunas are probably a favored prey item because they are abundant, they co-occur over the geographical range of blue marlin, and they are of an appropriate size for most adult marlin.

The consumption of larvae and juveniles of fish and crustaceans indicates that adult blue marlin are capable of feeding on very small prey. Erdman (1962) noted that a 135 kg blue marlin landed in Puerto Rico had consumed a 38 mm postlarval surgeonfish. In the present study small prey in the size range of 5 to 60 mm were commonly found. This is in contrast to previous studies where most prey were larger. The lack of gill rakers in blue marlin suggests that these predators are probably selectively picking individual prey. For example, one blue marlin weighing 323 kg taken in 1982 had fed on 52 crab megalops (3 to 5 mm carapace length), 1 stomatopod larvae (*Pseudosquilla ciliata*, 36 mm TL), 1 juvenile butterflyfish (*Chaetodon* sp., 10 mm SL), 3 prejuvenile ocean sunfish (*Masturus lanceolatus*, 18 to 24 mm TL), 1 juvenile filefish

(*Pervagor melanocephalus*, 32 mm SL), and 3 juvenile puffers (Family Tetraodontidae, 5 to 7 mm SL).

The relatively large number of juvenile inshore fishes found in blue marlin stomachs may be a reflection of where and when these predators were captured. The majority of the marlin caught in the HIBT are taken within 8 km of land. Moreover, the tournament is held during the summer, when many Hawaiian inshore juvenile fish recruit from the plankton to the adult habitat (Miller, Watson, and Leis 1979). The diet of blue marlin taken further offshore is dominated by oceanic forms (Royce 1957, Strasburg 1970, Eldridge and Wares 1974).

Any method used in the analysis of food habits of fishes may underrate the importance of easily digestible tissues and soft-bodied prey (Randall 1967). Thus, a bias often operates favoring large prey or prey with hard parts that are frequently retained. Squids, represented by their radula, were an important dietary item by number in the sampled blue marlin but added little to the volume of food present. This bias is also present with the unidentified fish and fish remains category (Table 1), which was often comprised of skeletal remains. In general, however, estimating the body size of squids ($\bar{x} \approx 5$ cm TL) based on the size of radulae suggests that their contribution to the total volume of food is small.

Little is known about the vertical movements and feeding activity of blue marlin. In the central Pacific they are frequently taken on longline gear which fishes between 60–180 m (Royce 1957) as well as on the surface (Strasburg 1970). Baker (1966) in New Zealand, Erdman (1962) in Puerto Rico, and Strasburg (1970) in Hawaii have found both surface and deep-dwelling prey in the stomachs of blue marlin. Most prey from the blue marlin sampled in this study appear to be surface-dwelling forms (occurring in the upper 100 m of the water column) and were probably captured there. Nakamura and Rivas (1972), cited in Rivas (1975), found that blue marlin will take trolled surface baits most often between 1000 and 1100 hours in the northern Gulf of Mexico.

No statistically significant relationship between the number of blue marlin captured and the time of day, state of the tide or volume of food present in stomachs was apparent in the present study. Sonic tags have been used to track a blue marlin off the Kona, Hawaii, coast for 22.5 hours (Yuen, Dizon, and Uchiyama 1974). Swimming depth of this fish ranged from the surface to about 73 m but most time was spent in the upper 40 m of the water column. Blue marlin taken in the HIBT are caught on the surface. The low average volume of material in blue marlin stomachs of this study relative to the potential stomach capacity and size of these predators suggests that these fish are hungry and are on the surface in search of food. The pursuit of prey at the surface is more two-dimensional than it would be in deeper water, thus capture is probably easier at the surface. In addition, prey would probably be more visible in these well-lighted regions, and perhaps many prey species are more concentrated there.

In conclusion, the varied diet of Hawaiian blue marlin suggests that they are opportunistic predators feeding on a wide range of organisms both in size and morphology. The frequent occurrence of juvenile inshore forms in these blue marlin stomachs is probably related to the capture of these predators at the surface and relatively near to shore.

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