Journal of the Marine Biological Association of the United Kingdom, 2015, 95(3), 579–591. © Marine Biological Association of the United Kingdom, 2014
doi:10.1017/S0025315414001842

Food sources of common dolphinfish (*Coryphaena hippurus*) based on stomach content and stable isotopes analyses

A. TRIPP-VALDEZ, F. GALVÁN-MAGAÑA AND S. ORTEGA-GARCÍA

Centro Interdisciplinario de Ciencias Marinas, IPN, Av. Instituto Politécnico Nacional s/n, Col. Playa Palo de Santa Rita, La Paz B.C.S. 23096, México

Dolphinfish (Mahimahi) are a high-demand resource for sport and coastal fisheries, mainly in the Pacific Ocean. Due to their economic and ecological importance, studies of their biology are very important to understand their function in ecosystems. We used stable isotope and stomach content analyses to determine the most important prey of the common dolphinfish, as well as the trophic level of this species in two areas of the southern Gulf of California. Stomach contents of 445 specimens were analysed. Using both techniques, we found that the most important prey for dolphinfish in the southern Gulf of California were three invertebrate species followed by fish. This contrasts with results from other authors who found that this species was mainly piscivorous in other locations. Stomach content analysis indicated differences in prey biomass by area, season and size class. The isotopic analysis did not show significant differences between seasons or sexes. Both stomach contents and stable isotope analyses showed that although this predator consumed a wide prey spectrum, only a few prey items made up the bulk of the diet, which resulted in a low SD in $\delta^{15}N$ values and low Levin's index values. We conclude that this fish is an opportunistic predator that may consume a wide prey spectrum, but that it mainly consumes prey that are abundant in the area, such as crustaceans and cephalopods in the Gulf of California.

Keywords: Trophic ecology, stable isotope analysis, mahi-mahi, Mexico

Submitted 9 February 2014; accepted 6 November 2014; first published online 17 December 2014

INTRODUCTION

The common dolphinfish (*Coryphaena hippurus* Linnaeus, 1758) is a widely distributed and abundant epipelagic predator. This species is reported from 46°N to 38°S worldwide (Palko *et al.*, 1982; Norton, 1999). It is caught in oceanic, coastal and estuarine waters, and its distribution is restricted mainly to waters less than 30 m deep and over 20°C (Kojima, 1966; Palko *et al.*, 1982). Common dolphinfish are caught in several regions of the world, and are important in commercial and sport fisheries (Palko *et al.*, 1982). In Mexico, this species is in high demand for sport and coastal fisheries, especially in the Pacific Ocean (Aguilar-Palomino *et al.*, 1998, Zúñiga-Flores *et al.*, 2008).

Diet and feeding habit studies are important to understand the function of species in ecosystems. Studies on the feeding habits of common dolphinfish in several parts of the world have revealed that this species feeds mainly on fishes, followed by cephalopods and crustaceans (Tester & Nakamura, 1957; Rothschild, 1964; Rose & Hassler, 1974; Manooch *et al.*, 1983; Oxenford & Hunte, 1999).

Several studies have been carried out in the eastern Pacific Ocean on the feeding habits of this species, such as those by Hida (1973), Saucedo-Barrón (1990), Campos *et al.* (1993), Aguilar-Palomino *et al.* (1998), Lasso & Zapata (1999), Olson & Galván-Magaña (2002), and Velasco-Tarelo (2003). These authors found that common dolphinfish are mainly piscivorous generalists.

All these earlier studies used stomach content analysis to describe diet; however, a technique that uses the accumulation of stable isotopes in animal tissues to describe their trophic ecology has recently become widely used (Minagawa & Wada, 1984). The stable isotope technique gives information on long-term feeding (depending on the tissue used), whereas stomach contents only provide short-term information of prey consumed at a given moment (Gearing, 1991). The most common isotopes used for trophic analyses are carbon (C) and nitrogen (N). Analysis of ^{15}N isotopes provides information on the trophic level of the predator, while ^{13}C isotopes analysis can trace the origin of the carbon through the trophic web (Clarke *et al.*, 2005). We used stable isotope analysis to describe the trophic ecology (Minagawa & Wada, 1984) of dolphinfish.

Further, we used previously published data on stomach contents of dolphinfish in Mazatlán to compare the diet composition between two areas in the southern Gulf of California (Tripp-Valdez *et al.*, 2010).

MATERIALS AND METHODS

Common dolphinfish were collected from the sport fishery of Cabo San Lucas (CSL) and from the artisanal fishing fleet of Mazatlán, during the years 2000, 2001 and 2003. Cabo San Lucas is located at 22°45′00″N and 109°30′00″W (Figure 1).

Corresponding author:
F. Galván-Magaña
Email: fgalvan@ipn.mx

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

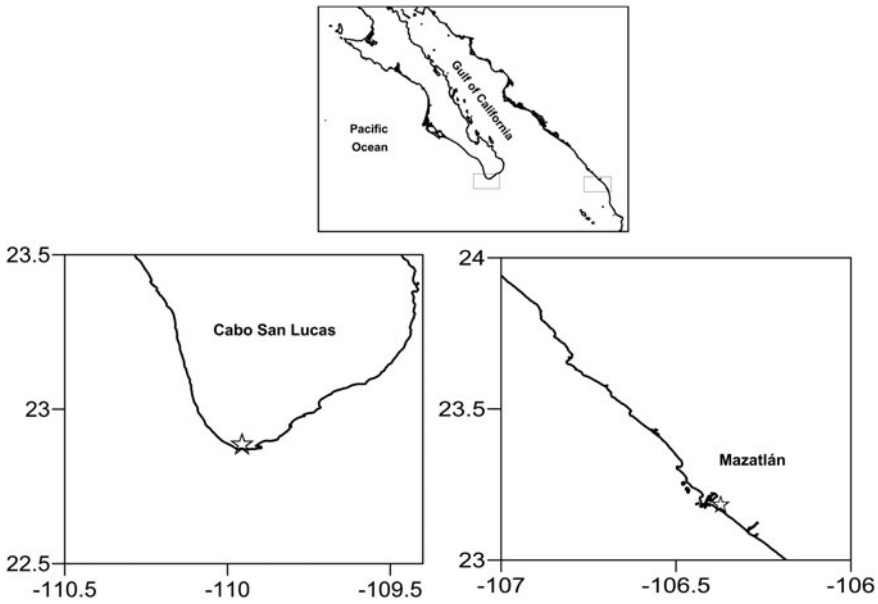


Fig. 1. Study area off the Baja California Peninsula in the Southern Gulf of California.

The sport fishing fleet in this area operates 20 to 30 nm from the coastline, trolling with rods or hand lines, with a lure or with live bait (mainly jack mackerel *Scomber japonicus*). Mazatlán is located at 23°04′25″N and 106°37′10″W; the artisanal fleets in Mazatlán operate in a similar manner to those of CSL, using hand lines.

Specimens collected were measured (fork length FL in cm), sex was determined, and stomachs were collected and preserved frozen. Data on stomach content from the Mazatlán area were obtained from the database used by Tripp-Valdez *et al.* (2010). Samples from the dorsal muscle region of dolphinfish were collected in 2003 when available. Muscle samples from selected prey species that were part of stomach contents and were in a minimal state of digestion were also collected for stable isotope analysis.

Stomach contents analysis

In the laboratory, prey items were identified to the lowest possible taxon, using specialized keys (Clothier, 1950; Iverson & Pinkas, 1971; Miller & Lea, 1972; Wolff, 1984; Clarke, 1986; Allen & Robertson, 1994; Fischer *et al.*, 1995; Thomson *et al.*, 2000). Prey items were counted (N) and weighed (W in g), and the frequency of occurrence (FO) was recorded (Hyslop, 1980). These measures were used because they are important in ecosystem models and comparative diet studies (Preti *et al.*, 2004).

To determine whether the analysed sample number was sufficient to accurately represent the common dolphinfish diet, we did a randomized cumulative Shannon diversity curve using the software EstimateS v8 and calculated the coefficient of variation (CV) of these values. When an asymptotic stabilization of the curve was obtained (Cortés, 1997) and a CV value below 0.05 was achieved, we considered that the minimum number of stomachs required to accurately describe the diet had been reached.

The N, W and FO values were combined to calculate the geometric importance index (GII) proposed by Assis (1996). This index was calculated using the following equation:

$$\mathbf{GII}_j = \frac{\left(\Sigma_{i=1}^{n} Vi\right)_j}{\sqrt{n}}$$

Where GII_j is the value of the index of geometric importance for the *j*th prey category, *Vi* is the sum of the percentages of the N, W and FO indices, and *n* is the number of indices used, in this case 3. This index measures prey importance as a distinct orthogonal vector; it combines the different index values into a resultant vector, and then solves for its components along a reference diagonal that represents maximum prey utilization. From the resulting geometry, the GII can be related directly to the degree of feeding specialization on a particular prey type (Assis, 1996; Preti *et al.*, 2001).

To determine differences in the diet of dolphinfish of different lengths, we grouped the specimens into three size classes: small (40–80 cm FL), medium (80–100 cm FL) and large (>100 cm FL) for analysis of size-related changes in diet. These size classes were chosen in such a way that all sizes were well represented based on the size distribution of dolphinfish in both areas.

Table 1. Number of samples by category for stomach contents and stable isotope samples

Categories		Stomachs with food		Stable isotopes samples	
		CSL	MAZ	CSL	MAZ
Sex	Males	72	93	7	9
	Females	91	111	7	8
Size Class	I	52	137	3	11
	II	76	40	4	4
	III	35	27	7	2
Season	Warm	108	164	11	13
	Cold	55	40	3	4

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

In order to determine whether there were differences in diet between sexes or size classes, similarity was analysed using permutation-randomization methods in a Bray–Curtis dissimilarity matrix (ANOSIM, PRIMER 6 v. 6.1.6). The global rank dissimilarity R ($0 \leq R \leq 1$) is a useful comparative measure of the degree of separation. When R is near zero, Ho cannot be rejected; i.e. there is no separation between groups (Clarke & Warwick, 2001).

The degree of selectivity of the common dolphinfish diet was determined using Levińs standardized index (Krebs, 1999):

$$B_i = \frac{1}{n-1\left\{\left(1/\sum P_{ij}^2\right)-1\right\}}$$

Where B_i is the trophic niche amplitude, $\sum P_{ij}$ is the proportion of the diet of predator i that includes prey j, and n is the total number of prey species. This index ranges from 0 to 1; values close to 0 (<0.6) indicate that the predator is selecting some prey groups; values close to 1 (>0.6) indicate that the predator is a generalist (Krebs, 1999).

The trophic level (TL) of common dolphinfish in the study area was determined using the TrophLab routine (available from www.fishbase.org) developed by Pauly *et al.* (2000), using the biomass of each principal prey group, as well as the trophic level of each prey. The prey trophic levels were obtained from the Fishbase database (http://www.fishbase.org) and SeaLifebase database (http://www.sealifebase.org).

In order to estimate seasonal changes in the dolphinfish diet we calculated the monthly sea surface temperature of the study area using AVHRR satellite images (4 km resolution) obtained from NOAA (http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/available.html).

Table 2. Composition of stomach contents from dolphinfish *Coryphaena hippurus* collected in Mazatlán expressed as absolute and percentage values of the frequency of occurrence (FO), numeric (N), weight (W) and GII indexes.

Prey items			FO	%FO	N	%N	W	%W	GII
Mollusca (Cephalopoda)	Argonautidae	*Argonauta cornuta*	20	9.8	109	4.49	98.7	1.032	8.8
	Loliginidae	*Loligo opalescens*	10	4.9	19	0.78	96.9	1.013	3.9
		Loliolopsis sp.	1	0.5	1	0.04	4.3	0.045	0.3
		Lolliguncula diomedeae	2	1.0	3	0.12	50.0	0.523	0.9
	Onychoteuthidae	*Onychoteuthis banksii*	3	1.5	3	0.12	137.2	1.436	1.7
	Thysanoteuthidae	*Thysanoteuthis rhombus*	1	0.5	1	0.04	4.6	0.048	0.3
Crustacea (Cirripedia)	—	—	1	0.5	1	0.04	0.1	0.001	0.3
Crustacea (Decapoda)	Galatheidae	*Pleuroncodes planipes*	3	1.5	52	2.14	20.9	0.218	2.2
	Goneplacidae	—	1	0.5	1	0.04	1.2	0.013	0.3
	Penaeidae	*Farfantepenaeus californiensis*	2	1.0	2	0.08	18.7	0.196	0.7
		Metapenaeopsis spp.	6	2.9	40	1.65	4.6	0.048	2.7
	Solenoceridae	*Solenocera florea*	1	0.5	2	0.08	0.9	0.009	0.3
	Brachyura	*Megalopa brachyuro*	1	0.5	1	0.04	4.3	0.045	0.3
		Crab[a]	1	0.5	1	0.04	0.5	0.005	0.3
Crustacea (Stomatopoda)	Squillidae	*Hemisquilla californiensis*	52	25.5	70	2.88	2443.9	25.572	31.1
	Squillidae	*Squilla panamensis*	1	0.5	1	0.04	2.6	0.027	0.3
Osteichthes	—	Remains of fishes	48	23.5	67	2.76	108.4	1.134	15.8
	Acanthuridae	*Prionurus punctatus*	1	0.5	3	0.12	0.4	0.005	0.4
	Ariidae	*Arius* sp.	1	0.5	1	0.04	100.0	1.046	0.9
	Balistidae	*Balistes polylepis*	54	26.5	97	4.00	98.6	1.032	18.2
		Sufflamens verres	1	0.5	1	0.04	2.5	0.026	0.3
	Batrachoididae	*Poricthys analis*	3	1.5	18	0.74	145.5	1.522	2.2
	Belonidae	*Tylosurus* spp.	1	0.5	1	0.04	0.1	0.001	0.3
	Blenniidae	*Ophioblennius steindachneri*	8	3.9	21	0.86	25.9	0.271	2.9
	Brotulidae	*Brotula clarkae*	1	0.5	1	0.04	1.5	0.016	0.3
	Carangidae	*Alectis ciliaris*	1	0.5	1	0.04	0.8	0.008	0.3
		Carangidae	1	0.5	1	0.04	0.7	0.007	0.3
		Caranx caballus	2	1.0	2	0.08	0.3	0.003	0.6
		Caranx caninus	3	1.5	4	0.16	90.3	0.945	1.5
		Caranx lugubris	5	2.5	11	0.45	66.3	0.694	2.1
		Caranx sp.	1	0.5	2	0.08	0.7	0.007	0.3
		Caranx speciosus	3	1.5	3	0.12	4.0	0.042	0.9
		Caranx vinctus	1	0.5	1	0.04	0.2	0.002	0.3
		Chloroscombrus orqueta	2	1.0	5	0.20	0.6	0.004	0.3
		Decapterus macrosoma	1	0.5	4	0.16	8.5	0.089	0.4
		Decapterus sp.	6	2.9	9	0.37	88.6	0.927	2.4
		Naucrates ductor	1	0.5	1	0.04	0.1	0.001	0.3
		Selar crumenophtalmus	1	0.5	1	0.04	26.0	0.272	0.5
		Selene brevoortii	1	0.5	1	0.04	1.5	0.015	0.3
		Selene peruviana	11	5.4	13	0.54	20.7	0.216	3.5
		Seriola lalandi	3	1.5	4	0.16	48.2	0.504	1.2
		Seriola sp.	1	0.5	1	0.04	0.1	0.001	0.3
		Trachinotus paitensis	1	0.5	1	0.04	0.6	0.006	0.3

Continued

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Table 2. Continued

Prey items			FO	%FO	N	%N	W	%W	GII
		Trachurus symmetricus	6	2.9	11	0.45	44.8	0.469	2.2
	Chaetodontidae	*Chaetodon humeralis*	1	0.5	1	0.04	22.4	0.235	0.4
		Johnrondallia nigrirostris	1	0.5	12	0.49	0.9	0.010	0.6
	Clupeidae	—	1	0.5	1	0.04	1.2	0.012	0.3
		Opisthonema sp.	3	1.5	3	0.12	69.2	0.724	1.3
		Sardinops caerulus	4	2.0	23	0.95	2.2	0.023	1.7
	Coryphaenidae	*Coryphaena hippurus*	4	2.0	4	0.16	31.9	0.333	1.4
	Diodontidae	*Diodon hystrix*	1	0.5	2	0.08	7.7	0.081	0.4
	Engraulidae	—	2	1.0	5	0.21	23.3	0.243	0.8
		Anchoa sp.	2	1.0	7	0.29	0.5	0.005	0.7
		Engraulis mordax	8	3.9	42	1.73	4.5	0.047	3.3
		Harengula thrissina	1	0.5	2	0.08	130.1	1.361	1.1
	Exocoetidae	—	1	0.5	1	0.04	45.6	0.477	0.6
		Hirundichthys marginatus	3	1.5	4	0.16	8.1	0.085	1.0
		Prognichthys tringa	1	0.5	1	0.04	43.7	0.458	0.6
	Fistularidae	*Fistularia comersonii*	2	1.0	2	0.08	16.2	0.169	0.7
	Gempylidae	*Gempylus serpens*	1	0.5	1	0.04	1.0	0.011	0.3
	Gerreidae	*Eucinostomus* sp.	1	0.5	1	0.04	42.9	0.448	0.6
	Gobiidae	*Ilypnus gilberti*	4	2.0	4	0.16	127.7	1.337	2.0
	Haemulidae	*Haemulopsis axilaris*	2	1.0	3	0.12	1.6	0.017	0.6
	Hemiramphidae	*Hemiramphus saltator*	6	2.9	62	2.55	4.6	0.049	3.2
		Hyporamphus unifasciatus	2	1.0	2	0.08	119.0	1.245	1.3
		Oxyporhamphus micropterus	1	0.5	1	0.04	27.8	0.291	0.5
	Holocentridae	*Sargocentron suborbitalis*	3	1.5	7	0.29	5.8	0.061	1.1
		Myripristis leiognathus	3	1.5	11	0.45	4.8	0.050	1.1
	Labridae	*Bodianus diplotaenia*	1	0.5	1	0.04	0.5	0.006	0.3
	Monacanthiade	*Aluterus monoceros*	10	4.9	14	0.58	44.5	0.466	3.4
	Mugilidae	*Chaenomugil proboscidens*	7	3.4	11	0.45	16.3	0.171	2.3
		Mugil cephalus	1	0.5	3	0.12	1.4	0.015	0.4
		Mugil hospes	6	2.9	7	0.29	282.3	2.954	3.6
		Mugil sp.	8	3.9	93	3.83	39.2	0.410	4.7
	Polynemidae	*Polydactylus approximans*	18	8.8	97	4.00	36.0	0.377	7.6
	Priacanthidae	*Heteropriacanthus cruentatus*	86	42.2	1203	49.55	201.6	2.109	54.2
		Priacanthus spp.	1	0.5	1	0.04	1.0	0.010	0.3
		Pristigenys serrula	5	2.5	10	0.41	6.1	0.064	1.7
	Scianidae	—	1	0.5	1	0.04	32.0	0.334	0.5
		Cynoscion parvipinnis	1	0.5	2	0.08	51.4	0.537	0.6
		Cynoscion sp.	4	2.0	7	0.29	0.9	0.010	1.3
		Cynoscion xanthulus	2	1.0	2	0.08	0.5	0.005	0.6
		Umbrina sinaloe	1	0.5	1	0.04	0.7	0.007	0.3
	Scombridae	—	2	1.0	3	0.12	1.8	0.019	0.6
		Auxis spp.	1	0.5	1	0.04	41.3	0.432	0.6
		Scomber japonicus	2	1.0	6	0.25	84.4	0.883	1.2
		Scomber japonicus	1	0.5	2	0.08	0.1	0.001	0.3
		Scomberomorus sierra	14	6.9	68	2.80	11.1	0.116	5.6
	Serranidae	*Paralabrax* sp.	3	1.5	6	0.25	14.7	0.154	1.1
	Serranidae	—	1	0.5	2	0.08	0.0	0.000	0.3
	Syngnathidae	*Hippocampus ingens*	8	3.9	17	0.70	3.6	0.038	2.7
	Tetradontidae	—	3	1.5	3	0.12	14.0	0.147	1.0
		Lagocephalus lagocephalus	1	0.5	1	0.04	1.3	0.013	0.3
		Sphoeroides annulatus	16	7.8	27	1.11	5.2	0.055	5.2
		Sphoeroides sp.	4	2.0	29	1.19	10.2	0.107	1.9
	Triglidae	*Prionotus horrens*	1	0.5	2	0.08	0.5	0.005	0.3

[a]No identified specimens.

Using this information we defined a cold season from December to June, and a warm season from July to November.

Stable isotope analysis

Samples of common dolphinfish muscle and their main prey were lyophilized to eliminate humidity. Since lipids are depleted in $\delta^{13}C$ relative to proteins and carbohydrates, and variation in lipid contents among organisms or among tissue types would introduce considerable bias in stable isotope analyses that use $\delta^{13}C$ (Post *et al.*, 2007), lipids were extracted using a MARS-5 microwave oven (CEM Corp., Matthews, NC), which is a fast and efficient method to extract lipids (Paré *et al.*, 1994; Renoe, 1994).

Samples were homogenized to a fine powder using an agate mortar. Stable isotope analysis was carried out using an

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Table 3. Composition of stomach contents from dolphinfish *Coryphaena hippurus* collected in Cabo San Lucas expressed as absolute and percentage values of the frequency of occurrence (FO), numeric (N), weight (W) and GII indexes.

Prey items			FO	%FO	N	%N	W	%W	GII
Mollusca (Cephalopoda)	—	Remains of cephalopods	6	3.7	6	0.14	133.2	0.745	2.6
	Argonautidae	*Argonauta* sp.	9	5.5	40	0.96	40.1	0.225	3.9
	Loliginidae	*Lolliguncula diomedeae*	2	1.2	2	0.05	4.4	0.025	0.8
	Ommastrephidae	Ommastrephidae	1	0.6	2	0.05	51.7	0.289	0.5
		Ancistrocheirus lesueuri	10	6.1	13	0.31	2173.1	12.158	10.7
		Dosidicus gigas	16	9.8	44	1.06	8591.7	48.069	34.0
		Sthenoteuthis oualaniensis	1	0.6	1	0.02	174.4	0.976	0.9
	Onychoteuthidae	*Onychoteuthis banksii*	1	0.6	1	0.02	137.0	0.766	0.8
	Pholidoteuthidae	*Pholidoteuthis boschmai*	2	1.2	3	0.07	162.8	0.911	1.3
Crustacea	—	Remains of crustaceans	3	1.8	201	4.84	2.6	0.015	3.9
Crustacea (Stomatopoda)	Hemisquillidae	*Hemisquilla ensigera californiensis*	1	0.6	1	0.02	0.1	0.001	0.4
Crustacea (Isopoda)	Cymothoidae	Cymothoidae	2	1.2	2	0.05	0.7	0.004	0.7
Crustacea (Decapoda)	Penaeidae	Penaeidae	1	0.6	1	0.02	0.03	0.000	0.4
	Sergestidae	Sergestidae	3	1.8	3	0.07	8.1	0.046	1.1
	Sicyonidae	Sicyonidae	1	0.6	1	0.02	0.8	0.004	0.4
	Caridea	—	2	1.2	2	0.05	19.5	0.109	0.8
	Galateidae	*Pleuroncodes planipes*	47	28.8	3172	76.32	2170.2	12.142	67.7
	Portuniidae	*Portunus xantusii*	1	0.6	1	0.02	3.0	0.017	0.4
Osteichthyes	Argentinidae	*Argentina sialis*	1	0.6	1	0.02	15.9	0.089	0.4
	Atherinidae	*Atherinops affinis*	1	0.6	1	0.02	0.1	0.001	0.4
	Balistidae	*Balistes polylepis*	18	11.0	73	1.76	95.1	0.532	7.7
	Batrachoididae	*Porichthys* sp.	1	0.6	1	0.02	1.3	0.007	0.4
	Belonidae	*Platybelone argalus pterura*	1	0.6	2	0.05	60.5	0.338	0.6
	Bleniidae	*Ophioblennius* sp.	1	0.6	1	0.02	1.9	0.011	0.4
	Carangidae	—	4	2.5	10	0.24	42.3	0.237	1.7
		Caranx caballus	1	0.6	5	0.12	11.5	0.064	0.5
		Caranx sp.	5	3.1	12	0.29	6.3	0.035	2.0
		Caranx vinctus	3	1.8	3	0.07	29.8	0.167	1.2
		Decapterus macrosoma	1	0.6	1	0.02	5.5	0.031	0.4
		Decapterus muroadsi	2	1.2	4	0.10	3.4	0.019	0.8
		Oligoplites sp.	1	0.6	1	0.02	0.1	0.001	0.4
		Selar crumenophthalmus	17	10.4	27	0.65	906.9	5.074	9.3
		Selene oerstedii	1	0.6	1	0.02	13.7	0.076	0.4
		Trachurus symmetricus	2	1.2	2	0.05	361.0	2.020	1.9
	Chaetodontidae	*Chaetodon falcifer*	1	0.6	1	0.02	1.5	0.009	0.4
		Chaetodon humeralis	3	1.8	3	0.07	2.6	0.014	1.1
		Jhonrandallia nigriostris	1	0.6	1	0.02	1.5	0.008	0.4
	Clupeidae	—	1	0.6	1	0.02	0.3	0.002	0.4
		Etrumeus tere	1	0.6	1	0.02	0.2	0.001	0.4
		Harengula thrissina	7	4.3	36	0.87	133.7	0.748	3.4
		Lile stolifera	1	0.6	2	0.05	0.2	0.001	0.4
		Ophistonema sp.	2	1.2	11	0.26	12.0	0.067	0.9
		Sardinops caeruleus	3	1.8	5	0.12	35.2	0.197	1.2
	Coryphaenidae	*Coryphaena hippurus*	3	1.8	3	0.07	457.2	2.558	2.6
		Coryphaena sp.	1	0.6	3	0.07	3.0	0.017	0.4
	Cottidae	*Icelinus quadriceriatus*	3	1.8	6	0.14	3.3	0.018	1.2
	Diodontidae	*Diodon holocanthus*	3	1.8	11	0.26	46.7	0.261	1.4
	Engraulidae	*Anchoa delicatissima*	2	1.2	3	0.07	0.4	0.002	0.8
		Anchoa mundeloides	1	0.6	1	0.02	0.6	0.003	0.4
		Anchoa sp.	2	1.2	9	0.22	3.2	0.018	0.8
		Anchovia macrolepidota	1	0.6	1	0.02	72.0	0.403	0.6
		Engraulis mordax	2	1.2	2	0.05	0.04	0.000	0.7
	Exocoetidae	*Cheilopogon papilio*	1	0.6	1	0.02	36.5	0.204	0.5
		Cypselurus callopterus	2	1.2	2	0.05	126.5	0.707	1.1
		Fodiator acutorostratus	1	0.6	1	0.02	32.7	0.183	0.5
	Gobiidae	—	1	0.6	3	0.07	4.0	0.022	0.4
	Hemiramphidae	*Hyporhamphus unifasciatus*	2	1.2	3	0.07	7.9	0.044	0.8
		Oxyporhamphus micropterus	3	1.8	26	0.63	51.4	0.287	1.6
	Holocentridae	—	3	1.8	4	0.10	1.1	0.006	1.1
		Myripristis leiognathus	1	0.6	1	0.02	1.8	0.010	0.4
		Sargocentron suborbitalis	2	1.2	2	0.05	1.0	0.006	0.7
	Istiophoridae	*Istiophorus platypterus*	1	0.6	2	0.05	3.6	0.020	0.4
	Lutjanidae	*Lutjanus argentiventris*	1	0.6	1	0.02	0.1	0.000	0.4

Continued

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Table 3. Continued

Prey items			FO	%FO	N	%N	W	%W	GII
	Merlucciidae	*Merluccius productus*	1	0.6	1	0.02	3.2	0.018	0.4
	Mugilidae	*Mugil cephalus*	1	0.6	1	0.02	0.3	0.001	0.4
	Myctophidae	*Diogenichthys laternatus*	4	2.5	7	0.17	4.5	0.025	1.5
	Priacanthidae	*Heteropriacanthus cruentatus*	3	1.8	3	0.07	0.7	0.004	1.1
	Scombridae	*Auxis* sp.	8	4.9	11	0.26	94.2	0.527	3.3
		Euthynnus lineatus	1	0.6	1	0.02	9.4	0.053	0.4
		Katsuwonus pelamis	1	0.6	1	0.02	10.0	0.056	0.4
		Scomber japonicus	8	4.9	8	0.19	404.0	2.260	4.2
		Scomberomorus sierra	1	0.6	3	0.07	6.7	0.037	0.4
	Serranidae	*Paralabrax maculatofasciatus*	1	0.6	1	0.02	0.4	0.002	0.4
	Syngnathidae	*Hippocampus ingens*	1	0.6	1	0.02	0.5	0.003	0.4
	Synodontidae	*Synodus* sp.	1	0.6	5	0.12	1.3	0.007	0.4
	Tetraodontidae	*Lagocephalus lagocephalus*	13	8.0	14	0.34	741.9	4.151	7.2
	Tetraodontidae	*Sphoeroides* sp.	2	1.2	2	0.05	2.1	0.012	0.7
	Trichiuridae	—	1	0.6	1	0.02	0.5	0.003	0.4
	Tripterigidae	—	1	0.6	1	0.02	0.1	0.000	0.4
	Zaniolepididae	*Zaniolepis* sp.	1	0.6	1	0.02	0.8	0.004	0.4
		Remains of fishes	41	25.2	126	3.03	293.7	1.643	17.2
	Other prey	Incidental food	4	2.5	4	0.10	14.0	0.078	1.5
		No ID Eggs	1	0.6	165	3.97	0.8	0.004	2.6
		UOM	2	1.2	2	0.05	8.6	0.048	0.8
		Polychaeta	1	0.6	1	0.02	0.1	0.000	0.4
		No ID Prey	3	1.8	9	0.22	7.0	0.039	1.2

isotope ratio mass spectrometer (IRMS) (20–20 mass spectrometer, PDZ Europa, Sanback, UK). Results are expressed as δ values in ‰ deviation from international standards, using the following equation (Park & Epstein, 1961):

$$\delta^{15}\mathrm{N} \text{ or } \delta^{13}\mathrm{C} = [(R_{\mathrm{sample}}/R_{\mathrm{standard}}) - 1] \times 1000$$

$R = {}^{13}\mathrm{C}/{}^{12}\mathrm{C}$ or ${}^{15}\mathrm{N}/{}^{14}\mathrm{N}$ respectively

Standard = atmospheric nitrogen for N and Pee Dee Belemnite for C.

Isotopic values of common dolphinfish and their prey were included into a mixing model, using the SISUS software (Erhardt, 2007; www.statacumen.com/sisus/) to convert the isotopic values to values representing the relative contribution of the food type to the diet.

The model applies a Bayesian approach that uses values of carbon and nitrogen isotopes to calculate the most probable contribution of the different sources (prey) to the mix (predator). The results of this analysis are distributions of the importance of each item to the diet in percentage values, which range from 1 to 99%.

Prior to the analysis, we corrected the isotopic fractionation (enrichment) value of the predator by subtracting 2.4‰ from the average isotopic signal of common dolphinfish. This value was calculated by obtaining the average value of the isotopic difference between $\delta^{15}\mathrm{N}$ values of the predator and each prey type (Kelly *et al.*, 2012) in both areas.

The common dolphinfish trophic level was estimated from the isotopic values using the equation proposed by Post (2002).

$$TL_{\mathrm{isotope}} = \lambda + \frac{(\delta^{15}\mathrm{N}_{\mathrm{Predator}} - \delta^{15}\mathrm{N}_{\mathrm{Base}}}{\Delta_n}$$

where $\delta^{15}\mathrm{N}_{\mathrm{Predator}}$ is the *N* isotopic composition of dolphinfish, λ is the trophic level of the organism used to estimate the *N* isotopic composition of the food base (δ^{15}NBase), and Δn represents trophic enrichment (Post, 2002). For CSL the base prey used was *Pleuroncodes planipes*, which has a trophic level (TL) of 2.85, according to the Fishbase database

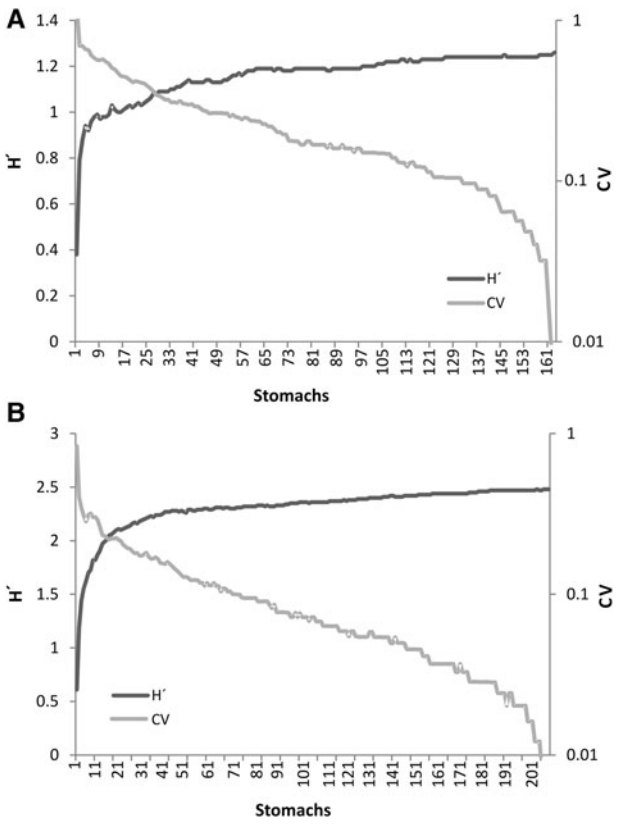


Fig. 2. Accumulated diversity curve for both areas, showing that the diet is well represented where the curve becomes asymptotic and the CV reaches a value under the 0.05. *A* = Cabo San Lucas, *B* = Mazatlán.

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

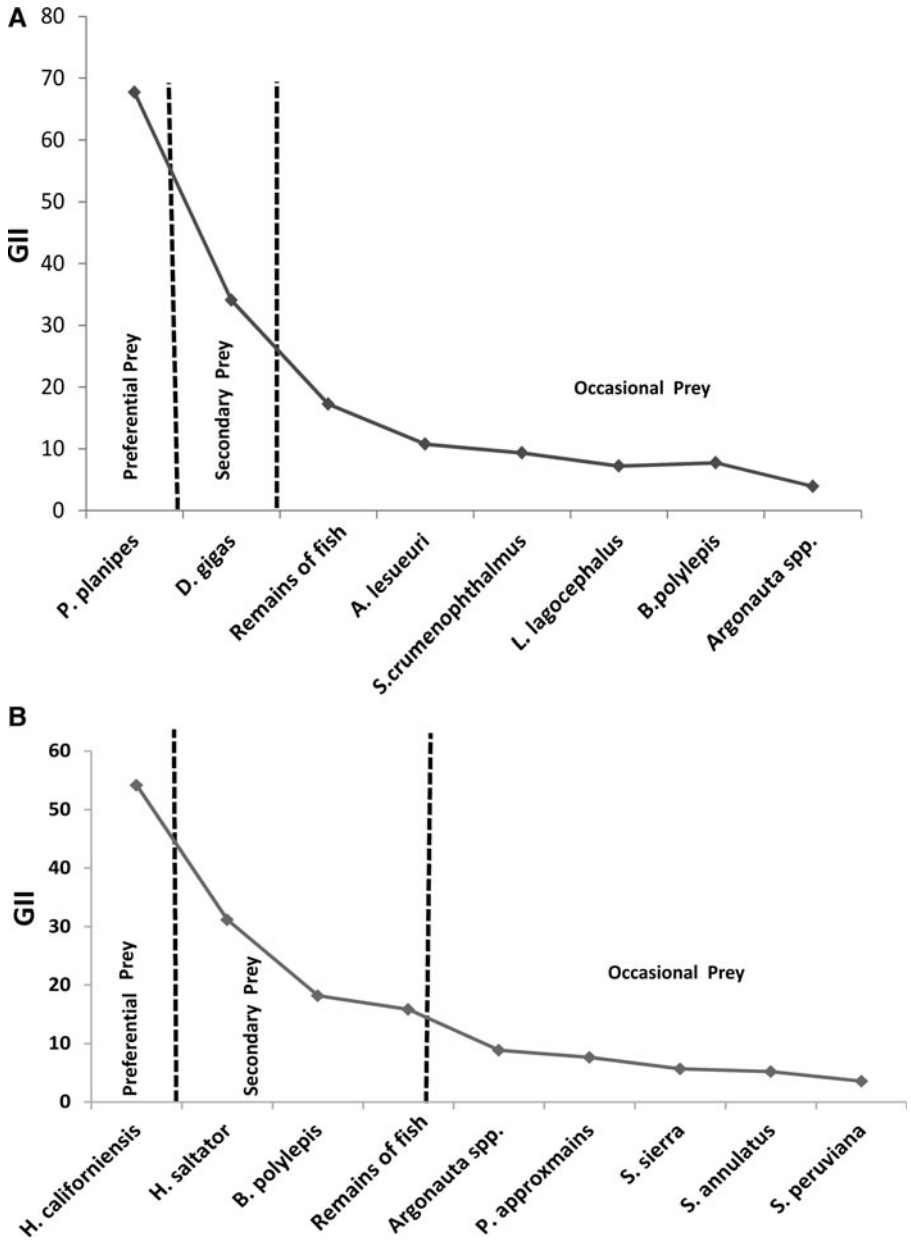


Fig. 3. Values of the geometric importance index, GII, for all fish analysed in both areas. Vertical lines separate preferential or primary prey from the secondary or occasional prey. *A* = Cabo San Lucas, *B* = Mazatlán.

(www.fishbase.org). For Mazatlán we used *Exocoetus volitans* as base prey, which has a TL of 3 according to Fishbase. For both zones we used an enrichment value of 2.4‰.

We tested differences in the diet between the different zones, size classes, seasons and sexes. We applied a multivariate analysis of variance (MANOVA) in R (R Development Core Team, 2011) version 2.14.1, using the vegan package for both stomach contents and isotopic values.

RESULTS

Stomach contents

A total of 215 stomachs were collected from CSL (Table 1). Sizes of dolphinfish ranged from 47 to 141 cm fork length, with an average size of 90 cm. Of 215 stomachs analysed, 76% contained food. The trophic spectrum comprised 86 prey items, of which 63 were fishes, nine were crustaceans, nine were molluscs (cephalopods) and the rest was unidentified organic matter (UOM) (Table 2).

A total of 230 stomachs were collected in Mazatlán (89% of them containing food). The size of dolphinfish ranged from 45 to 153 cm fork length, with an average of 77 cm. The trophic spectrum was composed of 98 prey items: 79 fishes, 10 crustaceans, seven molluscs, and UOM (Table 3). For both areas the number of analysed stomachs was deemed to be sufficient because the cumulative diversity curve reached an asymptote, and the CV was below 0.05 (Figure 2).

The MANOVA test showed significant multivariate effects of presence and biomass (W) of prey, which were attributed to season, area and size class ($F_{(1,294)} = 7.35$, 15.88, 4.39,

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

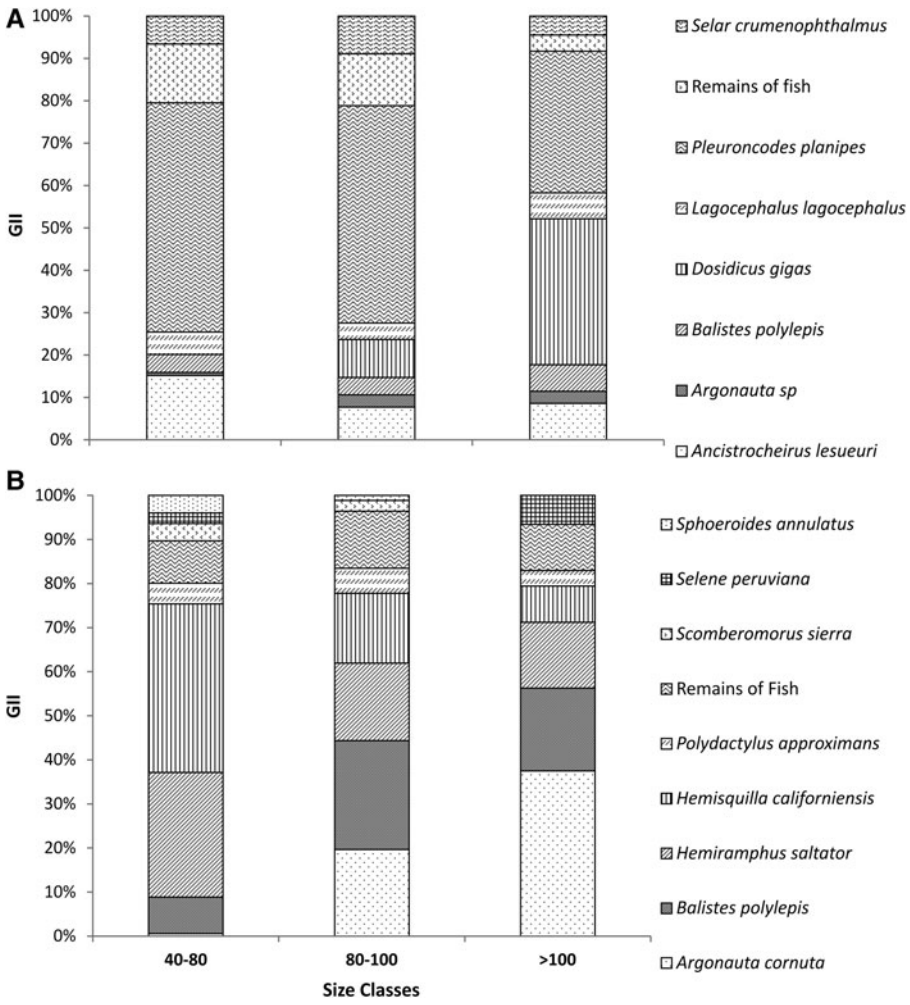


Fig. 4. Main dolphinfish prey species by size, expressed as % GII, as determined from samples taken during 2000, 2001 and 2003. *A* = Cabo San Lucas, *B* = Mazatlán.

$P = <0.001$). There was no significant effect due to sex $F_{(1,294)}$, $P = 0.747$. The species variability was explained by the season (2%), the area (5%) and the size class (1.4%).

In the CSL area, the geometric importance index (GII) indicated that *P. planipes* (GII = 67.7) was the most important prey, followed by the jumbo squid *Dosidicus gigas* (GII = 34). The remaining species were classified as secondary or rare prey (Figure 3, Table 2). In the Mazatlán area the GII indicated that the crustacean *Hemisquilla californiensis* (GII = 54) was the main prey, followed by the fish *Hemiramphus saltator* (GII = 31), the triggerfish *Balistes polylepis* (GII = 18) and fish remains (GII = 16). The remaining prey species were classified as secondary or rare prey (Figure 3, Table 3).

The diet was very similar for both sexes. The ANOSIM showed no diet separation between sexes. For CSL $R_{ANOSIM} = 0.013$ with $P = 0.07$, and for Mazatlán $R_{ANOSIM} = 0.005$ with $P = 0.231$.

Three size intervals were defined: 40–80 cm, 80–100 cm and >100 cm fork length. For CSL, we found that there was no separation in the diet of the first two size classes ($R_{ANOSIM} = 0.005$, $P = 0.622$), indicating that they were using the same prey in very similar proportions (Figure 4A). A comparison with the third size interval showed that there was a separation in the diet ($R_{ANOSIM} = 0.86$, $P = 0.001$); for this size class cephalopods had a higher importance than for the previous two size classes (Figure 4). For Mazatlán we found significant differences for each size class ($R_{ANOSIM} = 0.168$, $P = 0.001$), because the consumption of prey like cephalopods and fish seems to increase with size, and there is a reduction in the consumption of crustaceans in the larger fishes (Figure 4B).

We found differences between the two seasons in both areas. In the CSL area ($R_{ANOSIM} = 0.032$, $P = 0.026$) *P. planipes* had a higher importance during the cold season (GII = 95.27), than the warm season (GII = 52.84) (Figure 5A). In Mazatlán ($R_{ANOSIM} = 0.149$, $P = 0.001$) the crustacean *H. californiensis* (GII= 60) was important during the warm season, while cephalopods (GII = 37) and fishes (GII = 20) were important during the cold season (Figure 5B).

The trophic level estimated for common dolphinfish in CSL was 4.34 (SE = 0.35); while in Mazatlán the estimated TL was 4.4 (SE = 0.33). The trophic niche width index (Levin's index) gave low values for both areas ($B_i < 0.03$); which means that in spite of having a wide trophic spectrum this predator's diet was dominated by a few prey groups.

Stable isotopes analysis

We collected 14 common dolphinfish muscle samples from CSL and 17 from Mazatlán, of all sexes, sizes and seasons. $\delta^{15}N$ values ranged from 12.89 to 17.77‰, while $\delta^{13}C$

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

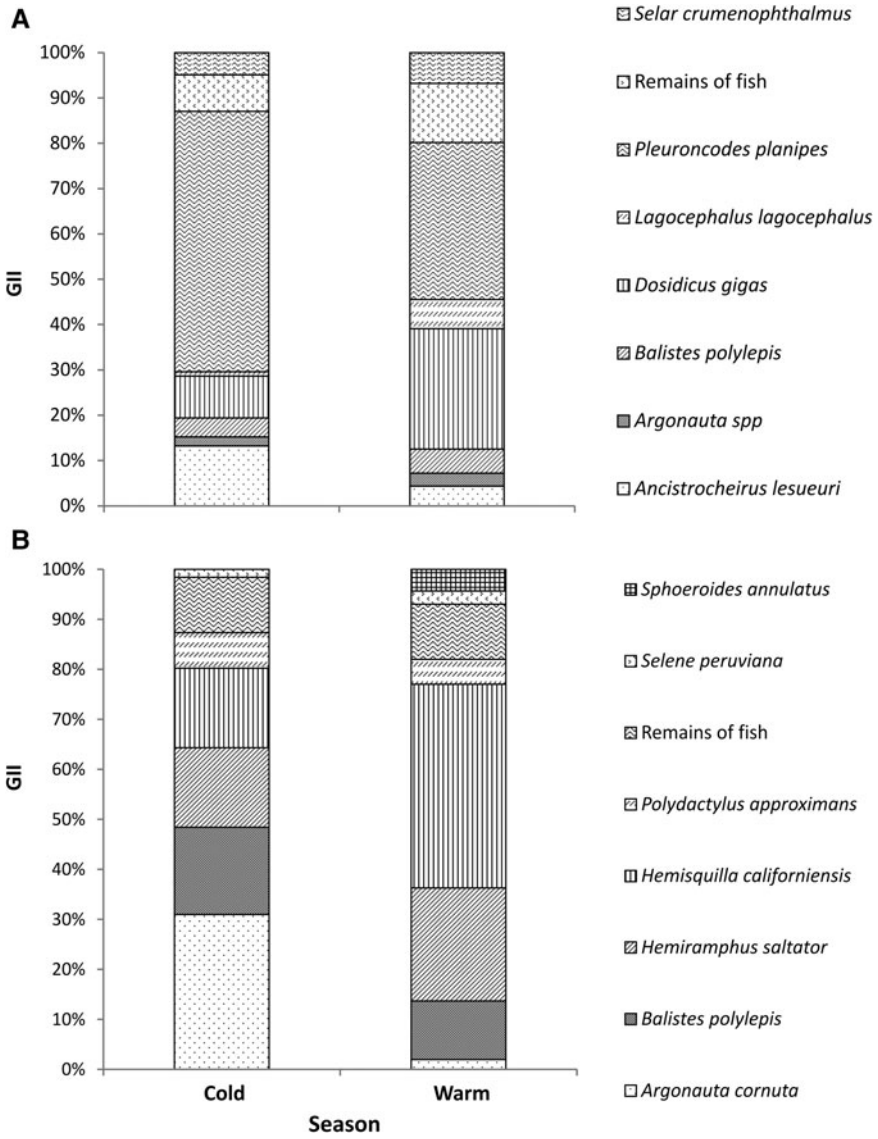


Fig. 5. Dolphinfish diet comparison between cold and warm seasons based on % GII, *A* = Cabo San Lucas, *B* = Mazatlán.

values ranged from −18.07 to −15.13‰ (Figure 6). The MANOVA test showed significant differences in C and N isotope values between the two areas ($F_{(1,26)} = 16.10$, $P = 0.001$).

Mixing models using isotopic values from prey items previously identified as important in stomach content analysis showed that the jumbo squid *D. gigas* was the most important prey in CSL, contributing from 0 to 68% to the diet, followed by the crustacean *P. planipes* (22–61%), and the squid *Ancistrocheirus lesueuri* (0–39%). For Mazatlán the main prey were *H. californiensis* (0–61%), followed by *D. gigas* (0–47%), *B. polylepis* (0–45%), and *H. saltator* (0–43%). The remaining species were secondary (Table 4).

The calculated trophic level (TL) using the method proposed by Post (2002) was 4.4 (SE = 0.62) in CSL; in Mazatlán TL was 4.6 (SE = 0.37). These values were very similar to those obtained using stomach content analysis, and similar to the 4.37 value reported by Fishbase. The standard deviation (SD) of $\delta^{15}N$ data was relatively low for Mazatlán (SD 0.9) and CSL (SD 1.2), suggesting low variability in the diet.

DISCUSSION

The results obtained with stomach content analysis corroborate previous findings that catalogued dolphinfish as a voracious predator with a wide trophic spectrum, feeding on fishes, cephalopods and crustaceans (Palko *et al.*, 1982). However, in this study, using both stomach content and stable isotope analyses, we found that three invertebrate species (*D. gigas*, *P. planipes* and *H. californiensis*) were the most important prey for dolphinfish, which contrasts with results from other authors such as Gibbs & Collete (1959), Rose & Hassler (1974) and Manooch *et al.* (1983), who found that this species was mainly piscivorous.

We found different prey species in the two areas. This was probably due to the CSL area having a very narrow continental shelf compared with Mazatlán (Alvarez-Borrego, 1983), which

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

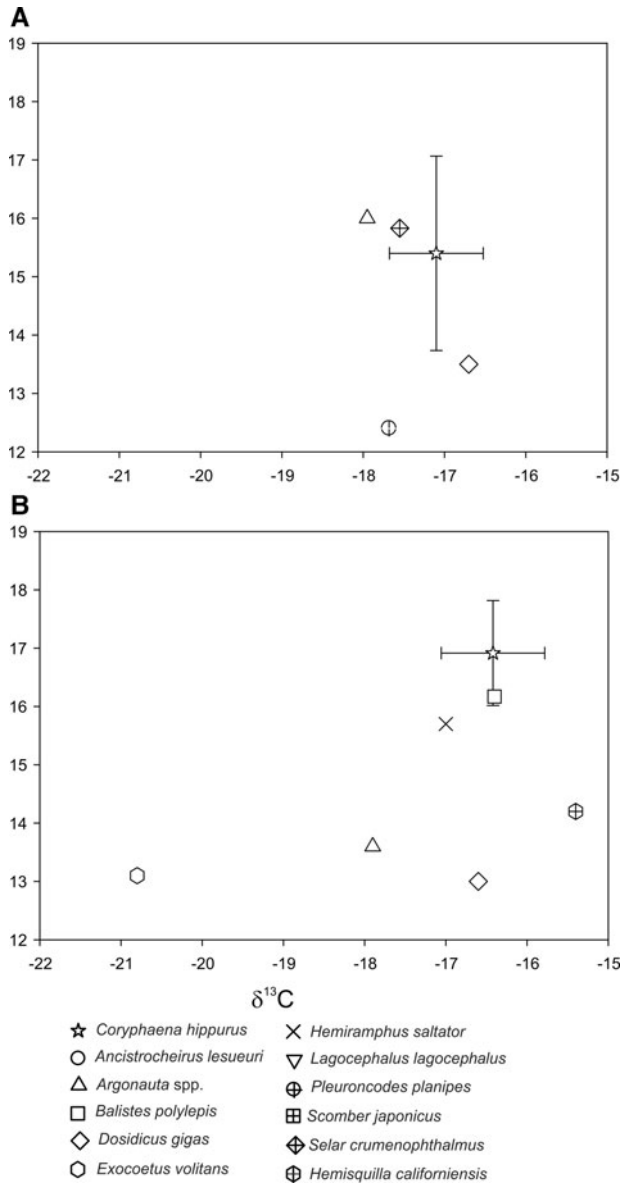


Fig. 6. Carbon and nitrogen isotope signatures of *C. hippurus* and its prey in Cabo San Lucas (A) and Mazatlán (B).

resulted in the prey species found in CSL being more related to the pelagic zone. This was the case of *P. planipes*, and of some cephalopod and fish species that are usually pelagic. *Balistes polylepis* which is categorized as demersal was found only in its pelagic juvenile stage (Eschmeyer *et al.*, 1983).

This type of prey was also found in 2005–2007 by Torres-Rojas *et al.* (2014) in this area, which indicates that this tendency is maintained over time. In Mazatlán we found more demersal prey, such as the crustacean *H. californiensis*, which in its megalops stage migrates from the bottom to the surface to feed (Salgado-Barragan, personal communication). We also found some fishes and pelagic prey such as squids and *Argonauta* spp.

Dolphinfish have opportunistic feeding habits, preying on the most abundant prey species in the environment. In the same study area of CSL in 1990 and 1991, Aguilar-Palomino *et al.* (1998) found that *P. planipes* and *D. gigas* were present in the diet of common dolphinfish. However, the fish *B. polylepis*, *Auxis* spp. and *Cypselurus callopterus* were more important in the diet, which suggests that in those years those fish species were more abundant.

This could be due to the sea surface temperature having reached higher levels in 1990 and 1991. This increase in temperature may have affected the distribution of *P. planipes*, which are associated with colder waters such as the California Current (Aurioles-Gamboa, 1995). In those years there was a greater abundance of fish in the diet of dolphinfish, while in 2001 and 2003 with the presence of colder waters this crustacean became a more abundant prey of this predator.

Dosidicus gigas is found year round in the Gulf of California; its abundance changes in each area of the Gulf depending on the season, being less abundant during winter (Ehrhardt *et al.*, 1986). However, it seems that variation in *D. gigas* abundance is not what determines dolphinfish diet; the feeding differences found with stomach content analysis during the warm and cold seasons in CSL could correspond to a higher abundance of *P. planipes* during the cold season rather than to a decrease in *D. gigas* abundance.

We detected a change in the dolphinfish diet in Mazatlán during the cold season that is related with an increase in the consumption of *Argonauta* spp. This increase could be a result of transport towards the coast during the cold season by currents or by the wind, caused by the presence of a shell that is formed to hold this organism's eggs (Laptikhovsky & Salman, 2003). However, the isotopic analysis did not show significant differences between seasons, suggesting that this increase in the consumption of *Argonauta* spp. was not enough to change the isotopic composition of the dolphinfish tissues.

We found differences in the diet among sizes using stomach content analysis in both areas. Larger and more mobile organisms are capable of catching a high biomass of fast prey, such as squid and fish (Olson & Galván-Magaña, 2002). However, stable isotope analysis showed few differences between dolphinfish of different sizes, which suggests that in spite of differences, found using stomach content analysis, the highly abundant *P. planipes* (Aurioles-Gamboa, 1995) seems to be assimilated in a higher proportion by all size classes of dolphinfish.

This suggests that this prey is consumed frequently by the predator, despite some other prey being consumed occasionally in higher proportion. *Pleuroncodes planipes* seems to always be a complementary food due to its abundance, and this is reflected over the long term in the isotope signature found in the muscle tissue. In Mazatlán the same situation seems to happen with *H. californiensis*, which results in the isotopic signal for all size classes being very similar.

We could not find differences in diet between common dolphinfish males and females in the southern Gulf of California. There exist only two previous reports by Rose & Hassler (1974) and Varghese *et al.* (2013), where the first authors found that males were more piscivorous than females and the second authors found a higher fish intake in females, which they suggest is due to higher energy requirements for reproduction. In our study males and females consumed the same prey at almost the same rate.

Stomach content and stable isotope analyses showed that although this predator consumed a broad prey spectrum, only a few prey items made up the bulk of the diet. This was mainly reflected in the low SD of $\delta^{15}N$ values and low Levin's index values. We consider that dolphinfish are

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Table 4. Isotopic values of *Coryphaena hippurus* and its potential prey, and their per cent contribution to the diet obtained from mixing models for both areas (Cabo San Lucas and Mazatlan).

Cabo San Lucas	$\delta^{13}C$(‰)	$\delta^{15}N$(‰)	Contribution to the diet (%)	N samples
Coryphaena hippurus	−17.1 ± 0.5	15.4 ± 1.6	–	14
Dosidicus gigas	−16.7	13.5	0–68	4
Balistes polylepis	−16.33	16.17	0–18	2
Pleuroncodes planipes	−17.68	12.4	22–61	8
Lagocephalus. lagocepahlus	−18.23	15.96	0–10	2
Ancistrocheirus lesueuri	−16.1	15.1	0–39	1
Scomber japonicus	−16.5	19.7	0–7	2
Selar crumenophthalmus	−17.55	15.83	0–13	2
Argonauta spp.	−17.95	16	0–11	2
Mazatlán				
Coryphaena hippurus	−16.3 ± 0.5	16.9 ± 0.9	–	17
Dosidicus gigas	−16.6	13	0–47	4
Balistes polylepis	−16.4	16.17	0–45	2
Argonauta spp.	−17.9	13.6	0–32	2
H. californiensis	−15.4	14.2	8–61	7
Hemiramphus saltator	−17.0	15.7	0–43	3
Exocoetus volitans	−20.8	13.1	0–15	1

opportunistic predators that may consume diverse prey (Palko *et al.*, 1982), although they mainly consume prey that is abundant in the area, such as crustaceans (Aurioles-Gamboa, 1995; Salgado-Barragan, personal communication).

The calculated trophic level using both methods gives us very similar results for both areas. This suggests that despite consuming different prey species in the two areas, the prey consumed occupy a similar position on the trophic web.

The isotopic analysis was a useful tool in this study, and helped to corroborate the importance in the predator's diet of prey items found using stomach content analysis. We initially thought that *P. planipes*, due to their size and low energetic content (Abitia-Cardenas *et al.*, 1997), would not be assimilated by the dolphinfish. However, the isotopic analysis corroborated that *P. planipes* was assimilated by the predator. This situation seems to also occur in the Mazatlán area with *H. californiensis*. Torres-Rojas *et al.* (2014) found for 2005–2007 in CSL that *P. planipes* was the most important component in the diet by using the same methodology.

In this study the stable isotope analysis was an important tool which indicated which prey items were being metabolized by predators (Dufour & Gerdeaux, 2001) and along with the use of stomach content analysis provided results with better resolution than the use of only one method (Chipps & Garvey, 2006). The use of both methods helped us to define which organisms were consumed by this predator and which were the most important components in its diet, in terms of consumption and assimilation.

This kind of information is important to know the types of trophic relationships that this kind of predator has with the rest of the ecosystem. This information is necessary to develop management strategies for the species and in general for the pelagic zone due to the importance of this species as predator.

In conclusion we found that this species is a highly opportunistic predator that feeds on the most abundant and easily catchable prey, which during the years of this study were mainly invertebrates, whereas in previous years they had been mainly fishes. We could therefore consider this predator as an indicator of the presence and abundance of certain prey in the area.

ACKNOWLEDGEMENTS

We would like to thank Marcela Zuñiga Flores for help during sampling.

FINANCIAL SUPPORT

FGM and SOG thank the Comisión de Operación y Fomento de Actividades Académicas (COFAA-IPN); ATV thanks CONACyT and PIFI-IPN.

REFERENCES

Abitia-Cardenas L.A., Galván-Magaña F. and Rodriguez-Romero J. (1997) Food habits and energy values of prey of striped marlin, *Tetrapturus audax*, off the coast of Mexico. *Fishery Bulletin* 95, 360–368.

Aguilar-Palomino B., Galván-Magaña F., Abitia-Cardenas L.A., Muhlia-Melo A.F. and Rodriguez-Romero J. (1998) Aspectos alimentarios del dorado *Coryphaena hippurus* Linnaeus, 1758 en Cabo San Lucas, Baja California Sur, México. *Ciencias Marinas* 24, 253–265.

Allen G.R. and Robertson D.R. (1994) *Fishes of the tropical eastern Pacific*. Honolulu, HI: University of Hawaii Press.

Alvarez-Borrego B.S. (1983) Gulf of California. In Ketchum B.H. (ed.) *Ecosystems of the world*. Volume 26, *Estuaries and Enclosed Seas*. New York, NY: Elsevier, pp. 427–449.

Assis C.A. (1996) A generalized index for stomach contents analysis in fish. *Scientia Marina* 60, 385–389.

Aurioles-Gamboa D. (1995) Distribución y abundancia de la langostilla bentónica (*Pleuroncodes planipes*) en la plataforma continental de la costa oeste de Baja California. In Aurioles-Gamboa D. and Balart E. (eds) *La langostilla: biología, ecología y aprovechamiento*. México: CIBNOR, pp. 59–78.

Campos J.A., Segura A., Lizano O. and Madrigal E. (1993) Ecología básica de *Coryphaena hippurus* (Pisces: Coryphaenidae) y abundancia de otros grandes pelágicos en el Pacífico de Costa Rica. *Revista de Biología Tropical* 41, 783–790.

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Chipps S. and Garvey J. (2006) Assessment of food habits and feeding patterns. In Guy C.S. and Brown M. (eds) *Analysis and interpretation of freshwater fisheries data*. Bethesda, MD: American Fisheries Society, pp. 472–514.

Clarke K.R. and Warwick R.M. (2001) *Changes in marine communities: an approach to statistical analysis and interpretation*. Plymouth: PRIMER-E.

Clarke L.R., Vidergar D.T. and Bennett D.H. (2005) Stable isotopes and gut content show diet overlap among native and introduced piscivores in a large oligotrophic lake. *Ecology of Freshwater Fish* 14, 267–277.

Clarke M.R. (1986) *A handbook for the identification of cephalopod beaks*. Oxford: Clarendon Press.

Clothier C.R. (1950) A key to some Southern California fishes based on vertebral characters. *Fisheries Bulletin* 79, 1–83.

Cortés E. (1997) A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 54, 726–738.

Dufour E. and Gerdeaux D. (2001) Apport des isotopes stables ($^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$, $^{36}S/^{34}S$, 87Sr/86Sr) aux études écologiques sur les poissons. *Cybium* 25, 369–382.

Ehrhardt N.M., Solís N.A., Jacquemin P.S., Ortiz C.J., Ulloa R.P., González D.G. and García B.F. (1986) Análisis de la biología y condiciones del stock del calamar gigante *Dosidicus gigas* en el Golfo de California, México, durante 1980. *Ciencias Pesquera* 5, 63–76.

Erhardt E.B. (2007) SISUS: Stable Isotope Sourcing using Sampling. http://statacumen.com/sisus/.

Eschmeyer W.N., Herald E.S. and Hammann H. (1983) *A field guide to Pacific coast fishes of North America*. Boston, MA: Houghton Mifflin.

Fischer W., Krupp F., Schneider W., Sommer C. and Carpenter K. (1995) *Guía FAO para la identificación de especies para los fines de pesca. Pacífico centro-oriental*. Rome: FAO.

Gearing I.N. (1991) The study of diet and trophic relationships through natural abundance ^{13}C. In Coleman D.C. and Fry B. (eds) *Carbon isotope techniques*. San Diego, CA: Academic Press, pp. 201–216.

Gibbs R.H. and Collete B.B. (1959) On the identification, distribution and biology of the dolphins *Coryphaena hippurus* and *C. equiselis*. *Bulletin of Marine Science of the Gulf and Caribbean* 9, 117–152.

Hida T.S. (1973) Food of tunas and dolphins (Pisces: Scombridae and Coryphaenidae) with emphasis on the distribution and biology of their prey *Stolephorus buccaneeri* (Engraulidae). *Fishery Bulletin* 71, 135–143.

Hyslop E.J. (1980) Stomach content analysis a review of methods and their application. *Journal of Fish Biology* 17, 411–429.

Iverson L.K. and Pinkas L. (1971) A pictorial guide to beak of certain eastern Pacific cephalopods. *California Fish and Game* 2, 83–105.

Kelly D.J., Robertson A., Murphy D., Fitzsimons T., Costello E., Gormley E., Corner L. and Marples N.M. (2012) Trophic enrichment factors for blood serum in the European badger (*Meles meles*). *PLoS ONE* 7, ee53071.

Kojima S. (1966) Studies on fishing conditions of the dolphin *Coryphaena hippurus* L. in the western Japan Sea, comparison of juvenile fish fauna in the sea and in contents of dolphin. *Bulletin of the Japanese Society for the Science of Fish* 29, 507–513.

Krebs C.J. (1999) *Ecological methodology*. New York, NY: Harper Collins.

Laptikhovsky V. and Salman A. (2003) On reproductive strategies of the epipelagic octopods of the superfamily Argonautoidea (Cephalopoda: Octopoda). *Marine Biology* 142, 321–326.

Lasso J. and Zapata L. (1999) Fisheries and biology of *Coryphaena hippurus* (Pisces: Coryphaenidae) in the Pacific coast of Colombia and Panama. *Scientia Marina* 63, 387–399.

Manooch C.S., Mason D.L. and Nelson R.S. (1983) Food and gastrointestinal parasites of dolphin, *Coryphaena hippurus*, collected along the southeastern and gulf coasts of the United States. *U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SEFC* 124, 36 pp.

Miller J.D. and Lea R.N. (1972) Guide to the coastal marine fishes of California. *California Department of Fish and Game Fisheries Bulletin* 157, 1–235.

Minagawa M. and Wada E. (1984) Stepwise enrichment of $\delta^{15}N$ along food chains: further evidence and the relation between $\delta^{15}N$ and animal age. *Geochimica et Cosmochimica Acta* 48, 1135–1140.

Norton J.G. (1999) Apparent habitat extensions of dolphinfish (*Coryphaena hippurus*) in response to climate transients in the Californian current. *Scientia Marina* 63, 239–260.

Olson R.J. and Galván-Magaña F. (2002) Food habits and consumption rates of common dolphinfish (*Coryphaena hippurus*) in the eastern Pacific Ocean. *Fishery Bulletin* 100, 279–298.

Oxenford H.A. and Hunte W. (1999) Feeding habits of the dolphinfish (*Coryphaena hippurus*) in the eastern Caribbean. *Scientia Marina* 63, 303–315.

Palko B.J., Beardsley G.L. and Richards W.J. (1982) Synopsis of the biological data on dolphin-fishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis Linnaeus*. *U.S. Department of Commerce, NOAA Technical Memorandum NMFS Circular* 443:1–28.

Paré J.R.J., Bélanger M.R. and Stafford S.S. (1994) Microwave-Assisted Process (MAPTM): a new tool for the analytical laboratory. *Trends in Analytical Chemistry* 13, 176–184.

Park R. and Epstein S. (1961) Metabolic fractionation of C13 and C12 in plants. *Plant Physiology* 36, 133–138.

Pauly D., Christensen V., Froese R. and Palomares M.L. (2000) Fishing down aquatic food webs. *American Scientist* 88, 46–51.

Post D.M. (2002) Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology* 83, 703–718.

Post D., Layman M.C.A., Arrington D.A., Takimoto G., Quattrochi J. and Montana C.G. (2007) Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. *Oecologia* 152, 179–189.

Preti A., Smith S. and Ramon D. (2001) Feeding habits of the common thresher shark (*Alopias vulpinus*) sampled from the California-based drift gill net fishery, 1998–1999. *CalCOFI Reports* 42, 145–152.

Preti A., Smith S. and Ramon D. (2004) Diet differences in the thresher shark (*Alopias vulpinus*) during transition from a warm–water regime to a cool–water regime off California–Oregon, 1998–2000. *California Cooperative Oceanic Fisheries Investigations Reports* 45, 1998–2000.

Renoe B.W. (1994) Microwave assisted extraction. *Technology, CEM Corporation American Laboratory*, 34–39.

R Development Core Team (2011) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. http://www.R-project.org/.

Rose C.D. and Hassler W.W. (1974) Food habits and sex ratios of dolphin *Coryphaena hippurus* captured in the western Atlantic Ocean off Hattera, North Carolina. *Transactions of the American Fisheries Society* 103, 94–100.

Rothschild B.J. (1964) Observations on dolphins (*Coryphaena* spp.) in the Central Pacific Ocean. *Copeia* 1964, 445–447.

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press

Saucedo-Barrón C.J. (1990) Aspectos de la alimentación del dorado *Coryphaena hippurus*, frente a las costas de Sinaloa. *Memorias del VII congreso de Oceanografía, Mazatlán, Sinaloa, México, 1990*.

Tester A.L. and Nakamura E.L. (1957) Catch rate, size, sex and food of tunas and other pelagic fishes taken by trolling off Oahu, Hawaii, 1951–55. *U.S. Fish and Wildlife Service Special Scientific Report Fisheries* 250, 25.

Thomson D., Findley L. and Kerstich A. (2000) *Reef fishes of the Sea of Cortez. The rocky-shore fishes of the Gulf of California*. Austin, TX: University of Texas Press.

Torres-Rojas Y.E., Hernández-Herrera A., Ortega-García S. and Soto-Jiménez M.F. (2014) Feeding habits variability and trophic position of dolphinfish in waters south of the Baja California Peninsula, Mexico. *Transactions of the American Fisheries Society* 143, 528–542.

Tripp-Valdez A., Galván-Magaña F. and Ortega-García S. (2010) Feeding habits of dolphinfish (*Coryphaena hippurus*) in the southeastern Gulf of California, Mexico. *Journal of Applied Ichthyology* 26, 578–582.

Varghese S.P., Somvanshi V.S., John M.E. and Dalvi R.S. (2013) Diet and consumption rates of common dolphinfish, *Coryphaena hippurus*, in the eastern Arabian Sea. *Journal of Applied Ichthyology* 29, 1022–1029.

Velasco-Tarelo P.M. (2003) *Hábitos alimenticios del dorado,* Coryphaena hippurus, *Linnaeus 1758. (Osteichtyes: Coryphaenidae), capturado en Punta Lobos y Los Barriles Baja California Sur, México, durante 2000 y 2001*. Bachelor thesis, Universidad Autónoma de Baja California Sur, México.

Wolff C.A. (1984) Identification and estimation of size from the beaks of eighteen species of cephalopods from the Pacific Ocean. *NOAA Technical Report NMFS* 17, 1–50.

and

Zúñiga-Flores M.S., Ortega-Garcia S. and Klett-Traulsen A. (2008) Interannual and seasonal variation of dolphinfish (*Coryphaena hippurus*) catch rates in the southern Gulf of California, Mexico. *Fisheries Research* 94, 13–17.

Correspondence should be addressed to:
F. Galván-Magaña
Centro Interdisciplinario de Ciencias Marinas, IPN, Av. Instituto Politécnico Nacional s/n, Col. Playa Palo de Santa Rita, La Paz B.C.S. 23096, México
email: fgalvan@ipn.mx

https://doi.org/10.1017/S0025315414001842 Published online by Cambridge University Press