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Research Article

Abundance and distribution of lantern fishes (Myctophiformes: Myctophidae) around San Pedro Martir Island, Gulf of California, during 2008

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ABSTRACT. Myctophids (Myctophidae) are a group of abundant mesopelagic fishes in the world´s oceans and are known as the main feeding resource for several high trophic level predators. Changes in abundance may be related to population size of some commercially important species that feed on them. Only two of the myctophid species reported for the Gulf of California were found in the present study: *Benthosema panamense* and *Triphoturus mexicanus*. The highest abundance and biomass of myctophids were found during the warm season (June and September), with *B. panamense* being the most abundant species (20,954 ind 1000 m^{-3}), as well as the one with highest biomass (17,165.8 g 1000 m^{-3}). *B. panamese* had a size mode interval of 35-40 mm, while *T. mexicanus* presented a size mode interval of 40-45 mm; both species had negative allometric growth. During the temperate season (February and April) *B. panamense* was distributed in the northwest, west, and southern regions around the island, while *T. mexicanus* was found in the north, west, and southern regions. During the warm season *B. panamense* was found distributed around the entire island and *T. mexicanus* was found in the west, south, and east regions of the island. These species are common around San Pedro Martir Island, with the highest values of abundance and biomass occurring during summer upwelling's.

Keywords: abundance, *Benthosema panamense*, *Triphoturus mexicanus*, myctophids, Gulf of California.

Distribución y abundancia de peces linterna (Myctophiformes: Myctophidae) alrededor de isla San Pedro Mártir, golfo de California, durante el año 2008

RESUMEN. Los mictófidos (Myctophidae), son un grupo de peces mesopelágicos abundantes en los océanos del mundo, y se identifican como el principal recurso alimenticio de depredadores con alto nivel trófico. Los cambios en su abundancia pueden relacionarse con el tamaño poblacional de algunas especies de importancia comercial que depredan sobre ellos. En el presente trabajo, de las especies de mictófidos que se reportan dentro del golfo de California, sólo se encontraron dos: *Benthosema panamense* y *Triphoturus mexicanus*. En la temporada cálida (junio y septiembre) se presentaron las mayores abundancias y biomasa, siendo *B. panamense* la especie más abundante (20,954 ind 1000 m^{-3}), así como también la de mayor biomasa (17,165.8 g 1000 m^{-3}). *B. panamense* se encontró con una moda en el intervalo de tallas de 35-40 mm, *T. mexicanus* presentó una moda en el intervalo de tallas de 40-45 mm; ambas especies mostraron un tipo de crecimiento alométrico negativo. Con respecto a su distribución, durante la temporada templada (febrero y abril) *B. panamense* se distribuyó en la región noroeste, oeste y sur, mientras que *T. mexicanus* se encontró en las regiones norte, oeste y sur de la isla. Durante la temporada cálida *B. panamense* se encontró alrededor de toda la isla; *T. mexicanus* se encontró en las regiones oeste, sur y este de la isla. Estas especies son comunes alrededor de la isla San Pedro Mártir, con mayor abundancia y biomasa durante las surgencias de verano.

Palabras clave: abundancia, *Benthosema panamense*, *Triphoturus mexicanus*, mictófidos, golfo de California.

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INTRODUCTION

Lantern fishes or myctophids (Myctophidae) are diverse and abundant in the world´s oceans, represented by 240 species, grouped in 32 genera (Nelson, 2006). In the central-eastern Pacific Ocean region there are 20 genera and 45 species (Hart, 1973; Paxton *et al.,* 1995). They are generally small (2-30 cm), with large eyes, and have photophores in both the head and body with specific distribution patterns depending on the species (Frost & McCrone, 1979; Castellanos-Galindo *et al.,* 2006). These fishes are predominant in the mesopelagic zone, being one of the most abundant fish families in this zone; but can also be found over the continental shelf or around islands. Almost all of the species (except for the bathypelagic ones) migrate vertically from depths greater than 200 m (where they remain during the day) to the upper water column layer where they remain during the night (Paxton *et al.,* 1995). The highest abundance of almost all myctophid species occur between depths of 300 and 1200 m during the day and between 10 and 100 m during the night (Nelson, 2006).

It has been identified that myctophids are the main feeding resource for several high trophic level predators (Pakhomov *et al.,* 1996; Bañon *et al.,* 2000; Phillips *et al.,* 2001). In stomach contents of jumbo squid, *Dosidicus gigas* (D´Orbigny, 1835), in the Gulf of California, it has been found that its diet is mainly dominated by *Benthosema panamense* (Tåning, 1932) and *Triphoturus mexicanus* (Gilbert, 1890) (Markaida & Sosa-Nishizaki, 2003; Markaida, 2006; Markaida *et al.*, 2008).

Jumbo squid is an important species in the food web of the pelagic ecosystem in the Gulf of California (Rosas-Luis *et al.,* 2008). In the past decade, this species has gained greater importance given that it represents one of the few fisheries whose abundance has surprisingly increased, although squid shows unpredictable density fluctuations depending on location (Martinez-Aguilar *et al.,* 2006).

Changes in abundance of prey likely influence distribution and population size of its predators as well as the energy-flow patterns and the performance of the pelagic ecosystems (Cury *et al.,* 2000). Knowing myctophid fish abundance variations is important given that they are an elementary component of the trophic web in the pelagic ecosystem of the central region of the Gulf of California, where currently, energy-flow seems to be regulated by an active myctophid predator, the jumbo squid. The present research was carried out to determine spatial and temporal distribution of myctophid fishes around San Pedro Martir Island in the Gulf of California, during 2008, as well as to determine myctophid species composition and to describe the size structure of these fishes in one of the main aggregation zones of the jumbo squid.

MATERIALS AND METHODS

San Pedro Martir Island is located in the central region of the Gulf of California at 28º23'N and 112º20'W (Fig. 1). Its total area is 2.8 km^2, and it is found equidistant to three regions with the highest primary productivity: summer/spring upwelling in the Guaymas area, winter/autumn upwelling outskirts in the Santa Rosalia area, and the annual surrounding tidal mix of Ballenas Channel. Given that San Pedro Martir Island is located near the temperate current dynamics of the Ballenas Channel area and near warmer waters located southwards of the island, hence affected by these water masses (Tershy *et al.,* 1992).

Biological material used in this survey comes from four oceanographic cruises focused in capturing juveniles and paralarvae of jumbo squid, *Dosidicus gigas* (DG) in the Gulf of California (GOLCA). Cruises were conducted in 2008 during February (DGGOLCA0208), April (DGGOLCA0408), June (DGGOLCA0608), and September (DGGOLCA09 08), comprising two seasons: temperate (February and April) and warm (June and September), on board of a research vessel called "BIP XII", in the area of San Pedro Martir Island, Gulf of California. On each cruise eight stations were sampled, for a total of 32 stations (Table 1).

Myctophid samples were obtained using an Isaacs-Kidd midwater trawl with 3 m mouth width and 33 m length, procedure consisted of oblique trawling at an approximated speed of 1 knot. Samples were fixated in 10% formaldehyde. Samples were later identified using a stereoscopic microscope Zeiss Stemi DV4, and fishes from family Myctophidae were separated. Identification was made following Wisner (1976) and Paxton *et al.* (1995) proposed criteria. Standard length (SL) was taken for each specimen using an ichthyometer (1 mm). Total weight (TW) was also measured in grams using an analytical balance OHAUS EP114C (0.001 g). Weight and size frequency were taken per species and per cruise without separating males from females because of the absence of external characters that showed sexual dimorphism.

To define the relation of weight increase according to myctophid´s length, the following linear equation was applied: $Y= a*X^b$, where: Y = dependent variable (weight), a = proportionality coefficient, X = indepen-

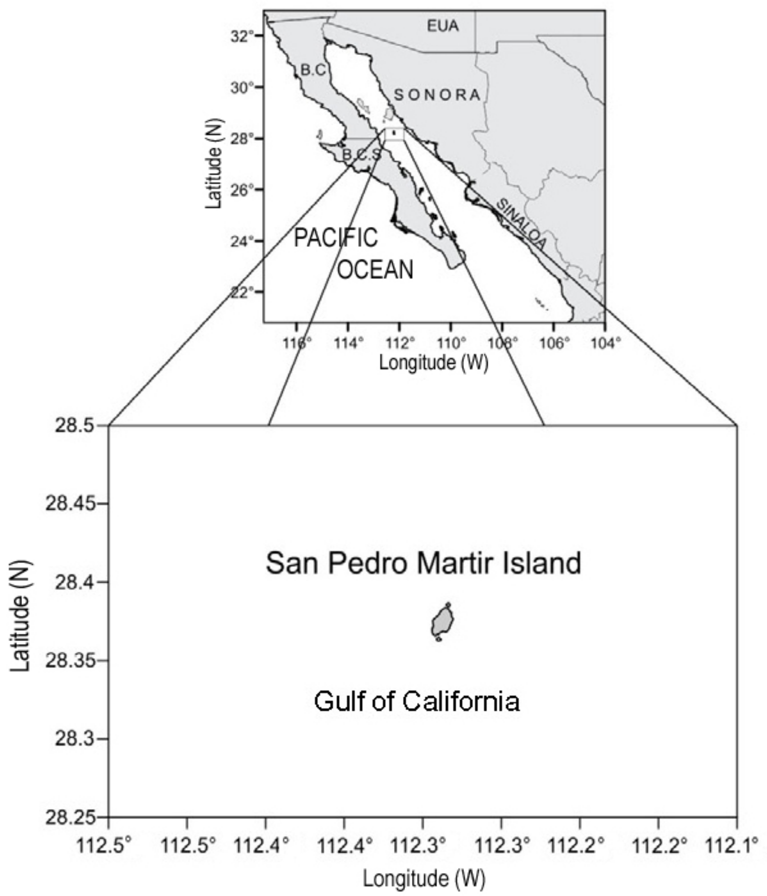

Figure 1. Study area located around San Pedro Martir Island.

dent variable (length), and b = allometric coefficient (Sparre & Venema, 1997).

To evaluate growth type, a t-Student test was performed for each of the "b" values obtained from the model, and compared with b = 3, the theoretical value representative of isometric growth.

Relative abundance was estimated through the filtered volume method (FVM). The midwater trawl method covered a well defined water sector of the pelagic zone; the distance length of each sector was calculated by dividing velocity (knots) and trawling period. FVM consists in multiplying sector´s length by net´s mouth width and length.

Distribution maps were made with estimated relative abundance (RA) values, from the number of captured specimens, according to filtered water volume in terms of number of individuals 1000 m^3, per analyzed cruise and per season (temperate and warm) using Surfer program (Golden Software V 9).

Relative biomass (RB) was estimated from weight of captured organisms per filtered water volume unity (g m^3). Biomass values were standardized to 1000 m^3.

RESULTS

A total of 3,510 organisms were sampled from the four cruises made, taxonomic composition of family Myctophidae was found represented by two species: *Benthosema panamense* with 1606 organisms and *Triphoturus mexicanus* with 1904 organisms. The general size range for the species *B. panamense* was between 1-55 mm (mode = 35-40 mm) and for *T. mexicanus* the size interval was 10- 65 mm (mode = 40-45 mm) (Fig. 2).

Results of length-weight relationship analysis for each species showed that allometric coefficient obtained for *B. panamense* (2.09) and *T. mexicanus* (2.79), according to t-Student test, statistically deferred from the theoretical value of 3 ($P < 0.05$), therefore, growth in these species is considered to have negative allometry (Fig. 3).

According to the distribution and relative abundance (RA), during temperate season, *B. panamense* was distributed in regions of the northwest, west, and south of the island with total RA value of 338 ind 1000 m^{-3}. *T. mexicanus* was found in regions north

Table 1. Characteristics of the oceanographic cruises made around San Pedro Martir Island in the central part of the Gulf of California. A: *Benthosema panamense*, B: *Triphoturus mexicanus*.

Cruise	Station	Date	Time	Depth (m)	Latitude (N)	Longitude (W)	Biomass ($g\ 1000\ m^{-3}$)		Abundance ($ind\ 1000\ m^{-3}$)	
							A	B	A	B
DGGOLCA0208	1	08/02/2008	19:36	118	28º 27.296	112º 27.912	26.17	140.71	98.17	229.07
	2	08/02/2008	21:03	165	28º 22.828	112º 11.815	0	0	0	0
	3	08/02/2008	00:10	236	28º 16.410	112º 17.380	0	10.90	0	21.81
	4	09/02/2008	03:16	236	28º 22.023	112º 25.043	0	0	0	0
	5	09/02/2008	09:24	236	28º 22.523	112º 22.059	0	0	0	0
	6	09/02/2008	11:16	165	28º 26.335	112º 18.590	0	0	0	0
	7	09/02/2008	15:00	95	28º 22.242	112º 14.254	0	0	0	0
	8	09/02/2008	16:41	236	28º 19.394	112º 17.239	0	0	0	0
DGGOLCA0408	1	19/04/2008	13:37	118	28º 27.748	112º 17.110	0	0	0	0
	2	19/04/2008	15:38	212	28º 23.020	112º 11.645	0	0	0	0
	3	19/04/2008	18:20	212	28º 16.245	112º 17.229	0	0	0	0
	4	19/04/2008	20:46	212	28º 21.448	112º 29.662	47.99	1415.88	87.26	2443.44
	5	19/04/2008	22:40	212	28º 22.928	112º 22.023	17.45	167.98	21.81	218.16
	6	20/04/2008	00:30	118	28º 26.814	112º 20.120	80.72	305.43	87.26	283.61
	7	20/04/2008	02:40		28º 22.283	112º 15.033	0	0	0	0
	8	20/04/2008	04:20	212	28º 18.955	112º 17.737	34.90	1644.95	43.63	2334.35
DGGOLCA0608	1	25/06/2008	20:42	106	28º 27.961	112º 17.165	3506.00	0	4581.45	0
	2	25/06/2008	22:46	148	28º 23.133	112º 12.096	5030.67	263.284	6634.18	475.99
	3	26/06/2008	01:00	318	28º 16.624	112º 17.299	7.55	2976.26	8.39	5655.49
	4	26/06/2008	03:16	318	28º 21.887	112º 24.570	147.78	3271.40	263.90	6460.48
	5	26/06/2008	05:15	318	28º 22.767	112º 22.771	317.89	129.02	635.79	205.69
	6	26/06/2008	06:49	318	28º 26.110	112º 18.952	7649.38	0	7853.91	0
	7	26/06/2008	08:48	318	28º 22.226	112º 14.407	31.00	0	34.44	0
	8	26/06/2008	10:05	318	28º 19.507	112º 17.289	381.78	378.15	666.61	618.13
DGGOLCA0908	1	27/09/2008	08:55	148	28º 27.932	112º 17.126	0	0	0	0
	2	27/09/2008	11:45	212	28º 23.440	112º 11.762	0	0	0	0
	3	27/09/2008	14:39	255	28º 15.967	112º 17.038	0	0	0	0
	4	27/09/2008	18:33	255	28º 21.494	112º 25.855	41.81	93.35	218.16	418.14
	5	27/09/2008	20:37	255	28º 21.766	112º 22.983	21.17	1027.93	38.49	1366.73
	6	27/09/2008	23:16	148	28º 25.769	112º 20.645	0	0	0	0
	7	28/09/2008	02:10	85	28º 20.304	112º 14.828	0	46.74	0	93.49
	8	28/09/2008	03:49	255	28º 18.573	112º 14.891	30.67	2200.73	20.45	3170.20

west, and south of the island with total RA value of 5,530 ind 1000 m^3, presenting higher RA in southern and western regions. During the warm season *B. panamense* was found all around the island with total RA value of 20,956 ind 1000 m^{-3}, this being the highest RA value found in this study, while *T. mexicanus* was found in regions west, south, and east of the island with total RA value of 18,464 ind 1000 m^{-3} (Fig. 4).

Highest relative biomass (RB) value for both species was found during the DGGOLCA0608 cruise being 17,072 g 1000 m^{-3} for *B. panamense* and 7,018.1 g 1000 m^{-3} for *T. mexicanus*. During the warm season, the highest RB was found for both species (*B*

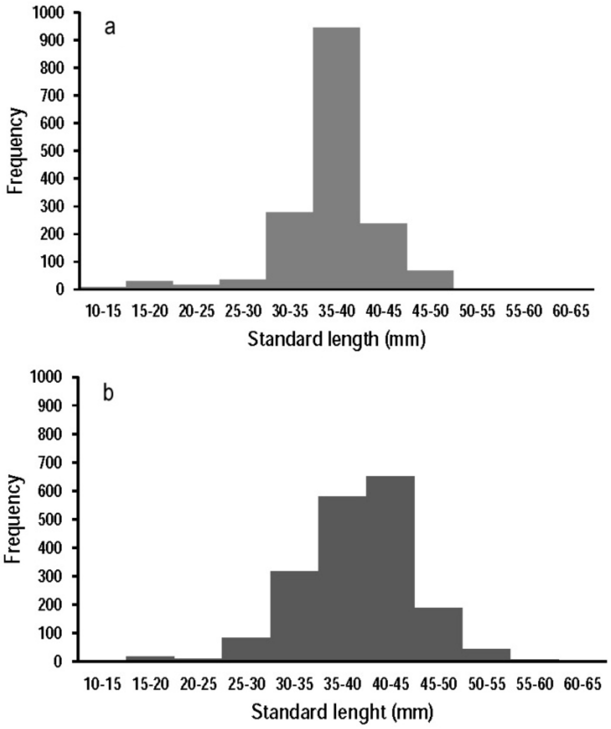

Figure 2. a) Size frequency of *Benthosema panamense*, b) size frequency of *Triphoturus mexicanus.*

panamense: 17,165.8 g 1000 m^{-3} and *T. mexicanus*: 10,386.9 g 1000 m^{-3}), with lower biomass in the temperate season with 207.3 g 1000 m^{-3} and 3,685.9 g 1000 m^{-3}, respectively (Table 1).

DISCUSSION

Present study contributes to the understanding of some of the biological aspects of the most abundant myctophid species in the central region of the Gulf of California (Aceves-Medina *et al*., 2003).

Of the 16 myctophid species present in the Gulf of California (Castro-Aguirre & Balart, 1996), two species were found in the cruises made during this study: *Benthosema panamense* and *Triphoturus mexicanus*. These species have been reported as abundant in fish larvae studies in the Gulf of California (Moser *et al*., 1974; Avalos-Garcia *et al*., 2003; Aceves-Medina *et al*., 2004), also, both have been part of the major constituents of mid-water trawling expeditions made in this area, where the center of its distribution is in the central part of the gulf (Lavenberg & Fitch, 1966; Robison, 1972; Moser *et al*., 1974), consistent to what was found in the present research. The low species richness of the collected specimens in this study may be due to the fact that the number of fish species living in the Gulf of California, decreases from south to north (Moser *et al*., 1974). Or else, because of the employed sampling depths range (85-318 m), given that myctophids depth distribution in the water column varies widely according to each species and even within a species depending on its ontogenetic development (Paxton *et al.,* 1995). Another factor that may be influencing low species richness in the surveys of this study could be the lack of prey availability for other myctophid species feeding in sampled area (Frost & McCrone, 1979).

Data of size structure shows that *T. mexicanus* had an interval size mode of 40-45 mm for SL (40-45 mm SL), while *B. panamese* presented an interval size mode of 35-40 mm for SL (Fig. 2). It has been reported that there are ontogenetic changes in depth distribution patterns as well as daily vertical migration of myctophid fish, the trend is that organism´s size increases according to depth (Frost & McCrone, 1979). Probably, myctophids with larger sizes were distributed at greater depths in the water column than

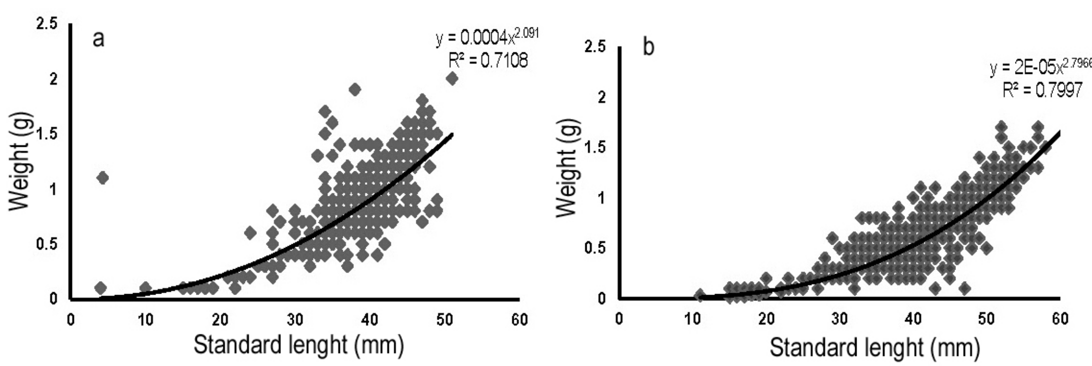

Figure 3. a) Standard length-weight relation of *Benthosema panamense*, b) standard length-weight relation of *Triphoturus mexicanus.*

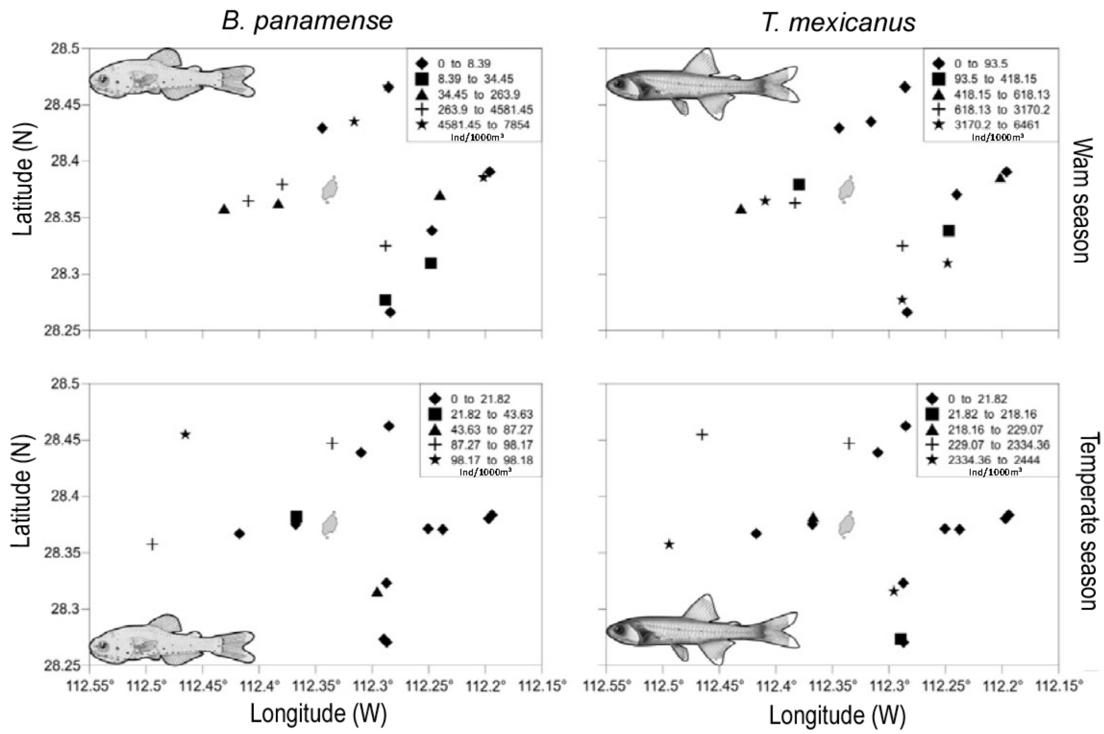

Figure 4. Relative abundance and distribution per season for *Benthosema panamense* and *Triphoturus mexicanus.*

the depth range covered in this survey. Nevertheless, despite depths of myctophid fish sampling during the different cruises, size intervals were diverse (85-318 m) for both myctophid species and were relatively constant, this may be due to fishing gear selectivity.

Regarding the aforementioned, *B. panamense* is found between 200 and 300 m depth during the day and at nights it migrates to shallow waters above 100 m and *T. mexicanus* is found at the oxygen minimum layer during the day and at nights it rises in less aggregated shoals also above 100 m (Robison, 1972).

Energetic cost of swimming for most fishes decreases with size increase among and within species; such a relationship indicates that it is more expensive for a small fish to move 1 g of its corporal mass a given distance than it is for a larger fish (Helfman *et al.,* 2009), in this study, the allometric negative growth that both myctophid species showed may be due to the daily vertical migration that these fishes perform (Robison, 1972). They live in a viscous medium through which they move daily: myctophids in the upper 100 m depth at night are active and swim horizontally, also, these fishes are capable of rapid evasive movements, while those found at depths below 100 m are immobile and vertically oriented (Barham, 1971), perhaps the elongated body might be an advantage in terms of locomotion.

According to abundance and considering that vertical migration patterns of fishes from the Myctophidae family are species specific (Watanabe *et al.,* 1999), and that they are found at specific depths, variations in presence or absence of species in sampling stations, the capture of different sizes, as well as in abundance within a cruise, could possibly be due to a bias error for not having established a day/night schedule for sampling or considered species specific distribution depths. Doing so would have assured that all of the distributional range was covered when sampling.

One of the main natural fertilization mechanisms of the Gulf of California is the wind-induced upwelling (Alvarez-Borrego, 2010); winds that change directions seasonally and the strong tides (because of sea bottom shape) cause strong upwelling (Maluf, 1983); these upwelling during the winter (December-May) are caused by northern winds that drive the water surface layers out of the Gulf, having a significant effect on phytoplankton communities, this has been determined by the high chlorophyll concentration that has been found in these areas (>100 mg m^{-3}) (Roden, 1958; Alvarez-Borrego, 2010). It was found in this study that during the temperate season myctophids were located towards the northwestern and southern regions of San Pedro Martir Island; also, in this season the lowest abundance values for both species were obtained. Upwelling's during the summer (June-November), are caused by southern winds that drive oceanic water into the gulf at great depths, however these winds have a weak effect on phytoplankton communities and biomass because of the low chlorophyll concentration values (≈0.5 mg m^{-3}) (Roden, 1958; Álvarez-Borrego, 2010), during the warm season myctophids were present all around the island and abundances were significantly higher. Myctophid abundances in this study might be determined by other biological factors rather than just feeding, it could possibly be related to reproduction, given that it has been found in previous studies, that these species show marked seasonal abundance and its larvae are found concentrated along the western side of the gulf, decreasing in density towards the east during the temperate season (Moser *et al*., 1974). In the central portion of the Gulf of California, high concentration of sperm whales around San Pedro Martir Island likely indicates that there is probably a high concentration of jumbo squid, *Dosidicus gigas* (Gilly *et al.*, 2006), which feeds on myctophid fishes (Markaida & Sosa-Nishizaki, 2003).

The largest biomass values during the temperate season was determined to be *T. mexicanus* 3,686 g 1000 m^3 and during the warm season *B. panamense* biomass was 17,166 g 1000 m^3, the latter being the species having the largest biomass values from all cruises. Aforementioned explains why *D. gigas* diet in the Gulf of California is dominated firstly by *B. panamense* and secondly by *T. mexicanus* (Markaida & Sosa-Nishizaki, 2003; Markaida, 2006; Markaida *et al.*, 2008).

According to the analysis carried out it can be concluded that *B. panamense* and *T. mexicanus* are common around San Pedro Martir Island; both species presented negative allometric growth, indicating that length and width increase is not proportional; with highest abundance occurring for both species during the warm season. Of the two species, *B. panamense* was the most abundant.

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