FOOD HABITS OF THE VAQUITA, *PHOCOENA SINUS*

FINAL REPORT

(Part of the group of research projects concerning "Biology of the Vaquita" of the overall project "Conservation of the Fragile Ecosystem of the Upper Gulf of California")

PRESENTED TO

CONSERVATION INTERNATIONAL

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by

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port in the fisherman's boat (*panga*), plus the time needed for the biologist receiving the carcass to make preliminary measurements, photographs and notes, and then carry it over the wide beach to the walk-in freezer where it could be frozen whole and (finally) the digestive process halted. Because the digestive juices continue their degredative action on food items in the vaquita's stomach following the moment of death, the usually advanced state of digestion of the stomach contents analyzed in this study is not surprising.

<u>Frequency of occurrence (percentage) of prey species</u>

Due to the state of advanced digestion of most stomach contents examined, it was deemed impractical to attempt any type of volumetric or gravimetric (weight) analyses of food items, as has been carried out in similar studies working with fresher material. Therefore, the following analyses performed on our sample are all taken from among those quantitative analytical methods generally grouped under "**frequency** (or periodicity) **of occurrence** (appearance)," based on the frequency of occurrence of prey species and/or number of prey individuals of each species found in the sample. These methods supply information on the importance of each prey species in the food habits of the predator.

The first of these analyses performed was that of **percentage frequency of occurrence of prey species**, a standard analytical method used in food habits studies (e.g., Hyslop 1980, Yáñez-Arancibia *et al.* 1976, Cailliet *et al.* 1986, Amezaga 1988, Lowry and Oliver 1986, Recchia and Read 1989, Román-Rodríguez 1990, Smith and Read 1992), and is expressed by the formula:

$$Fo_i = (e_i / E) \times 100$$

where:

Fo_i = Percentage frequency of occurrence of prey species **i**
e_i = Number of stomachs containing prey species **i**
E = Total number of stomachs examined

In order to distinguish prey species showing a <u>proportionally</u> greater frequency of occurrence, we derived the standard deviation of the percentage frequency of occurrence for each one (Z_{foi}) [an innovative method that we have not seen reported in similar studies] by:

a) Calculating the standard deviation of the total percentage frequency of occurrence, utilizing the formula:

$$S_f = [\ S\ (Fo_i - Fo_m)^2\ /\ (t - 1)\ ]^{(1/2)}$$

where:

S_f = Standard deviation of the total percentage frequency of occurrence
Fo_i = Percentage frequency of occurrence of prey species **i**
Fo_m = Mean of the percentage frequency of occurrence of all prey species
t = Total number of prey species;

and then:

b) Calculating the standardized deviation of percentage frequency of occurrence for each prey species, by using the formula:

$$Z_{foi} = (Fo_i - Fo_m)\ /\ S_f$$

where:

Z_{foi} = The standardized deviation of percentage frequency of occurrence for prey species **i**.

By this method, those prey species having a value of Z_{foi} greater than 1 are considered to be more important in the diet of the vaquita ("primary" or "preferred" species), while those species with resultant values for Z_{foi} between -1 and 1 are classed as less important ("secondary") prey species, and those species with values of less than -1 can be considered incidentals ("accidentals").

Relative abundance (percentage) of prey species

This, too, is a standard method of analysis utilized by several workers (e.g., Hyslop 1980, Cailliet *et al.* 1986, Amezaga 1988, Recchia and Read 1989, Gales and Pemberton 1992) in which the percentage relative abundance of prey species is derived by the formula:

$$A_i = (n_i\ /\ N)\ X\ 100$$

where:

A_i = Percentage relative abundance of prey species **i**

n_i = Total number of individuals of prey species **i**

N = Total number of individuals of all prey species.

The standardized deviation of percentage relative abundance for each prey species was calculated in order to distinguish among prey species of primary numerical importance in the diet of the vaquita from those of secondary and lower importance. For this, we followed the same procedural method developed above for deriving the standardized deviation of the percentage frequency (periodicity) of occurrence for each prey species, only substituting the values for Fo_i and Fo_m for those of A_i and A_{im}, respectively.

Index of Relative Importance (IRI) of prey species

In larger perspective, because it may prove difficult to evaluate the results from the two analytical procedures outlined above for the one that best estimates the relative importance of a prey species in a predator's diet, a commonly used combinatory or "synthetic" method of analysis, the Index of Relative Importance, was developed by Pinkas *et al.* (1971) and has been used by several subsequent workers (e.g., see Hyslop 1980, Cailliet *et al.* 1986). This index is defined by the formula:

$$IRI = Fo_i \times (A_i + V_i)$$

$$[\text{or: } IRI = Fo_i A_i + Fo_i V_i]$$

where:

IRI = Index of Relative Importance of prey species **i**

Fo_i = Percentage frequency of occurrence of prey species **i**

A_i = Percentage relative abundance of prey species **i**

V_i = Percentage relative volume of prey species **i**.

However, as previously mentioned, due to the advanced state of digestion of most stomach contents, we were unable to make volumetric measurements on prey species from the vaquita stomachs. Therefore, an attempt was made at understanding the relative importance of prey species to the vaquita by modifying the above formula to eliminate volumetric considerations while maintaining the values obtained from the analyses of percentage frequency of occurrence of each species with its respective value of percentage relative abundance. This modification thus eliminates the product of the percentage relative volume of each prey species by the percentage frequency of occurrence of that species, and results in the formula:

$$IRI = Fo_i X A_i$$

We obtained the standardized deviation of the Index of Relative Importance of each prey species in order to classify its importance in the vaquita's diet relative to other prey species by following the same procedure for calculation of the standardized deviation of percentage frequency of occurrence, only substituting the values for Fo_i and Fo_m with those for IRI_i and IRI_m , respectively.

RESULTS

Identification of prey species

The contents of the 24 stomachs of *Phocoena sinus* yielded a total of 17 species of teleost fishes and two species of squids (Table 2, which also includes two additional fish species previously reported by Fitch and Brownell, 1968).

Table 2. Prey species (with family names) identified in stomach contents of vaquitas. (Asterisks denote the two species reported by Fitch and Brownell, 1968.)

Species	Family
Squids	
Loliolopsis diomedeae	Loliginidae
Lolliguncula panamensis	Loliginidae
Fishes	
Anchovia macrolepidota	Engraulididae
Anchoa mundeoloides	Engraulididae
Anchoa helleri	Engraulididae
Cetengraulis mysticetus	Engraulididae
Engraulis mordax	Engraulididae
Cynoscion othonopterus	Sciaenidae
Cynoscion reticulatus	Sciaenidae
Isopisthus altipinnis	Sciaenidae
Larimus pacificus	Sciaenidae
Micropogonias megalops	Sciaenidae
Cheilotrema saturnum	Sciaenidae
Bairdiella icistia *	Sciaenidae
Orthopristis reddingi *	Haemulidae
Pomadasys panamensis	Haemulidae
Diplectrum macropoma	Serranidae
Diplectrum pacificum	Serranidae
Porichthys analis	Batrachoididae
Porichthys mimeticus	Batrachoididae
Synodus scituliceps	Synodontidae

Identification of parasitic isopods (Crustacea : Isopoda)

A preliminary list of identifications to date of the relatively few isopods found in the stomach contents of the sample appears below. Note that all taxa identified (by Dr. Richard Brusca, Grice Marine Biology Laboratory of the University of Charleston, South Carolina) belong to the family Cymothoidae, a taxon specializing in the external parasitization of marine fishes. Therefore, as previously mentioned, these organisms are not to be considered prey species of *Phocoena sinus* because their ingestion occurs along with ingestion of their host fish. Nonetheless, when this work in progress is completed, the expanded parasite list may provide biological insights into several aspects of the isopods' host fishes that figure in the diet of the vaquita (as well as insights into the biology of those same species of isopods).

Preliminary list of ichthyoparasitic isopods recovered from vaquita stomachs (by R.C. Brusca)

Family Cymothoidae:

- *Cymothoa exigua*
- *Nerocila acuminata*, form *acuminata*
- *Elthusa* (?)
- juvenile cymothoids (aegathoid stage)

Verification of representative sample size

Applying the method (derived from information theory) proposed by Buesa (1977) for obtaining a minimum sample size of study organisms, we took as an initial sample all identified prey species and their minimum counts of individuals from the contents of the two chronologically oldest (captured) vaquita stomachs and calculated the diversity index (Shannon-Weaver) value for that sample. Then, the same numerical characteristics from the next oldest (collected) stomach contents were added (accumulated) to the former sample and a new diversity index value calculated for the resulting (accumulated) sample. This procedure was followed step-wise for the contents of all 24 stomachs. The resulting diversity index values for the entire accumulated sample were graphed against the number of accumulated stomachs (contents) and a curve fitted to the results (Fig. 2).

Inspection of the general trend in the graph shows that the diversity index values begin to decrease following the fifteenth accumulated stomach (contents), indicating that the information obtained following this point becomes repetitive. This is taken as evidence that the minimum size of a representative sample of vaquita stomach contents was obtained for this study.

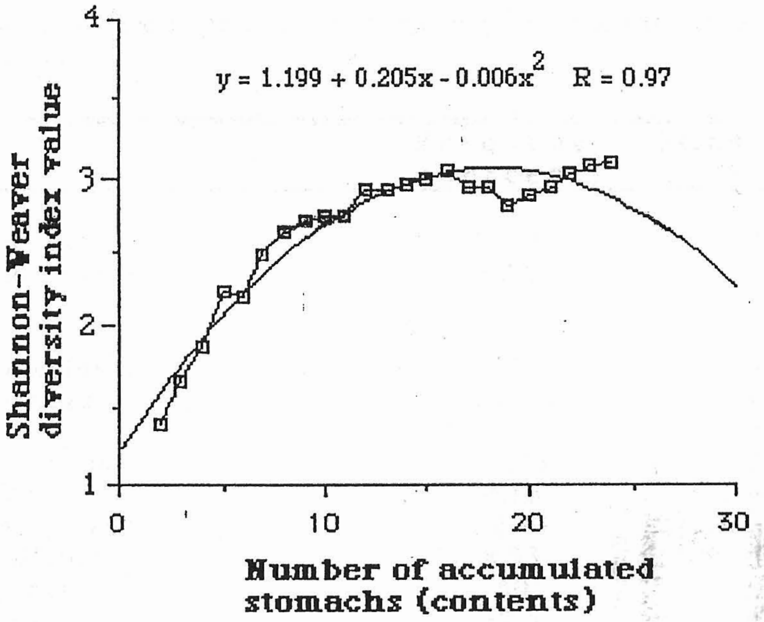

Fig. 2. Values of diversity indices (Shannon-Weaver) for the step-wise chronologically accumulated contents (prey species and minimum number of prey individuals) from the 24 stomachs. Also shown is the curve fitted to those values, the equation for its derivation (y), and the coefficient of correlation (R).

In Fig. 2, it is interesting to note that diversity index values again begin to show an upward trend following accumulation of the eighteenth stomach (contents). We take this as suggestive of a change in the type of information being added following this point, and interpret this change as possibly indicating subtle dietary differences due to a slight change in the provenance (capture locality) of these stomach contents, as well as their being collected approximately two years later than the previous (larger) set of samples. This hypothesis deserves future investigation.

Frequency of occurrence (percentage) of prey species

Table 3 gives the percentage value and standardized deviation of the frequency of occurrence of each prey species identified in the sample. For interpretation of results, see Discussion.

Table 3. Prey species, their percentage frequency of occurrence and its standardized deviation.

Species	Frequency (percent)	Stand. dev. of % freq.
Squids		
Loliolopsis diomedeae	54.16	1.63
Lolliguncula panamensis	62.5	2.07
Fishes		
Anchovia macrolepidota	4.16	-0.97
Anchoa mundeoloides	29.16	0.33
Anchoa helleri	8.33	-0.75
Cetengraulis mysticetus	33.33	0.54
Engraulis mordax	4.16	-0.97
Cynoscion othonopterus	20,83	-0.10
Cynoscion reticulatus	8.33	-0.75
Isopisthus altipinnis	50	1.41
Larimus pacificus	12.5	-0.53
Micropogonias megalops	33.33	0.54
Cheilotrema saturnum	4.16	-0.97
Pomadasys panamensis	20.83	-0.10
Diplectrum macropoma	4.16	-0.97
Diplectrum pacificum	4.16	-0.97
Porichthys analis	4.16	-0.97
Porichthys mimeticus	37.5	0.76
Synodus scituliceps	37.5	0.76

Relative abundance (percentage) of prey species

Table 4 gives the percentage value and standardized deviation of relative abundance of each prey species identified in the sample. For interpretation, see Discussion.

Table 4. Prey species, their percentage relative abundance and its standardized deviation.

Species	Relative abundance (percent)	Stand. dev. of relative abundance
Squids		
Loliolopsis diomedeae	5.25	-0.001
Lolliguncula panamensis	10.50	0.63
Fishes		
Anchovia macrolepidota	0.72	-0.54
Anchoa mundeoloides	5.61	0.04
Anchoa helleri	0.72	-0.54
Cetengraulis mysticetus	7.60	0.28
Engraulis mordax	0.54	-0.56
Cynoscion othonopterus	2.17	-0.37
Cynoscion reticulatus	1.99	-0.39
Isopisthus altipinnis	32.97	3.33
Larimus pacificus	1.26	-0.48
Micropogonias megalops	2.71	-0.30
Cheilotrema saturnum	0.18	-0.61
Pomadasys panamensis	2.53	-0.32
Diplectrum macropoma	0.18	-0.61
Diplectrum pacificum	1.26	-0.48
Porichthys analis	0.18	-0.61
Porichthys mimeticus	20.47	1.82
Synodus scituliceps	3.07	-0.26

Index of Relative Importance (IRI) of prey species

Table 5 gives the value and standardized deviation of the Index of Relative Importance for each prey species identified in the sample, and Figure 3 shows the two parameters (percentage frequency of occurrence and percentage relative abundance) used in calculating those indices, which are graphically rendered for each prey species. For interpretations, see Discussion.

Table 5. Prey species, their Index of Relative Importance and its standardized deviation.

Species	Index of Relative Importance	Stand. dev. of the index
Squids		
Loliolopsis diomedeae	284.57	0.16
Lolliguncula panamensis	656.70	1.06
Fishes		
Anchovia macrolepidota	3.01	-0.52
Anchoa mundeoloides	163.79	-0.13
Anchoa helleri	6.03	-0.51
Cetengraulis mysticetus	253.62	0.08
Engraulis mordax	2.26	-0.52
Cynoscion othonopterus	45.28	-0.41
Cynoscion reticulatus	16.60	-0.48
Isopisthus altipinnis	1648.55	3.48
Larimus pacificus	15.85	-0.49
Micropogonias megalops	90:57	-0.30
Cheilotrema saturnum	0.75	-0.52
Pomadasys panamensis	52.83	-0.40
Diplectrum macropoma	0.75	-0.52
Diplectrum pacificum	5.28	-0.51
Porichthys analis	0.75	-0.52
Porichthys mimeticus	767.66	1.33
Synodus scituliceps	115.48	-0.24

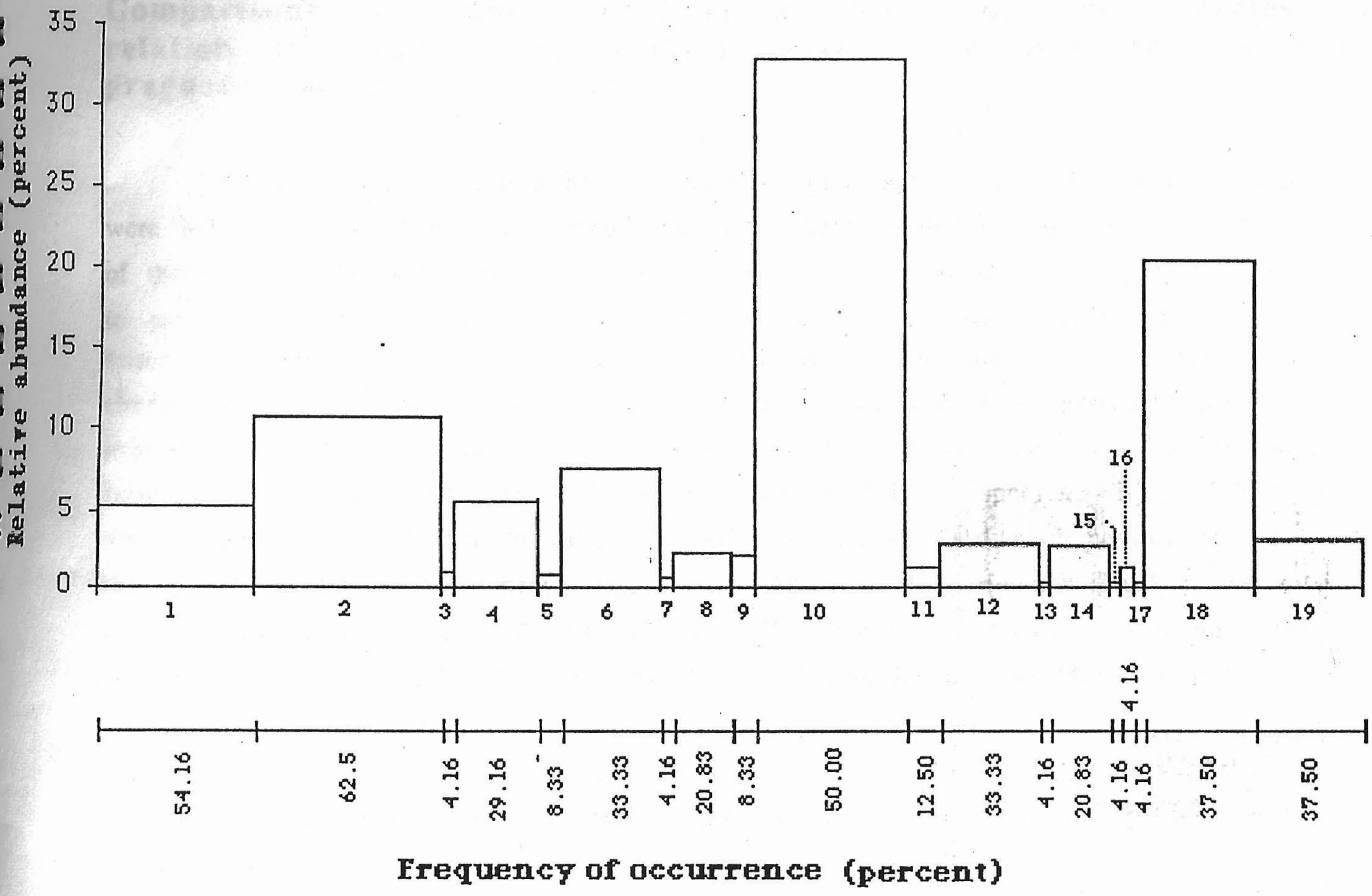

Fig. 3. Index of Relative Importance (IRI) of prey species and their percentage relative abundance (percentage representing number of individuals of species "x" of total individuals of all species) and percentage frequency of occurrence values (percentage of total vaquita stomachs containing prey species "x").

Species represented by numbers are:

1. *Loliolopsis diomedeae*; 2. *Lolliguncula panamensis*; 3. *Anchovia macrolepidota*; 4. *Anchoa mundeoloides*; 5. *Anchoa helleri*; 6. *Cetengraulis mysticetus*; 7. *Engraulis mordax*; 8. *Cynoscion othonopterus*; 9. *C. reticulatus*; 10. *Isopisthus altipinnis*; 11. *Larimus pacificus*; 12. *Micropogonias megalops*; 13. *Cheilotrema saturnum*; 14. *Pomadasys panamensis*; 15. *Diplectrum macropoma*; 16. *Diplectrum pacificum*; 17. *Porichthys analis*; 18. *Porichthys mimeticus*; and 19. *Synodus scituliceps*. (The first two species are squids; the remaining are teleost fishes.)

Comparisons of some ecobehavioral traits of prey species in relation to vaquita age classes, sexes, and pregnant vs non-pregnant mature females

While making tentative identifications of prey species of fishes whose remains were being sorted out of the stomach contents, three ecobehavioral traits (see below) of these species became suspect of being of possible importance to analyze in relation to some life history parameters within the vaquita population. This suspicion was based as well on a general knowledge of some anatomical and ecobehavioral characteristics of those prey species, and a familiarity with pertinent literature available on similar studies. Such studies have explored several distributional, ecological and behavioral traits of the porpoise or dolphin species with which they were concerned in relation to often similar distributional and ecobehavioral traits of that particular odontocete's prey organisms. As examples of such studies, we cite those of McKinnon (1988), Reyes and Van Waerebeek (in press), Smith and Read (1992), Recchia and Read (1989), Gaskin *et al.* (1974), Barros and Myrberg (1987), and Barros and Odell (1990).

The three ecobehavioral trait groups of vaquita prey species that we defined and analyzed are:

1) **General depth distribution in the habitat:** Prey species were categorized as either "Pelagic" (= at or near the surface of the water column), or "Benthic-Demersal" (= on or near the bottom, at least most of the time). [Note that the use of the term "pelagic" for that category does not refer to distance offshore.]

2) **Sound-emitting capabilities:** Prey species were categorized as either "Not Sound-emitters" (= incabable of making concentrated sounds, or at least unknown to produce such sounds), or "Known or Suspected Sound-emitters" (= capable of producing concentrated sounds, usually through contractions of specialized muscles acting on a well-developed swimbladder and causing it to vibrate, or suspected of being able to produce such sounds).

3) **Schooling behavior:** Prey species were categorized as either "Forming organized, integrated schools (with a high level of internal cohesion), or "Not known to form such schools (aggregations or "congregations" may occur, especially for

purposes of reproduction, but organized, integrated, internally cohesive schools are not formed).

Table 6 shows prey species identified from vaquita stomachs grouped in one of the two alternative categories for each of the three ecobehavioral trait groups defined above. Figures 4, 5 and 6 compare the alternative categories of the three ecobehavioral trait groups by percentage of prey species so categorized, between: 1) sexually mature and immature vaquitas (stomachs in the sample); 2) female and male vaquitas (stomachs); and 3) non-pregnant mature female and pregnant female vaquitas (stomachs). For interpretations, see Discussion.

Table 6. Prey species grouped by alternatives of three ecobehavioral traits: A) general depth distribution in the habitat; B) sound-emitting capabilities; and C) schooling behavior.

A. General Depth Distribution

"Pelagic" (at or near surface)	vs	"Benthic-Demersal" (or on near bottom)
Anchoa helleri		*Micropogonias megalops*
Anchoa mundeoloides		*Cheilotrema saturnum*
Anchovia macrolepidota		*Larimus pacificus*
Cetengraulis mysticetus		*Bairdiella icistia* *
Engraulis mordax		*Orthopristis reddingi**
Cynoscion othonopterus		*Pomadasys panamensis*
Cynoscion reticulatus		*Porichthys analis*
Isopisthus altipinnis		*Porichthys mimeticus*
		Diplectrum macropoma
		Diplectrum pacificum
		Synodus scituliceps
		Lolliguncula panamensis
		Loliolopsis diomedeae

B. Sound-emitting Capabilities

Do not emit sounds (or unknown)	vs	Known or suspected sound-emitters
Anchoa helleri		*Micropogonias megalops*
Anchoa mundeoloides		*Cheilotrema saturnum*
Anchovia macrolepidota		*Cynoscion othonopterus*
Cetengraulis mysticetus		*Cynoscion reticulatus*
Engraulis mordax		*Isopisthus altipinnis*
Diplectrum macropoma		*Larimus pacificus*
Diplectrum pacificum		*Bairdiella icistia* *
Synodus scituliceps		*Orthopristis reddingi**
Lolliguncula panamensis		*Pomadasys panamensis*
Loliolopsis diomedeae		*Porichthys analis*
		Porichthys mimeticus

C. Schooling Behavior

Form organized, integrated schools	vs	Not known to form organized schools
Anchoa helleri		*Micropogonias megalops*
Anchoa mundeoloides		*Cheilotrema saturnum*
Anchovia macrolepidota		*Cynoscion othonopterus*
Cetengraulis mysticetus		*Cynoscion reticulatus*
Engraulis mordax		*Isopisthus altipinnis*
		Larimus pacificus
		Bairdiella icistia *
		*Orthopristis reddingi**
		Pomadasys panamensis
		Porichthys analis
		Porichthys mimeticus
		Diplectrum macropoma
		Diplectrum pacificum
		Synodus scituliceps
		Lolliguncula panamensis
		Loliolopsis diomedeae

*Reported by Fitch and Brownell (1968). *Lolliguncula* and *Loliolopsis* are squids, all others are teleost fishes.

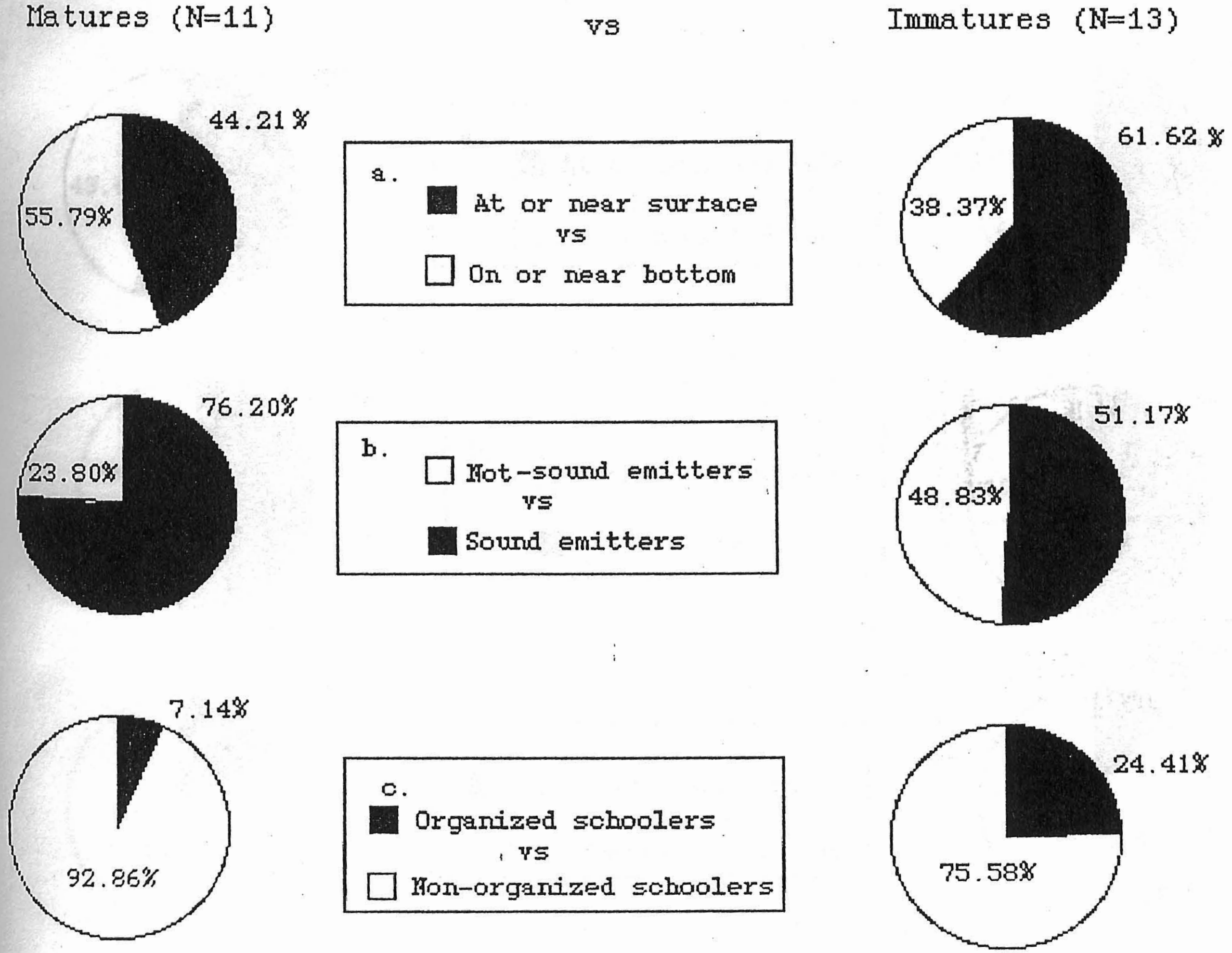

Figure 4. Comparisons of three ecobehavioral trait groups (a, b, c) by percentage of so categorized prey species identified from stomachs of sexually mature and immature vaquitas. For names of prey species included in each trait group, see Table 6.

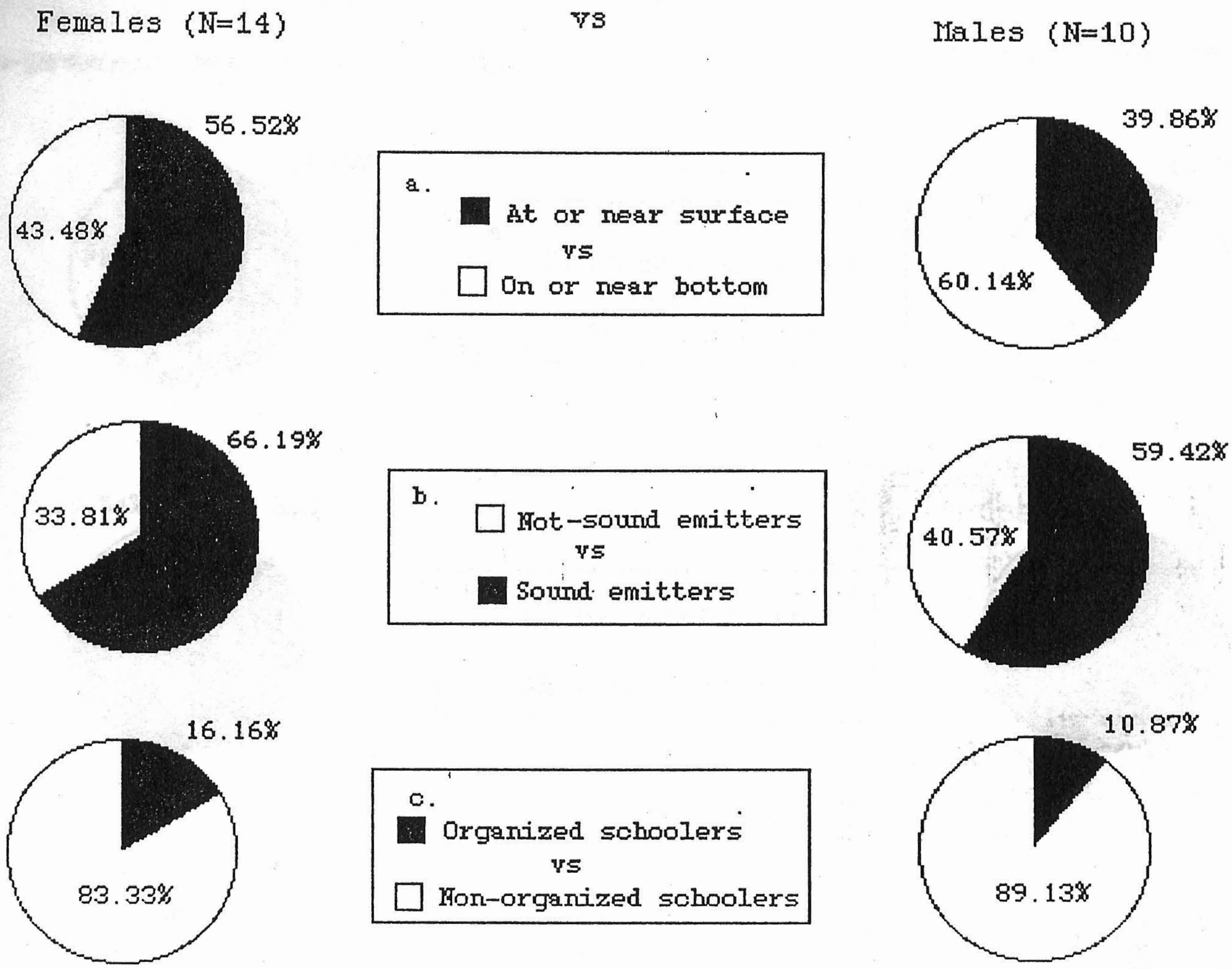

Figure 5. Comparisons of three ecobehavioral trait groups (a, b, c) by percentage of so categorized prey species identified from stomachs of female and male vaquitas. For prey species included in each trait group, see Table 6.

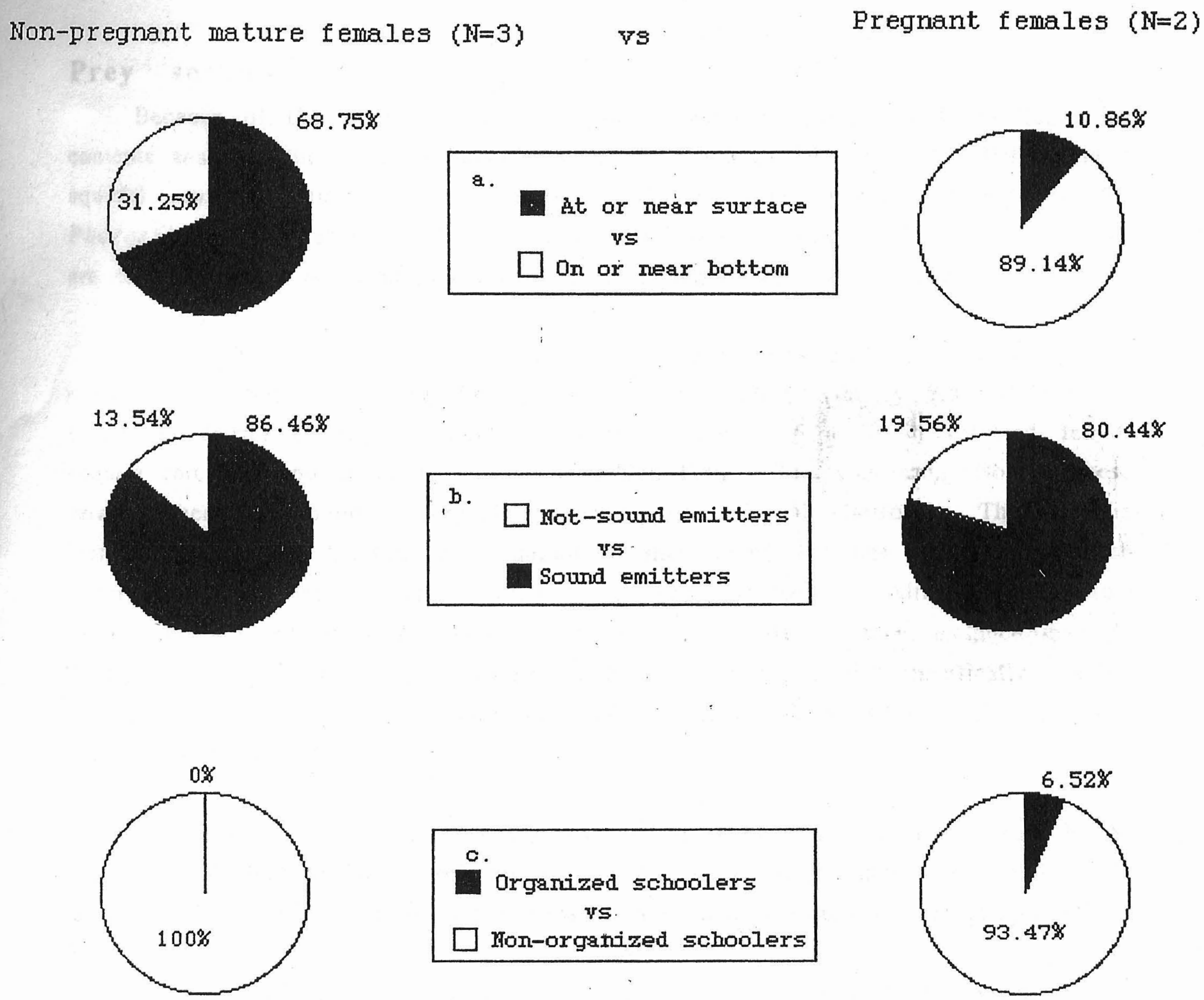

Figure 6. Comparisons of three ecobehavioral trait groups (a, b, c) of so categorized prey species identified from stomachs of non-pregnant mature female and pregnant female vaquitas. For prey species included in each trait group, see Table 6.

DISCUSSION

Prey species

Because of the relatively large sample of vaquita stomachs (24) available for contents analyses, the resulting identifications of a total of 19 species (17 fishes and 2 squids) represents the most comprehensive list of prey species yet reported for *Phocoena sinus* (Table 2). Previous reports mentioning prey species of the vaquita are sparse and are based on much more limited sample sizes of stomach contents.

Fitch and Brownell (1968) reported the presence of otoliths representing two shallow-water bottom-dwelling fishes, *Orthopristis reddingi* (family Haemulidae) and *Bairdiella icistia* (family Sciaenidae), in the stomach of a beach-collected female vaquita carcass found about 20 km north of San Felipe, Baja California (Norte). These small fishes are abundant throughout the upper Gulf of California. The specific identifications, made by the senior author of that report, the late John E. Fitch, an expert in otolith studies, are deemed to be very trustworthy. Although these two species did not appear in the sample analyzed in our study, we have included them in Tables 2 and 6. In their small sample, Fitch and Brownell (1968) specifically mention that they did not encounter squid remains [contrary to what Silber (1990) states concerning their report].

Another beached vaquita carcass collected near El Golfo de Santa Clara by R. Brownell had the remains of sciaenid fishes ("croakers") in its stomachs (Vidal *et al.*, in press). The remains of several species of sciaenids appeared in our sample (Table 2).

Silber (1990) reported a preliminary examination of the stomach contents of two vaquitas producing squid beaks, numerous unidentified otoliths, part of a very small crab, and several whole fishes (less than 12 cm in length) which were tentatively identified as "*Anchoa nasus* and *Sardinops* spp." As pointed out (by Findley) in Vidal *et al.* (in press), if the generic identification of *Sardinops* is correct, then it could only be *Sardinops sagax caerulea* , for no other species of *Sardinops* occurs in the northeastern Pacific. However, pending confirmation, both of these tentatively identified fishes are excluded from lists of vaquita prey species in the present report. (Another potencial problem is that neither species appears to be common in the upper Gulf of California where the sample was secured.)

Vidal *et al.* (in press) report that the remains of numerous squids appearing in the stomach contents of six vaquitas incidentally captured in gillnets in the northeasternmost Gulf were referable to the species *Lolliguncula panamensis* and *Loliolopsis diomedeae*, the only squid species also found in our sample.

Analysis of frequency of occurrence (percentage) of prey species

Reference to the absolute values of percentage frequency ("periodicity") of ocurrence calculated for the 19 prey species in our sample (Table 3) shows that both species of squids and one of the croakers, *Isopisthus altipinnis*, show values of 50% or more. Applying the critera utilized in a study of food habits of fishes by Yáñez-Arancibia *et al.* (1976), these three species would be categorized as primary or "preferred" prey species in the diet of the vaquita, while eight species (with values between 10 and 50%) would be categorized as secondary prey species; these are two of the anchovies (*Cetengraulis mysticetus* and *Anchoa mundeloides*), three croakers (*Micropogonias megalops*, *Cynoscion othonopterus*, *Larimus pacificus*), a grunt (*Pomadasys panamensis*), a midshipman toadfish (*Porichthys mimeticus*), and a lizardfish (*Synodus scituliceps*). The remaining eight species in our sample (values below 10%) would be classified as "incidentals" ("accidentals").

Reference to the calculated standarized deviations of the percentages of frequency of occurrence of the species presented in Table 3 demonstrates concordance with the above method of defining preferred prey species in that both of the squids and the same croaker, *I. altipinnis*, show values in excess of 1.

However, in categorizing secondary and "incidental" species, concordance is not demonstrated between the two methods since none of the remaining 16 species show values of less than -1, and all thus fall only into the category of species of secondary importance (in terms of frequency of occurrence) as defined by the analytical method we follow.

This difference in categorization between the two methods undoubtedly resides in the definitions utilized by each for the "incidental" ("accidental") species. Yáñez-Arancibia *et al.* (1976) arbitrarily define that category as those species occurring in less than 10% of their sample, but without evaluating (i.e., supplying quantitative support) if their sample size can be considered representative. In contrast, the methodology followed in the present report statistically assures that our sample contains at least 90% of the desired information, while the unavailable 10% represents the area where incidental prey species have more probability of occurring. Therefore, in order to accurately distinguish "incidental" ("accidental") species in the diet of the vaquita, it would be necessary to know the total spectrum of prey species consumed by all vaquitas over a complete time period (at least a year); data that would be practically impossible to obtain.

Analysis of relative abundance (percentage) of prey species

A comparison of the values for the standardized deviation calculated from the percentage relative abundance of each prey species in the sample (Table 4) demonstrates that two species of fishes (*Isopisthus altipinnis* and *Porichthys mimeticus*) show high relative abundances (values in excess of 1) and can be categorized as of primary numerical importance in the diet of vaquita. The remaining 17 species are classified as of secondary importance since the calculated standarized deviations of their percentage relative abundances are less than 1 but more than -1. The absence of any species categorized as incidental (by the methology followed) can be explained by the same logic expressed in the final paragraph of the immediately preceeding section.

Analysis of the Index of Relative Importance of prey species

Reference to Table 5 and its values for the standardized deviation calculated from the Index of Relative Importance values (derived from our modified formula) for each prey species shows that one of the squids (*Lolliguncula panamensis*) and two of the fishes (*Isopisthus altipinnis* and *Porichthys mimeticus*) appear as the prey species of highest relative importance (values of more than 1) in the diet of the vaquita. (Also, see Fig. 3.) The remaining 16 prey species (values between -1 and 1) are categorized as of secondary importance by this method of analysis. Again, the absence of any species categorized as "incidental" can be explained by the same logic expressed in the final paragraph of the above section "Analysis of frequency of occurrence (percentage) of prey species."

Ecobehavioral traits of prey species in relation to some vaquita life history parameters

Although sample sizes are small, we discern no markedly distinct patterns that might provide clear insights into details of vaquita ecology though our categorization of prey species into three ecobehavioral trait groups (Table 6) and their subsequent comparisons among three selected vaquita life history parameters (Figs, 4, 5, 6). That is, no marked differences are seen between sexually mature *vs* immature vaquitas (Fig. 4), between female *vs* male vaquitas (Fig. 5), and between pregnant *vs* non-pregnant mature vaquitas (Fig. 6) for the selected trait groups of prey species analyzed.

However, some patterns or trends appear to be indicated by considering the species as a whole, without distinguishing between age classes and sexes. For example, it appears that *Phocoena sinus* may prefer prey species that do not form organized, integrated, and internally cohesive schools (Part "c" of Figs. 4, 5, 6)(matures, 92.86%; immatures, 75.58%; females, 83.33%; males, 89.13%; non-pregnant mature females, 100%; and pregnant females, 93.47%). In general, these possibly preferred species are those usually living solitarily or forming only small, loosely organized aggregations.

A preference for prey fishes that are known (or suspected) to be emitters of concentrated sounds may also be indicated for the vaquita (Part "b" of Figs. 4, 5, 6)(matures, 76.20%; inmatures, 51.17%; females, 66.19%; males, 59.42%; non-pregnant mature females, 86.46%; pregnant females 80.44%). Again, the sample sizes are small (especially for the latter two categories), but it is interesting to note that Barros and Myrberg (1987) and Barros and Odell (1990) report several species of prey fishes that figure prominently in the diet of bottlenose dolphins, *Tursiops truncatus*, in the southeastern U.S.A., that are strong sound emitters (various "grunts, whistles, growls"). These authors propose that these dolphins detect and orient to several prey species by passive listening to their sounds rather than by a process of continual active ecolocation for detecting prey while foraging. The ecology of *Tursiops truncatus* in that region appears to be similar in several respects to that of *Phocoena sinus* in the northern Gulf of California.

Because several species of organisms preyed upon by the vaquita and the bottlenose dolphin are "silent," it is evident that neither of these coastal cetaceans relies solely on sound-emitting organisms for food. But, it is interesting to note that slightly more than 50% of all prey species identified for the vaquita in our study are known or suspected strong sound-emitters (Table 6, part "B"), a percentage we suspect to be much more than would expected if all species of potential prey organisms available to the vaquita in the northern Gulf of California were to be considered. This may be even more noteworthy if the generally turbid waters of the vaquita's habitat, with their resulting amplification of prey-detecting difficulty for a solely visually orienting predator, are considered.

Also, in this vein, the slight difference observed in sound-emitting prey organisms taken by mature (76.20%) and immature (51.17%) vaquitas in our sample (Fig. 4, Part "b") may possibly be explained by speculating that young vaquitas require a long learning period to be able to efficiently recognize, filter (from background noise), and orient on sounds from several prey species, whereas their ecolocatory capabilities may be relatively more developed at an earlier age. This hypothesis deserves further investigation.

Besides the relatively small sample size (as compared to similar studies on food habits of other species) which we had for analysis, the dearth of knowledge on even basic biology of the species utilized by the vaquita as food resources can provide few insights of a detailed nature on vaquita ecology. (For example, a prey species we identify as figuring importantly in the vaquita's diet, *Porichthys mimeticus*, was not even scientifically described until 1988.) However, from the albeit incomplete and generalized knowledge we have on habits and depth distributions of the prey species, we can categorize the coastal vaquita as a versatile, rather non-selective predator subsisting principally on shallow-water, soft bottom-dwelling, non-schooling, and (possibly) sound-producing fishes, but able to regularly exploit some species of schooling species at or near the surface of the water column.

Comparison of food habits of vaquita and totoaba

Because the vaquita and a similarly distributed large corvina-like fish, the totoaba (*Totoaba macdonaldi*, family Sciaenidae), have sometimes been anecdotally linked as utilizing similar if not identical food resources, we present a brief comparison of what is known concerning food habits of these two endangered species.

In her analysis of the stomach contents of 106 totoabas, Román-Rodríguez (1990) reported 13 species and species groups of fishes, four crustaceans, and one mollusk. None of the five species of invertebrates were found in our sample of vaquita stomach contents. Of the 13 fishes, only three species/species groups appeared in stomach contents of the vaquita: *Cetengraulis mysticetus*, *Micropogonias megalops*, and *Cynoscion* spp. The first two species were reported as the most important in the diet of the totoaba (Román-Rodríguez, 1990), while they appeared in only a third of the vaquita stomachs analyzed in our study and together formed only 10% of the estimate of total minimum number of individual prey organisms. Species of the corvina genus *Cynoscion* do not figure importantly in the diet of either predator.

It therefore appears that the totoaba and the vaquita do not compete in a significant manner for food, and that it is unlikely that the documented incidental mortality of vaquitas in the clandestine totoaba gillnet fishery in the upper gulf is due to an overlap in food resources between the two predators.

CONCLUSIONS AND RECOMMENDATIONS

1. The three principal prey species utilized by the vaquita are the corvina, *Isopisthus altipinnis*, the midshipman toadfish, *Porichthys mimeticus*, and the squid, *Lolliguncula panamensis*. Sixteen other species (15 fishes and one squid) identified in this study are categorized as of secondary relative importance to this endangered porpoise. Biological/ecological information on these species is essentially non-existent and the status of their populations in the vaquita's habitat is unknown.

2. Due to the relatively limited sample size of stomach contents available for study, we are unable to demonstrate with certainty any significant differences in the diets of vaquitas in relation to sexes or to the two age classes considered, although a possible difference in the capture of sound-emitting fishes between sexually immature and mature vaquitas may be indicated. If real, this would indicate that mature vaquitas are more efficient passive listeners.

3. Again, although the sample is small, the vaquita may be categorized as a versatile, rather non-selective predator on at least 21 species of shallow-water-occurring fishes and squids (*ca.* 0-50 m in this case) living on or over soft substrates.

4. Significant competition for food resources does not appear to exist between the vaquita and the totoaba (*Totoaba macdonaldi*), and incidental mortality of the former species in gillnets set for the latter species is not likely due to similar food habits.

5. Efforts should continue to acquire and preserve for scientific study by qualified biologists any vaquitas that are incidentally caught and die in the regional fisheries in order to increase our understanding of the species' food habits as well as other aspects of its biology.

6. We recommend that biological/ecological studies on the food resources of the vaquita be undertaken as soon as possible and the status and health of its prey populations be determined in the context of unmonitored continuing or recently developing regional fisheries that regularly take large members of species fed upon by the vaquita (*e.g.*, the bottom-trawl fishery targeted for shrimp but taking

several "by-catch" species utilized by the vaquita, and the gillnet fishery targeting "chano," *Micropogonias megalops*). Similarly, studies on its principal prey species (especially the squid, *Lolliguncula panamensis*, and the corvina, *Isopisthus altipinnis*) should commence as soon as possible.

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APPENDIX

Financial report for the research project: Food habits of the vaquita, *Phocoena sinus*

Expenses (US dollars) to date (Sept. 1994):

1. Academic stipend:

For one PI (Findley transfered from ITESM to CIDESON control with CI approval)

	budgeted	spent	remaining
Total of stipend.........	**5,500.00**	**5,500.00**	**0.00**

2. Trips:

2.1) Natural History Museum of Los Angeles County and Scripps Institution of Oceanography (to identify otoliths), Santa Barbara Museum of Natural History (to identify squid beaks) and San Diego Museum of Natural History (for isopod identifications). Originaly, the budget for this trip was for two investigators (L.T. Findley and J.Torre). The total budget was 2,300.00, and 1,150.00 was tranfered from ITESM to CIDESON control with CI approval.

	budgeted	spent	remaining
- Airline round-trip tickets, Guaymas-Los Angeles..............	1,100.00	0.00	1,100.00
- Car rental......................	300.00	0.00	300.00
- Meals...........................	300.00	225.78	74.22
- Hotel...........................	500.00	93.03	406.97
- Transportaion and related........	0.00	204.62	- 204.62
- Incidental expenses..............	100.00	67.48	32.52
Total...............	**2,300.00**	**590.91**	**1,709.09**

2.2) Expenses of L.T. Findley to attend the "Tenth Biennial Conference on the Biology of Marine Mammals," Galveston, Texas, 11-15 Nov. 1993, and to participate in its "Symposium on Research and Conservation Efforts with the Vaquita" with three scientific papers (see abstracts appended).

	budgeted	spent	remaining
- Airline ticket, Hermosillo-Houston - Guaymas................	0.00	403.78	- 403.78
- Hotel...........................	0.00	363.38	- 363.38
- Meals...........................	0.00	90.10	- 90.10
- Conference registration fees.....	0.00	165.00	- 165.00
- Transportation (taxis, airport limo. service)..................	0.00	121.83	- 121.83
Total...............	**0.00**	**1,144.09**	**-1,144.09**

	budgeted	spent	remaining
Total of trips............	**2,300.00**	**1,735.00**	**565.00**

3. Materials:

	budgeted	spent	remaining
- Computer supplies...............	50.00	0.00	50.00
- Preservation and curation........	200.00	11.26	188.74
- Page costs for publication.......	450.00	0.00	450.00
- Fax, telephone, mail, etc. (transfered from ITESM to CIDESON control with CI approval)........	200.00	26.16	173.84
Total for materials.......	**900.00**	**37.42**	**862.58**
GRAND TOTAL...........	**8,700.00**	**7,272.42**	**1,427.58**

SUMMARY

- Total budget as approved	8,700.00
- Total present budget (after cut by CI).......	8,287.00
- Difference..................................	**413.00**
- "Remaining" in project......................	1,427.58
- Difference (from above).....................	- 413.00
Total "remaining"...................	**1,014.58**

Expenses yet to cover:

- Computer supplies...........................	50.00
- Materials for preservation and curation......	188.74
- Page costs for publication..................	450.00
- fax, telephone,mail, etc....................	173.84
TOTAL yet to cover.............	**1,014.58**