# LAGOON BATHYMETRY, BENTHIC SURVEYS, AND PRODUCTIVITY STUDIES OF LAGUNA SAN IGNACIO BAJA CALIFORNIA SUR, MEXICO

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# ABSTRACT

Productivity studies indicate that Laguna San Ignacio, Baja California is highly productive and well mixed along its entire length. Nitrogen biomass was fairly constant and values were similar to those for other productive coastal regions. The system appears to be cycling very rapidly, with nitrogen as a limiting nutrient. Carbon/nitrogen ratios were high, reflecting a large detrital carbon component in the plankton. Low nitrogen values were suggestive of rapid phytoplankton growth.

Lagoon bathymetry may be divided into four areas: the inlet, defined by a breaker line is comprised of an entry channel bordered by the inner-inlet delta to the north and the barrier island to the south; the lower lagoon consists of a relatively deep, steep-walled channel bordered by broad intertidal flats; the middle lagoon is characterized by a system of three channels separated by shoals; and the upper lagoon is a gently sloping, shallow basin containing two islands.

Bottom samples collected from 31 locations revealed no concentrations of benthic infauna (particularly crustaceans).

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# INTRODUCTION

The 1980-1981 gray whale (Eschrichtius robustus) calving and breeding season was the fourth consecutive winter of research by the author at Laguna San Ignacio (LSI) in Baja California Sur, Mexico. Two major categories of objectives for this fourth of a five year program resulted from research already completed. The first was a continuation of studies of the gray whales' biology and behavior and the second addressed physical and biological studies of the lagoon habitat. This paper reports the findings of habitat studies that sought to provide information relative to the lagoon as an ecosystem and to aid in the analysis of gray whale movements, distribution, and possible utilization of food resources within the lagoon.

Little is known of the benthic fauna and productivity of coastal lagoons in Baja California, except for the work of Phleger and Ewing (1962) and Phleger (1965) in Ojo de Liebre and Guerrero Negro Lagoons. No prior studies have been conducted in LSI. In addition, the most recent hydrographic chart for this lagoon dates from 1896 (U.S. Navy Hydrographic Chart No. 1494) and does not accurately represent the lagoon in its present state. Because these data were nonexistent and the whales have demonstrated a preference for, and possible dependence upon specific lagoon areas, it was highly desirable to initiate baseline studies while human activities (particularly tourism) within the lagoon were in their early stages of development. These baseline data characterize components of the lagoon ecosystem and provide a background against which future changes can be evaluated. These studies, however, provide only a reconnaissance. Additional study is required.

The objectives of the habitat study were to:

1. describe the bathymetry of Laguna San Ignacio.

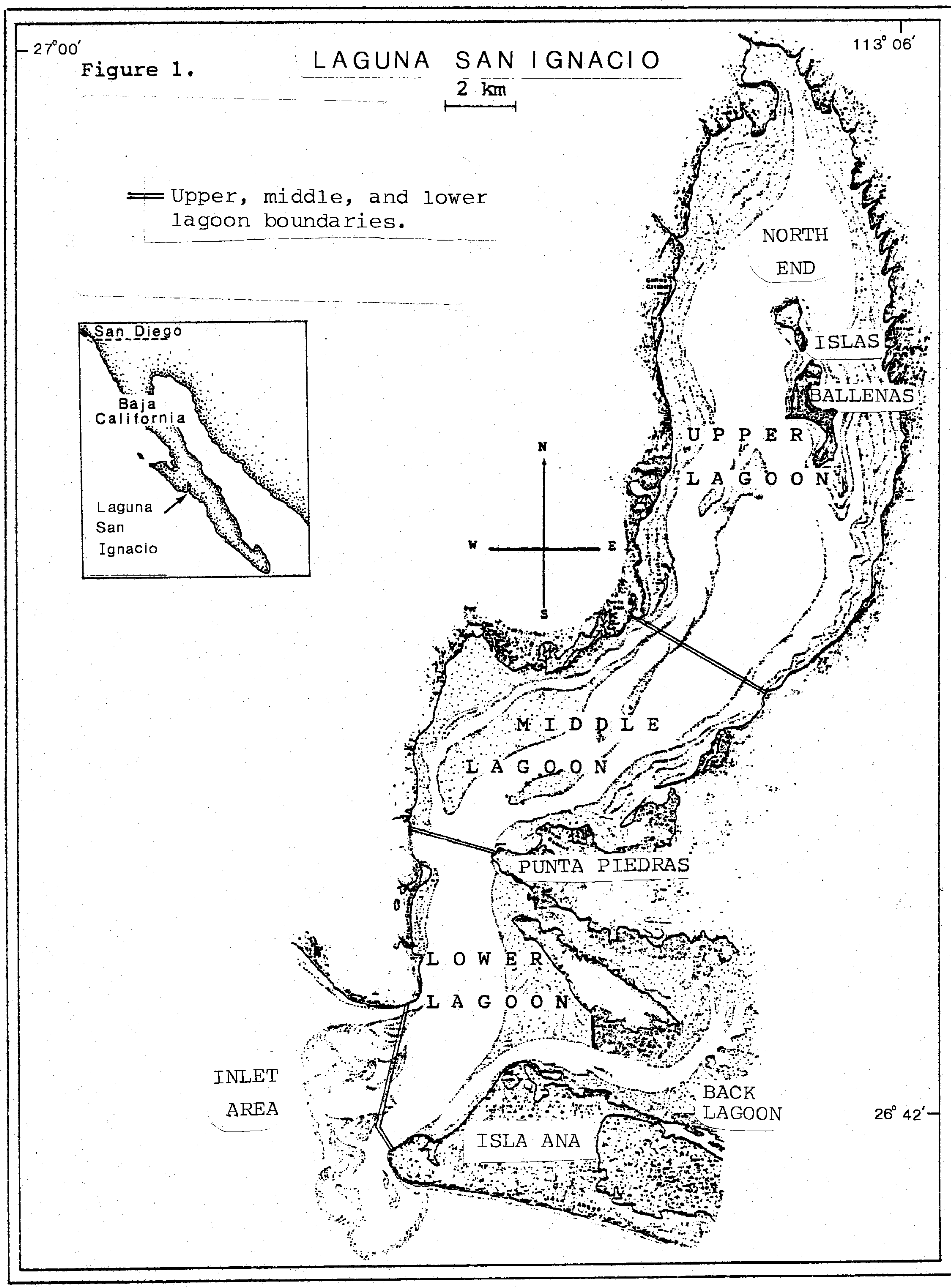
2. inventory benthic communities and examine bottom features with particular reference to potential gray whale (feeding) prey abundance.

3. measure specific physical and chemical variables indicative of wintertime primary productivity.

# METHODS

## Study Area

Laguna San Ignacio is on the Pacific coast of Baja California adjacent to Bahia Ballena approximately 680 km south of the International Border between lat. 26°42' and 27°00' N and long. 113°7' and 113°18' W (Fig. 1). The lagoon is part of the Vizcaino Desert and borders a gently sloping, dry, coastal flood plain the sediments of which are presumed to be Cretaceous and Tertiary, capped by Pleistocene alluvium (Mina, 1957).


27°00'
113° 06'
Figure 1.
LAGUNA SAN IGNACIO
2 km
Upper, middle, and lower lagoon boundaries.
San Diego
Baja California
Laguna San Ignacio
NORTH END
ISLAS
BALLENAS
UPPER LAGOON
N
W
E
S
MIDDLE LAGOON
PUNTA PIEDRAS
LOWER LAGOON
INLET AREA
BACK LAGOON
ISLA ANA
26° 42'

The climate is arid with an annual average rainfall of 56 mm (2 in) which falls mainly during winter months; there is no runoff and no fresh water streams or rivers flow into the lagoon (Bostic, 1975).

The lagoon lies on a north to south axis and is perpendicular to the coast. It extends inland approximately 32 km, ranges from 1.8 to 6.5 km wide, and has an area of 77.5 km² (Swartz and Jones, in press). There are three principal islands: Isla Ana, the barrier island directly southeast of the inlet, and Islas Ballenas in the northernmost section of the lagoon.

## Lagoon Bathymetry

Fifty-two cross-sectional depth profiles were made of the lagoon by means of a portable recording fathometer operated from a small boat. The profiles included areas not frequented by the whales as well as locations where apparent feeding behavior was previously observed (Swartz and Jones, 1980a, 1980b). Depth contours were transferred to a lagoon chart for evaluation.

## Benthic Surveys

A SCUBA diving program was conducted to make visual inspections of the lagoon floor and to obtain core samples of the sediments and benthic infauna. Thirty-one dives were made at 31 different sites, selected to be representative of all lagoon areas; the inlet, lower lagoon, middle lagoon, upper lagoon, and back lagoon channel (Fig. 2). Forty samples were collected with a cylindrical coring device, 10 cm by 15.2 cm deep and washed on 3, 2, and 1 mm sieve screens. Relative abundance of organisms was recorded and representative subsamples were fixed in 10% Formalin and preserved in 70% alcohol. No mechanical analyses of the sediments were made; however, the dive sites were visually examined and sediment samples characterized by color and generally by type as: shell fragments; coarse, medium, and fine grain sand; mud; and silt.

## Productivity Studies

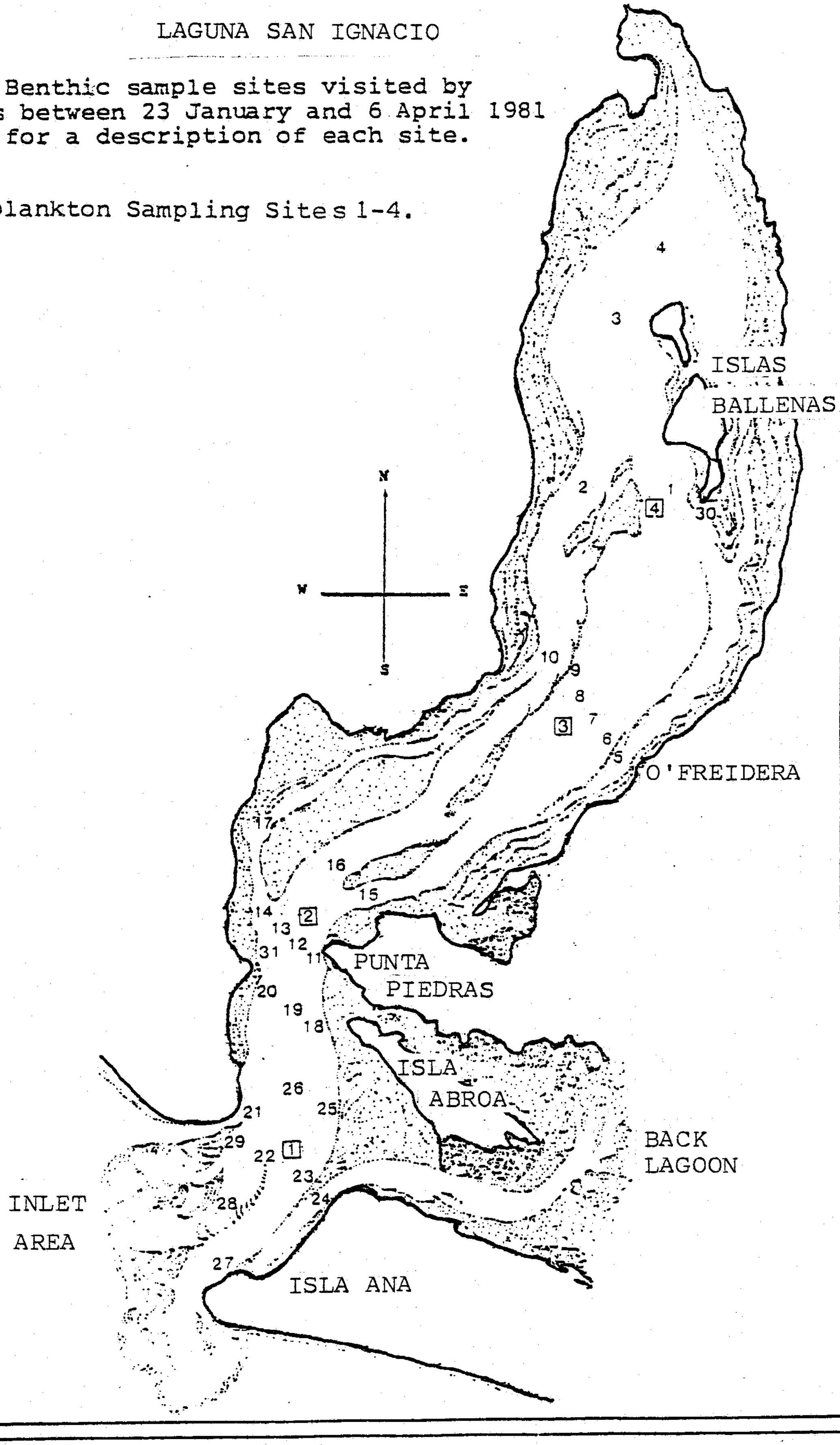
A preliminary program to estimate the wintertime primary productivity of phytoplankton in LSI was initiated. This program sought to measure specific physical and chemical variables indicative of primary production within the lagoon to evaluate the contribution of phytoplankton to total lagoon production. Phytoplankton production rates indicate production rates at higher trophic levels. Therefore, measurements of lagoon primary productivity reflect the lagoon's potential for supporting significant standing stocks of prey species that would be available to gray whales.

Four sampling stations were selected allowing for simultaneous comparison of the four primary lagoon areas {i.e., the inlet (station No. 1), the lower lagoon (station No. 2), the middle lagoon (station No. 3), and the upper basin (station No. 4), (Fig. 2)}. In all, 48 samples of surface water were collected and analyzed for dissolved nutrients, phytoplankton

LAGUNA SAN IGNACIO

Figure 2 . Benthic sample sites visited by SCUBA divers between 23 January and 6 April 1981 See Table 1 for a description of each site.

⊡ = Phytoplankton Sampling Sites 1-4.



carbon/nitrogen (C/N) ratios, and phytoplankton primary production rates via radiocarbon uptake.

The following procedures were utilized for collection of samples:

Dissolved nutrients (DN). At 3-4 week intervals duplicate 2 l samples of surface water were collected from each station. A 50 ml plastic bottle was filled from each 1 l bottle and was frozen until analysis. In the laboratory, filtered samples were analyzed for carbon biomass (PC), nitrogen biomass (PN), dissolved nitrate ($NO_3$), dissolved ammonia ($NH_4$), and phosphates ($PO_4$) using a Technicon [1]Auto Analyzer System (Model II). The analysis and reagents used followed those of Murphy (1962), Armstrong, Stern, and Strickland (1967), and Slawyk (1972). The results were graphed by a Digital Minc Mini Computer System equipped with a Technicon Plotter.

Carbon/Nitrogen (C/N) ratios. At two-week intervals surface water was sampled from each station for phytoplankton C/N ratios. Approximately 100 ml (exact volume was recorded) of water were drawn by suction through 13 mm diameter organic-free, glass fiber filters. The filters with retained phytoplankton were placed in a nickle combustion capsule and held in a vacuum dessicator until dry. These dried samples were stored in individual, screw-top, glass vials for analysis. C/N ratios were determined by combusting the dried samples in a Perkin-Elmer Model 240B CHN Elemental Analyzer.

Radiocarbon experiments. On 6 March and 6 April measurement of phytoplankton primary production rate was attempted utilizing the $^{14}C$ uptake technique (Strickland and Parsons, 1968). One liter surface water samples collected from stations No. 1 and 3 were spiked with 10 uc $^{14}C$ sodium bicarbonate. Samples were mixed well and poured into one dark and two light incubation bottles of equal volume. The bottles were suspended in a rack just below the surface of the water and incubated for 3 hrs. Following the incubation period, a known quantity of water (approximately 100 ml) taken from each bottle was filtered onto Millipore 0.45 um organic-free filters and stored in liquid scintillation fluor.

In the laboratory, samples were "counted" on a Packard 3000 Liquid Scintillation Spectrometer for 20 min or 20,000 counts. The counts per minute were converted to disintegrations per minute by utilizing a machine efficiency calibration constant, corrected for dark bottle counts and length of incubation.

## RESULTS

### Lagoon Bathymetry

LSI has a distinctive topography characteristic of lagoons with an appreciable tidal range (semi-diurnal tide; range, 0.9 to 2.4 m). The

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[1]The use of trade names in this report is for documentation purposes and does not imply endorsement by the author.

bathymetry and sedimentology may be divided into four areas: the inlet, and lower, middle, and upper lagoon.

The 3.8 km wide inlet is defined by a breaker line and is comprised of a 1 km wide entry channel with a maximum depth of 16.8 m (55 ft), bordered by the inner-inlet delta averaging 3.6 m (12 ft) in depth (Fig. 3, profile 1). This steep-walled channel runs northward and parallels the west shore of the barrier island (Isla Ana). 1.5 km inside the inlet, the delta ends and the channel becomes deep over its entire width (Fig. 3, profile 2). Sediments range from hard-packed, medium-grain sand with large shell fragments on the inner-delta to irregular rock rubble covering the floor of the inlet channel. The delta was devoid of plant life, but the channel supported sparse vegetation in the rocky areas (Table 1, sites 27-29).

The lower lagoon consists of a steep-walled channel with a maximum depth of 25.9 m (85 ft). It narrows from 3 km wide near the inlet to a constriction 1.8 km wide at Punta Piedras, where it terminates as the lagoon trends northeast. This segment is the widest, relatively deep channel in the lagoon. West of Isla Ana, a tributary channel 0.5 km wide and 9.1 m (30 ft) deep leaves the main lagoon, turns southeast behind Isla Ana, and runs 5.1 km to a shallow lagoon 1.5 to 2.4 m (5 to 8 ft) deep (Fig. 3, profiles 13-15). West of Isla Ana, the bottom is composed of coarse and medium-grain sand mixed with crushed shells. Extending north from Isla Ana, the channel floor varies from a series of irregular, sand ridges perpendicular to the lagoon axis to rocky areas overlain with sand. The deepest regions of the channel were covered with hard-packed, fine to coarse-grain sand. West of Punta Piedras, medium-grain sand ridges were interspersed with occasional rock outcroppings 4 to 6 m tall (Table 1, sites 11-14, 18-26, 31).

The middle lagoon is characterized by a system of three channels ranging from 7.6 to 21.3 m (25-70 ft) deep, which become shallower and irregular in profile west of O'Freidera (Fig. 3, profiles 5, 6). Sediments are well washed fine to coarse-grain sand with crushed shell, and some rocky areas. Extensive sand bars support stands of eelgrass, *Zostera marina*, but the channels contain little plant life (Table 1, sites 5-10, 15-17).

The upper lagoon is a gently sloping basin with an average depth of 4.6 m (15 ft). Two islands (Islas Ballenas) separated by a very shallow isthmus are located approximately mid-lagoon (Fig. 3, profiles 8-12). The areas at the head of the lagoon north and east of the islands contain fine sand, mud, and silt. The bottom in the north is dominated by dense stands of eelgrass containing a variety of gastropods, pelecypods, encrusting hydroids, sponges, and tunicates. Red and brown algal epiphytes and encrusting invertebrates are attached to rocks, shells, and eelgrass blades (Table 1, sites 1-4, 30).

Figure 3. Depth profiles of Laguna San Ignacio based on echograms. Horizontal scale approximate. Soundings are in feet. Vertical exaggeration 100x.

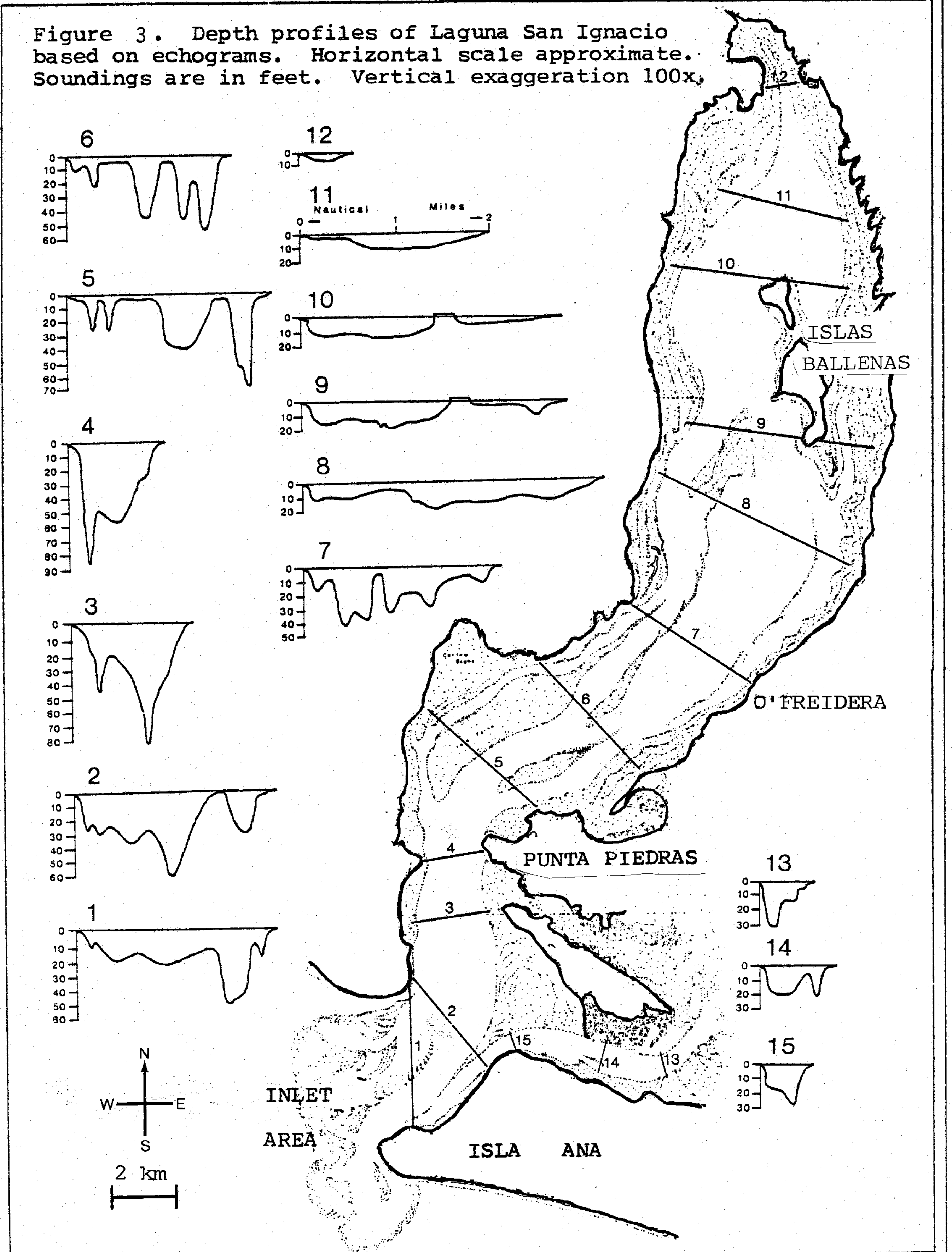


Table 1. Summary of the benthic samples collected from 31 dive sites. For the location of each sight, see Fig. 2.

| Sample Site | Date | Water Depth | Sediment | Surface Organisms | Benthic Infauna |
|---|---|---|---|---|---|
| 1 | 23 Jan | 4.9m (16') | medium to coarse sand w/ crushed shell | eelgrass, _Zostera marina_ scallops, _Pecten circularis_ sea pens, Renillidae | none |
| 2 | 23 Jan | 4.3m (14') | medium to coarse sand w/crushed shell | eelgrass scallops sea pens | none |
| 3 | 23 Jan | 3.6m (12') | medium to coarse sand w/crushed shell | dense eelgrass scallops sea pens | none |
| 4 | 23 Jan | 3.6m (12') | black mud & silt | dense eelgrass | polychaete worms (one) |
| 5 | 24 Jan | 6.1m (20') | black-sandy mud w/shell fragments | eelgrass red sponges | isopod (one) |
| 6 | 24 Jan | 12.8m (42') | black-sandy mud | none | none |
| 7 | 24 Jan | 8.2m (27') | brown-sandy mud w/ crushed shell | none | none |
| 8 | 24 Jan | 11.6m (38') | Same as site No. 7 | none | none |
| 9 | 24 Jan | 14.6m (48') | black-sandy mud w/ crushed shell | sea pens red sponges | none |
| 10 | 24 Jan | 7.3m (24') | Same as site No. 9 | none | none |

Table 1 (cont., p.2)

| Sample Site | Date | Water Depth | Sediment | Surface Organisms | Benthic Infauna |
|---|---|---|---|---|---|
| 11 | 15 Feb | 6.1m (20') | black-sandy mud w/ eel-grass and mangrove detritus | none, infaunal tubes | *Donax sp.* (one) |
| 12 | 15 Feb | 4.6m (32') | medium sand w/crushed shell, gravel, and cocina rock | infaunal tubes brittle stars, Ophiuroidae gorgonians, Gorgoniidae sponges, Porfiera | none |
| 13 | 15 Feb | 12.2m (40') | medium sand w/crushed shell, gravel, apparent whale pits | none, infaunal tubes | none |
| 14 | 15 Feb | 11.0m (36') | Same as site No. 13 | none, infaunal tubes | none |
| 15 | 15 Feb | 15.8m (58') | fine sand | sea pansies, Renillidae shrimp (few) | none |
| 16 | 15 Feb | 11.0m (36') | coarse sand w/crushed shell | none, infaunal | sand worm tube |
| 17 | 15 Feb | 9.1m (30') | fine dark sand | scattered eelgrass | *Macoma sp.* (one) |
| 18 | 31 Mar | 10.7m (35') | cocina rock w/thin overlay of sand w/ crushed shell | yellow gorgonians, sponges, bryozoans | none |
| 19 | 31 Mar | 14.9m (49') | Same as site 18 | " | " |
| 20 | 31 Mar | 27.1m (89') | medium sand w/crushed shell | brittle stars (2) | Jacknife clams (2) *Tagelus sp.* |
| 21 | 31 Mar | 10.7m (35') | fine sand w/large shell fragments | none, infaunal tubes | polychaete tubes |

Table 1 (cont., p.3)

| Sample Site | Date | Water Depth | Sediment | Surface Organisms | Benthic Infauna |
|---|---|---|---|---|---|
| 22 | 31 Mar | 10.7m (35') | coarse sand w/crushed shell, poorly sorted | none | none |
| 23 | 31 Mar | 10.7m (35') | Same as site 22 | " | " |
| 24 | 31 Mar | 8.8m (29') | Same as site 22 | " | " |
| 25 | 3 Apr | 6.1m (20') | coarse sand w/crushed shell | none, infaunal tubes | polychaete worm (one) |
| 26 | 3 Apr | 11.0m (36') | fine sand w/large shell fragments | Sand dollars, <u>Encope micropora</u>, infaunal tubes | none |
| 27 | 6 Apr | 15.8m (52') | coarse, unsorted, sand and crushed shell over cocina rock | spiny lobster, <u>Panulirus sp</u>. gorgonians | none |
| 28 | 6 Apr | 6.7m (22') | medium to coarse sand w/crushed shell and large shell fragments | red and brown benthic algae | none |
| 29 | 6 Apr | 1.8m (6') | fine sand | none | <u>Donax sp</u>. (one) |
| 30 | 3 Feb | 1.5m (5') | rock intertidal; cohesive, muddy, tube mat underlain by fine sand | polychaete worm tube mass w/ sponges, hydroids, brittle stars, gammarids, brown algae | none |
| 31 | 17 Mar | 9.1m (30') | medium sand w/crushed shell; large rock outcroppings | hydroids, gorgonians spiny lobster, green turtle, <u>Chelonia mydas</u> | no sample |

## Benthic Surveys

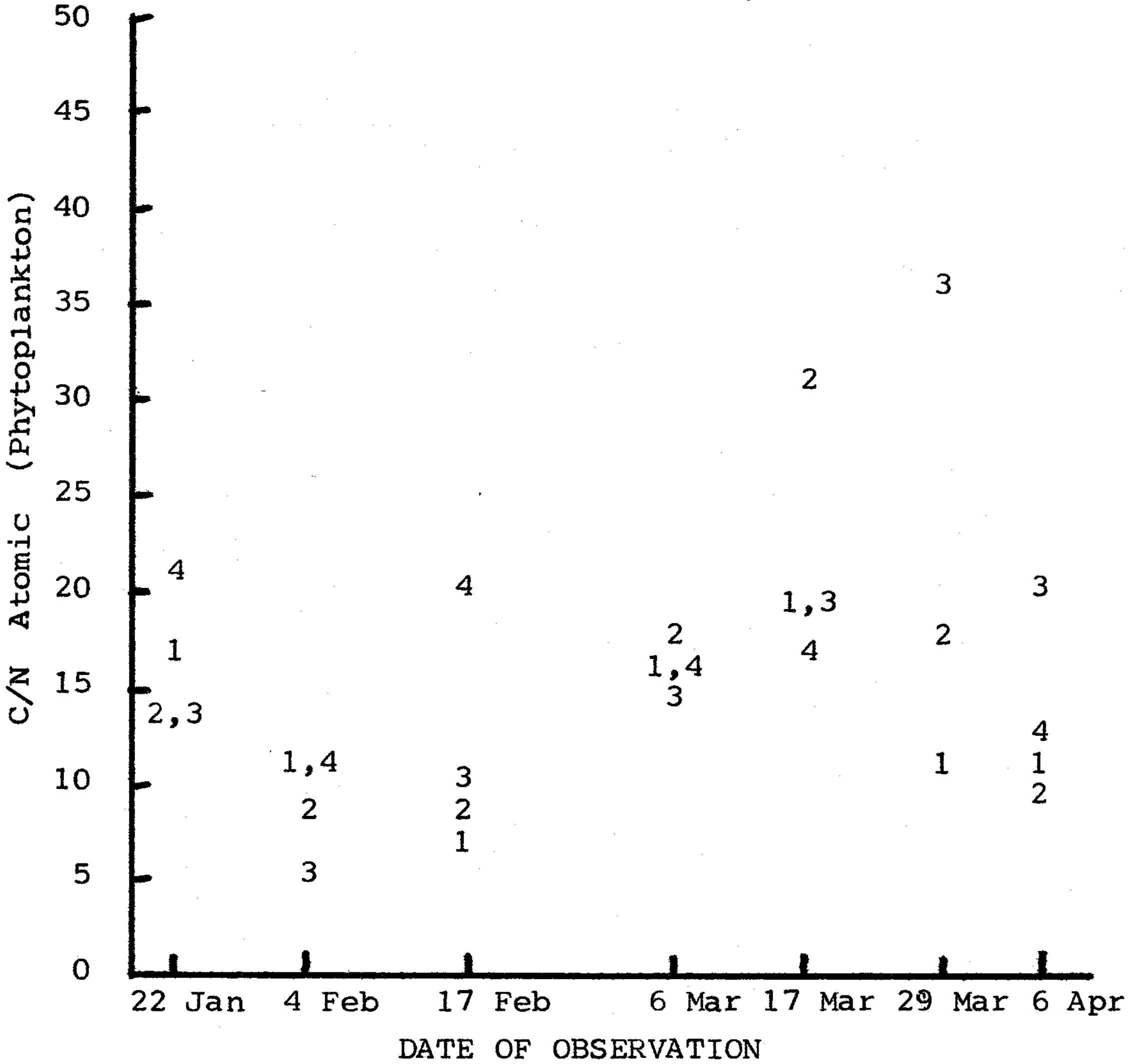
Notably, no concentrations of moderate-sized benthic crustaceans (>1 mm) were collected in LSI. Twenty-two of the 31 samples collected contained no benthic infauna, and 9 samples collectively contained several amphipods, isopods, and polychaete worms. Epibenthic fauna were collected in 11 samples and included: two shrimp, Pandalidae sp. and Hippolylidae sp.; sea pens and sea pansies Renillidae sp.; brittle stars, Ophiuroidea; pelecypods, *Pecten sp.*, *Argopecten sp.*, *Tivela sp.*, *Macoma sp.*, *Donax sp.*, *Tagelus sp.*, and *Solen sp.*, bryozoans and gorgonians (Johnson and Snook, 1967) (Table 1).

## Productivity Studies

The preliminary analyses of carbon, nitrogen, and dissolved nutrient content of the phytoplankton are summarized in Figs. 4A-F. Results suggest the lagoon is well mixed along its entire length; there were no statistically significant seasonal differences in the C/N ratios between sampling sites. Nitrogen biomass (P/N) was fairly constant ($\overline{X}$ = 3.527, S = 1.4333 ug atoms N/liter), and the carbon to nitrogen ratios (C/N) were not suggestive of an oligotrophic system. On the contrary, C/N ratios were often high ($\overline{X}$ = 14.6123) reflecting a large detrital component in the plankton. In general, the higher the C/N ratio, the more organic carbon is present in the water. Organic carbon is directly proportional to the phytoplankton biomass present. The lagoon system seems to be cycling very rapidly, particularly in the period of mid-February to mid-March, with nitrogen appearing as the limiting nutrient. The extremely low nitrogen during that period compared to carbon ($\overline{X}$ = 46.8086 ug atoms C/liter) is indicative of rapid plankton growth. However, the constant biomass leads us to suspect that most of the production goes into herbivore biomass or is flushed out of the lagoon with the tides, and not toward increasing phytoplankton standing stock.

Disintegrations per minute measured for the $^{14}C$ phytoplankton samples collected on 6 March were 2,439 and 2,696 for station No. 1 and 4,616 and 4,737 for station No. 3. Samples obtained on 6 April were 5,299 and 4,993 dpms for station No. 1 and 3,838 and 3,776 dpms for station No. 3.

To determine the amount of organic carbon production and its cycling rate within the lagoon system it is necessary to assess the alkalinity (pH) and bicarbonate content of the water in addition to the salinity and temperature (Strickland and Parsons, 1968). Unfortunately a pH meter malfunction in the field prevented the calculation of mg C/m$^3$/hr. However, the level of dpms calculated from the liquid scintillation counts suggest the lagoon is very productive near station No. 3 compared to station No. 1 in March, and slightly less productive than station No. 1 in April depicting the verge of a phytoplankton bloom.

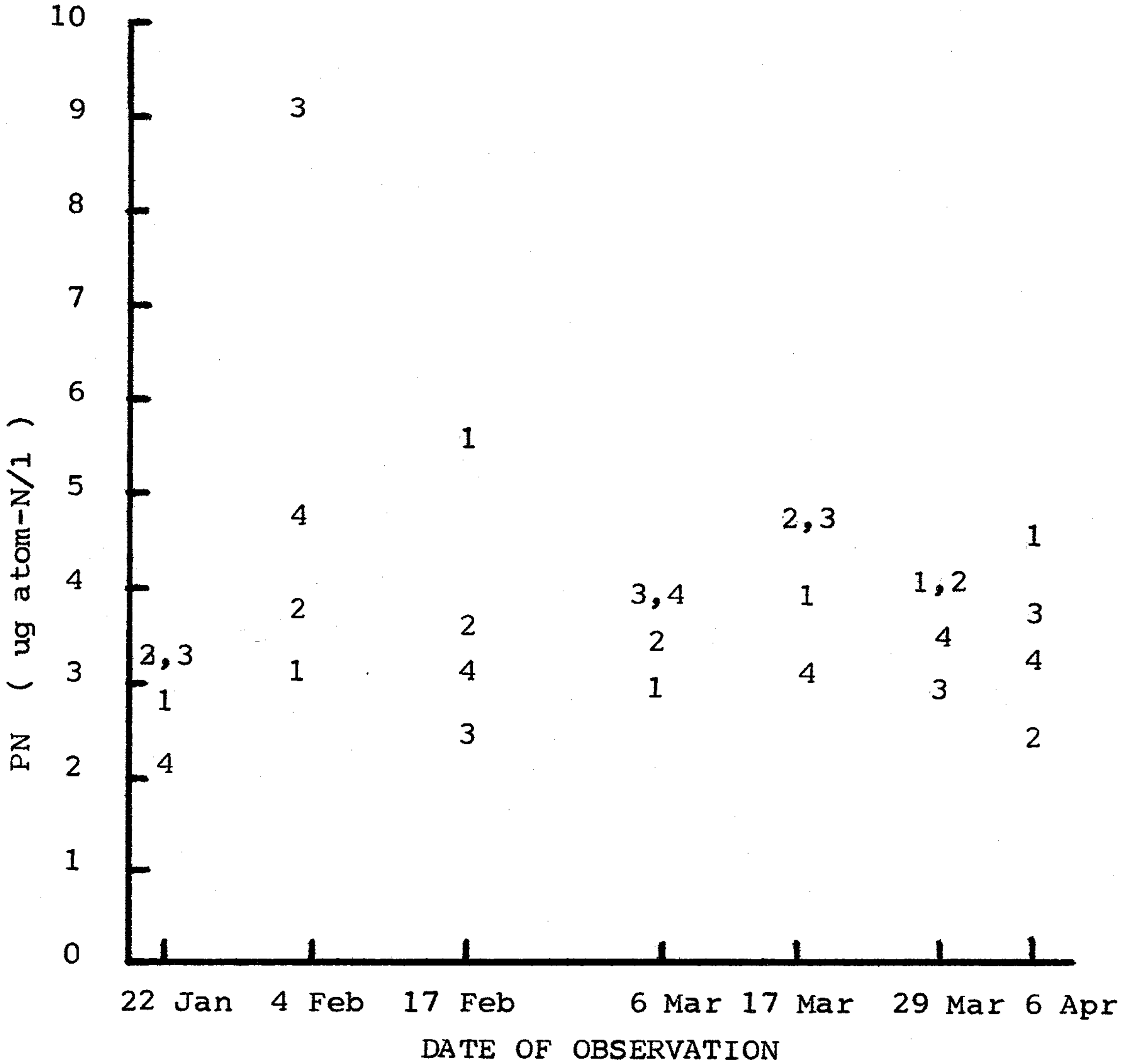



| Station No. | $\bar{X}$ C/N |
|---|---|
| 1 | 13.1317 |
| 2 | 14.5610 |
| 3 | 16.1749 |
| 4 | 14.5817 |

$\bar{X}$ = 14.6123
s = 5.9910
n = 44

.95 Confidence Interval
16.4376 -12.7869

Figure 4A. Phytoplankton C/N ratios at four stations in Laguna San Ignacio based on 11 samples collected between 22 January and 6 April 1981.

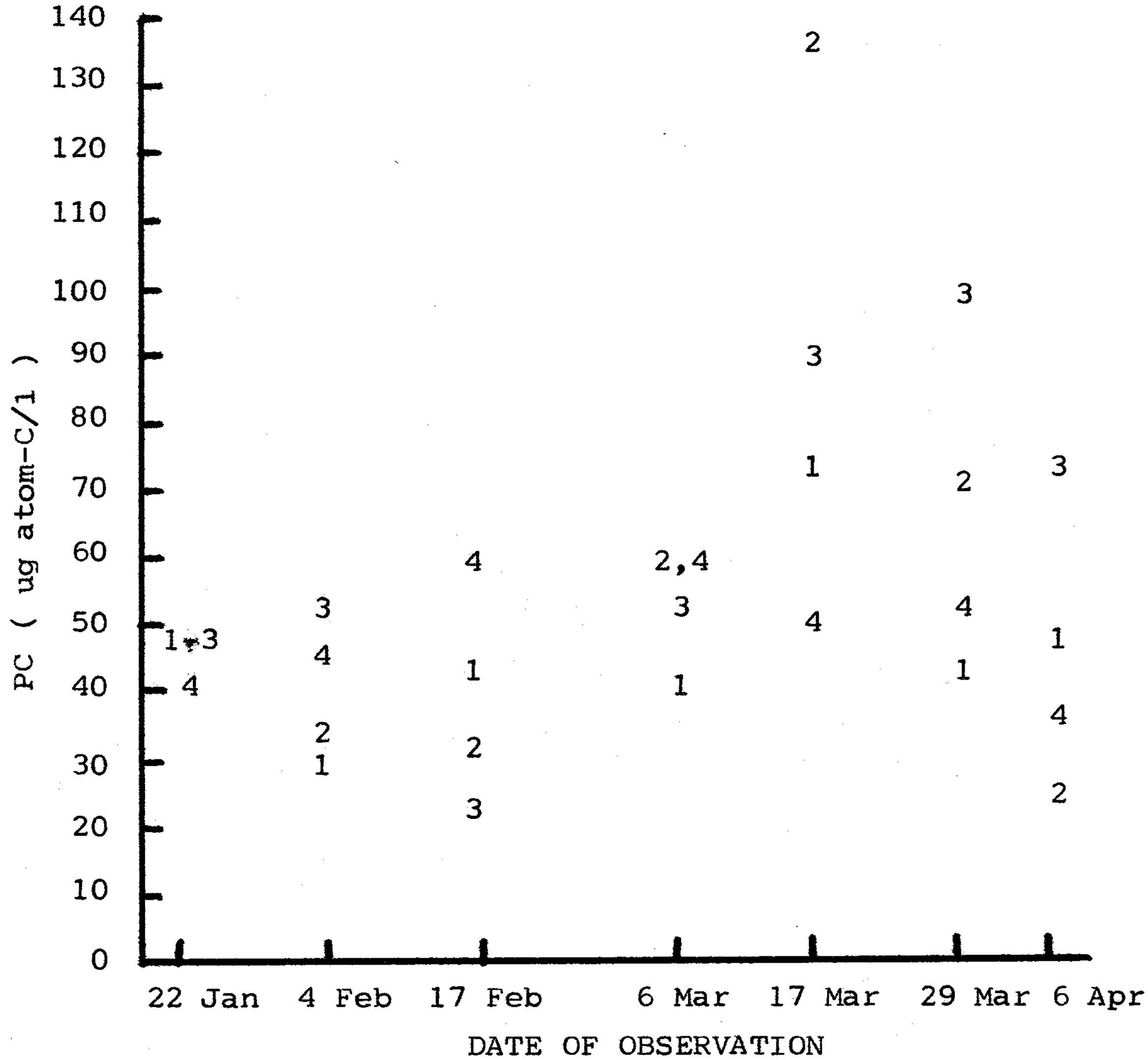



| Station No. | $\bar{X}$ PN |
|---|---|
| 1 | 3.3627 |
| 2 | 3.2018 |
| 3 | 3.1944 |
| 4 | 3.2863 |

$\bar{X}$ = 3.5270
s = 1.4329
n = 44

.95 Confidence Interval
3.9636-3.0905

Figure 4B. Phytoplankton nitrogen biomass at four stations in Laguna San Ignacio based on 11 samples collected between 22 January and 6 April 1981.




| Station No. | $\bar{X}$ PC |
|---|---|
| 1 | 42.2063 |
| 2 | 48.7090 |
| 3 | 57.8727**, p less than .01 |
| 4 | 46.2081 |

$\bar{X}$ = 46.8086
s = 15.7764
n = 44

.95 Confidence
Interval
51.6153-42.0018

Figure 4C. Phytoplankton carbon biomass at four stations in Laguna San Ignacio based on 11 samples collected between 22 January and 6 April 1981.

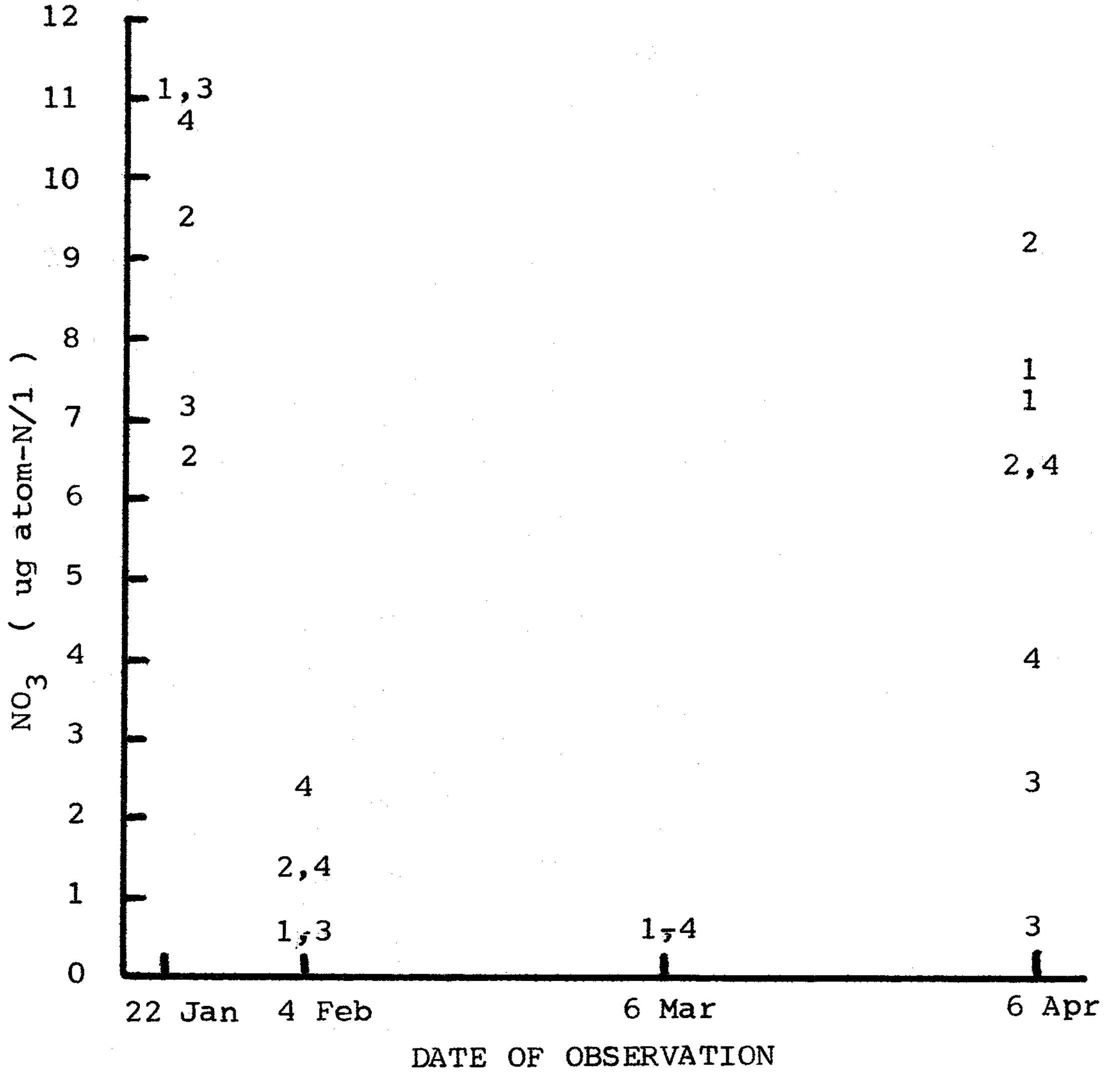



Figure 4D. Dissolved nitrate at four stations in Laguna San Ignacio based on eight samples collected between 22 January and 6 April 1981.

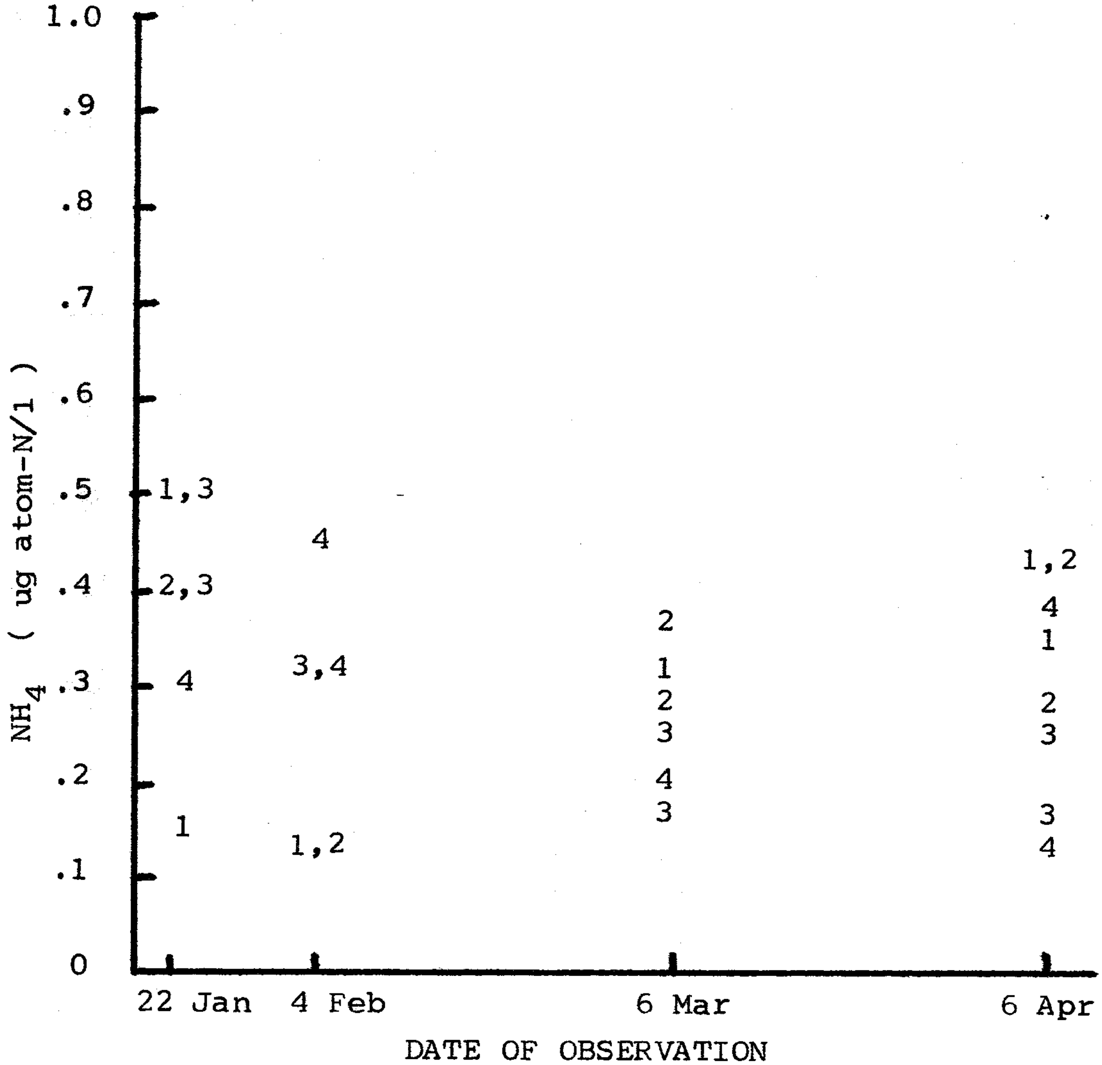



Figure 4E. Dissolved ammonia at four stations in Laguna San Ignacio based on eight samples collected between 22 January and 6 April 1981.

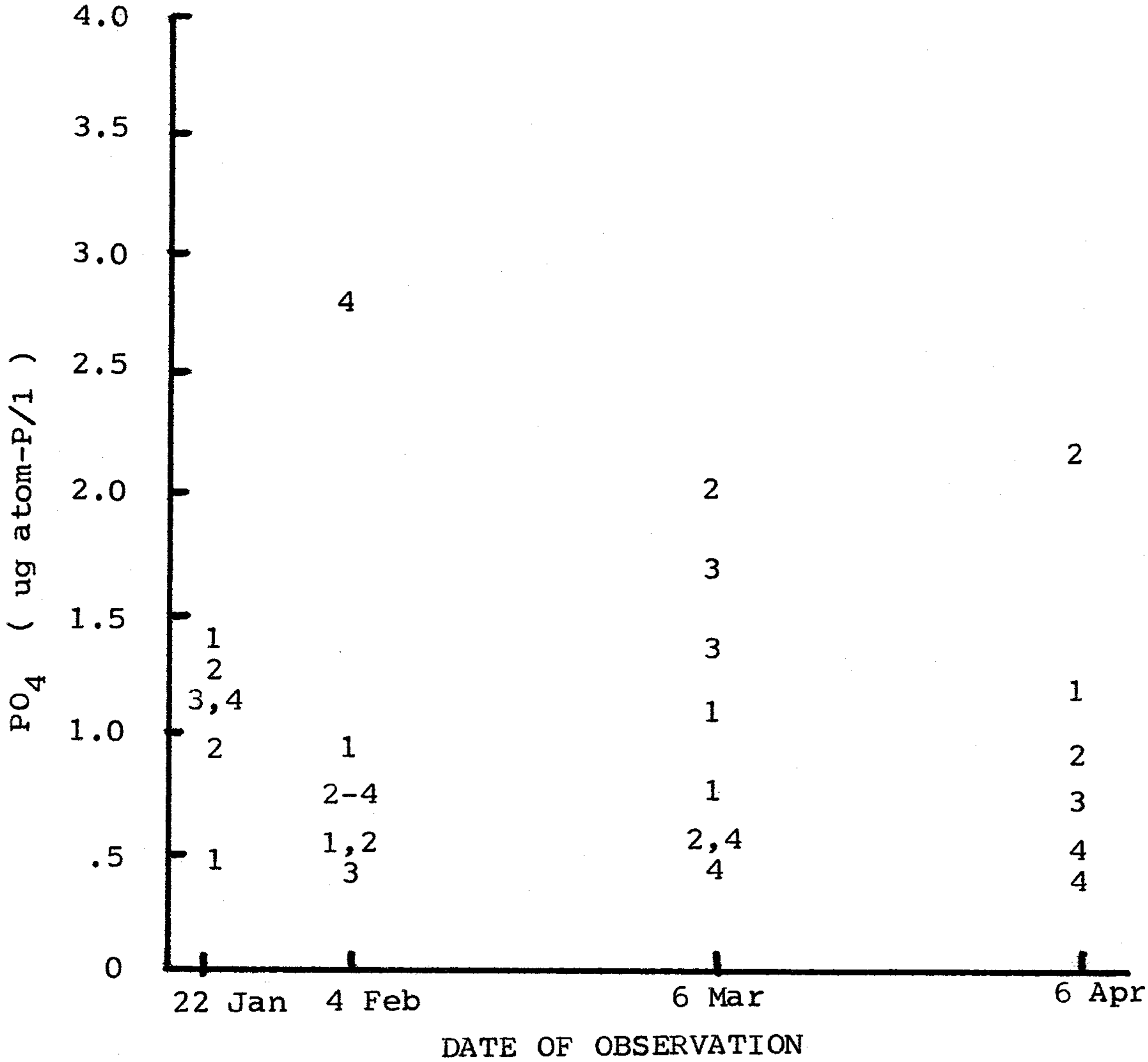



Figure 4F. Dissolved phosphate at four stations in Laguna San Ignacio based on eight samples collected between 22 January and 6 April 1981.

# DISCUSSION AND CONCLUSIONS

## Lagoon Bathymetry

The navigable area available to whales in the middle and upper lagoon is greatly reduced at low tide, and whale movement is highly correlated with tidal flow (Swartz and Jones, 1980b). However, the lower lagoon channel is relatively deep and wide ($\overline{X}$ depth 15.2 m, 1.8-3 km wide) and the area utilized by whales is not lessened even at lowest low water; thus, tidal state appears to be less of a controlling factor. The preference for the lower lagoon by all whales may be related to access to the deep, lower lagoon channel and close proximity to the inlet and open ocean, or both.

## Benthic Surveys

Benthic surveys within the lagoon did not reveal concentrations of crustaceans, either epibenthic or infaunal. However, we observed water borne shrimp and suspect that specimens "escaped" our sampling technique. Benthic furrows and pits, as described by Nerini (1980) for the gray whales' northern feeding grounds, were observed in the lower lagoon west of Punta Piedras. Nerini hypothesized that these features may be traces left in the bottom by foraging gray whales. Samples from this area were collected while the maximum number of whales was present, and it is possible that the infauna were depleted prior to sampling. Bivalve communities in the lagoon support a fishery for which the area is noted, and the near-shore waters adjacent to the lagoon support a shrimp fishery where catches of 800 kg/boat/night are reported (Abreojos Fisherman's Cooperative, pers. comm.). Whether or not these resources are utilized by the whales is unknown.

## Productivity Studies

The initial information on primary productivity within LSI collected in 1981 supports the contention that coastal lagoons of Baja California are extremely productive areas were primary production rates can average 47.2 mg Carbon/$m^3$/day (Phleger and Ewing, 1962). This production provides the organic basis for the subsequent trophic levels represented in the lagoon fauna.

The period of rapid nutrient cycling indicated by the analysis of phytoplankton and dissolved nutrient samples corresponds with the period of greatest whale abundance in the lagoon (mid-February to mid-March) (Swartz and Jones, 1978, 1980a, 1980b, in press). Despite the implication of rapid phytoplankton growth, the phytoplankton standing stock appears stable throughout January to April. We suspect that either grazing by zooplankton and the abundant bivalve communities within the lagoon, or loss to the sea via tidal flushing, or both, serve to limit the buildup of phytoplankton biomass.

Gray Whale Feeding

One of the continuing controversies in gray whale biology is focused on the theory that gray whales do not feed for approximately nine months of the year. Research has indicated that "Virtually no food is consumed during migration" and "There is little evidence that gray whales feed on their winter grounds off Baja California" (Rice and Wolman, 1971). Currently, based on a growing body of direct and indirect evidence to the contrary, this theory is being modified.

The feeding behavior of gray whales in the north Pacific and Bering Sea has been described by several investigators including Wilkie and Fiscus (1961), Pike (1972), Darling (1977), and Nerini (1980). Similar "mud-trailing" and "sediment flushing" behavior suggestive of feeding has been observed in LSI (Swartz and Jones, 1980a, 1980b). Whales orient themselves into the current and surface vertically, throat grooves distended, with sediment laden water draining from their mouths. In 1981 on 11 occasions whales (including calves) were observed "skimming" and ingesting large floating mats of eelgrass. Eelgrass accumulates in windrows which move throughout the lagoon with the tides. Examination of these detrital mats revealed encrusting ectoprocta on the blades of the grass, and small crustaceans including copepods, amphipods, mysids, and larval fish under the mats. We assume that whales ingest these associated organisms along with the eelgrass.

An event indicative of feeding is the passing of feces. On four occasions in the lagoon in 1981 adult whales were observed defecating a yellow-green to dark-green semi-liquid material; and two fecal samples were recovered. The first consisted of a dark-green, strong smelling paste. Microscopic examination revealed no cellular structure. The second sample was a greenish wad of fiberous material with the same odor as the first sample, and consisted of densely packed strands of filamentous algae, Ectocarpus sp. (common in the lagoon), bits of eelgrass, bits of colonial tunicates, and sand. Although compressed into a tight wad, this material remained relatively undigested.

Our observations suggest the following tentative hypotheses regarding feeding by gray whales in LSI.

1) Direct and indrect evidence indicates that a sub-group of gray whales, particularly cows with calves, opportunistically consume appreciable amounts of prey within the lagoon and its near-shore waters.

2) However, the apparent lack of benthic infauna, in quality or quantities similar to those reported by Nerini (1980) for the gray whale summer feeding grounds off Alaska, suggests that gray whales are not feeding on previously identified prey within the lagoon.

## RECOMMENDATIONS

1. A main question of habitat studies at LSI is "Are whales feeding

in the lagoon; and if so, on what?" Additional benthic core samples should be collected both before the whales' arrival at the lagoon, and after peak occupation in an effort to clarify the finding that "no concentrations of epibenthic or infaunal crustaceans were discovered in the lagoon" by ruling out the possibility that these organisms were impacted by the whales prior to sampling.

2. Evidence of correlation between the presence of benthic furrows (observed in the lower lagoon) and the presence of whales is needed, and could be obtained by visual inspection of a marked area before, during, and after lagoon occupation.

3. Direct and indirect evidence indicates that a sub-group of gray whales is feeding in the lagoon. Research to identify potential food categories (other than traditional prey species) and to develop measures of abundance and distribution should be expanded to include water column sampling with trawling being conducted at various depths during both days and nights.

4. Due to the large variation in our nutrient data, plankton studies should be modified. The number of stations should be decreased to one (lower lagoon), but the number of samples collected for PN, PC, $^{14}C$, and nutrients should be increased. A minimum of three one-week periods of daily sampling at the same stage of the tide during the season is suggested.

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# LITERATURE CITED

Armstrong, S. A. J., C. R. Stern, and J. D. H. Strickland. 1967. Measurement of upwelling and subsequent biological processes by means of a Technicon Auto Analyzer and other associated instruments. Deep Sea Research, 14:381-389.

Bostic, D. L. 1973. A natural history guide to the Pacific Coast of north central Baja California and adjacent islands. Biological Educational Expeditions, P. O. Box 1484, Vista, CA 92083, 184 pp.

Darling, J. 1977. The Vancouver Island gray whales. Waters (J. Vancouver Aquar.), 2:5-19.

Mina, U. F. 1957. Bosquejo geologico del Territorio Sur de la Baja California: Bol. Asoc. Mexicana de Geologos Petroleros, 9(3,4):139-270.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for determining phosphate in natural waters. Analytical Chem. ACTA, 12:162-176.

Nerini, M. K. 1980. Gray whale feeding ecology. Final Report. OCSEAP, RU593 N. M. M. L. cont. No. R7120828.

Phleger, F. B. 1965. Sedimentology of Guerrero Negro Lagoon, Baja California, Mexico : in Whitlard, W. F. and Bradshaw, R., Submarine Geology and Geophysics, Butterworths, London, 205-237 pp.

Phleger, F. B. and G. C. Ewing. 1962. Sedimentology and oceanography of coastal lagoons in Baja California, Mexico. Geologic Soc. Amer. Bull., 73:145-182.

Pike, G. C. 1962. Migration and feeding of the gray whale (*Eschrichtius gibbosus*). J. Fish. Res. Board, Canada, 1915 :815-838.

Rice, D. W. and A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Am. Soc. Mam. Spec. Publ. No. 3, 142 pp.

Slawyk, G. and J. J. MacIssac. 1972. Compilation of two automated methods in a region of coastal upwelling. Deep Sea Research, 19 : 521-524.

Sokal, R. R., and E. J. Rohlf. 1969. Biometry, the principals and practices of statistics in biological research. W. H. Freeman and Co., San Francisco, 776 pp.

LITERATURE CITED (cont'd.)


Strickland, J. D. H. and T. R. Parsons. 1968. A practical hand book of seawater analysis. Fisheries Research Board, Canada, Ottowa.

Swartz, S. L. and M. L. Jones. 1978. The evaluation of human activities on gray whales (Eschrichtius robustus) in Laguna San Ignacio, Baja California, Mexico. U. S. Dept. of Commerce, N. T. I. S. Publ. No. PB-289 737, 42 pp.

------. 1980a, 1980b. Gray whales (Eschrichtius robustus) during the 1977-78 and 1978-79 winter seasons in Laguna San Ignacio, Baja California Sur, Mexico. U. S. Dept. of Commerce, N. T. I. S. Publ. No. PB80-202989, 34 pp.

------. In press. Demographic studies and habitat assessment of gray whales (Eschrichtius robustus) in Laguna San Ignacio, Baja California Sur, Mexico. U. S. Dept. Commerce.

Wilke, F. and C. H. Fiscus. 1961. Gray Whale observations. J. Mamm, 42 (1) :108-109.