

## Year 1 Progress Report including Year 2 Budget and Plans

"Aspects of the ecology of the red squid *Ommastrephes bartramii*, a potential target for a major Hawaiian fishery"

Richard E. Young and Jed Hirota, PIs; Matthew Parry, grad. assistant

Gear development: We have completed two cruises aboard the FTS HOKUSEI MARU (Feb., 1996; Feb. 1997) of 15 days each to study the red squid (Fig. 1). We used four methods for catching adult squid (pole and lines, automatic jig machines, squid drift lines and a large, ca. 200 m<sup>2</sup> mouth, trawl), but none have proven sufficiently effective as yet to warrant commercial exploitation. The jig machines are more effective, at this point, in catching males but rarely can pull a large (5-6 kg) female from the water. For large females, the squid drift lines are the most effective. One innovation appears to be helpful in retrieving large squid once hooked on drift lines. The heavy weight of a squid is often sufficient to cause jig barbs to pull through the muscular tissue of the arms as it is lifted from the water to the ship. To prevent this loss we used a large dipnet to land each animal. This was, however, rather slow. We now attach a large double-treble hook on the jig and, after being hooked, the squid further impales itself in the head or arms on the added hook as it is being pulled from the water. This provides the needed additional support for successful landing. We have also experimented with monofilament dropper lines and braided nylon lines. The latter is easier to handle and this does not appear to affect the catchability of the gear. Much more progress clearly needs to be made in finding effective capture methods for adult squids in Hawaiian waters. We emphasize, however, that these same jigging methods are very effective on the northern, summer feeding grounds of this species.

Distribution of adult males and females: Catches of males of the red squid were made at all stations sampled (Fig. 2). The largest catch, however, for each year's sampling was made at or north of the subtropical front (i.e. colder waters) as defined by the 19° C isotherm. Catches based on effort (catch/boat hour) present a virtually identical pattern. The mean catch rate for 1997 was 1.28 squid/ boat-hour and the maximum was 3.16 squid/ boat-hour. Females were caught less frequently than males during both cruises (Fig. 2). Of the 22 females caught only two were caught south of the subtropical front (i.e. warmer waters). The peculiar distribution of females compared to males seems to be an artifact of catchability. The presence of mature females in warm waters during these winter time-

periods, even though virtually absent from our catches, is confirmed by (1) the presence of paralarvae in the warm water regions of the sampled area (see below) and (2) the capture of a large, mature female well south at 17° N Lat. by a commercial longliner (Stephen Gates, MISS LISA) within two days of our 1997 sampling period. We suspect that mature females south of the front occupy somewhat deeper waters which makes them less vulnerable to our gear.

During the 1997 cruise the average size of males and females was larger than during 1996 (Figs. 3-6). In addition, both males and females show a trend toward larger size at lower latitudes. (Fig. 7).

Distribution of paralarvae: Three to six oblique tows with a 1-m diameter plankton net (0.33 mm mesh) were taken at each station. Paralarvae of the red squid were not abundant in either 1996 or 1997 although a substantial catch (32 paralarvae) was made at one station in 1996 (Fig. 8). The 1997 data should be viewed as presence/absence data as a maximum of 3 paralarvae was taken in the oblique tows at any station. During both years, the only stations where paralarvae were taken occurred in waters warmer than 19° C, that is, they were taken south of the front. This is consistent with earlier sampling that found paralarvae sporadically over a wide area of distribution south of the subtropical front although sampling in colder waters was sparse.

Feeding: Most of our effort ashore has been in examining the feeding habits of the red squid. We have completed initial processing of 185 stomachs. The feeding studies have two aspects, looking for trends in stomach fullness that may indicate preferred feeding areas and identification of the contents to see how the squid fits into the trophic structure of the central North Pacific, especially with respect to the swordfish. Stomach fullness data are difficult to interpret because abnormal feeding often occurs under the influence of ship's lights just before capture. One way to deal with this problem is to reject all squids with fresh material in their stomachs. We have looked at the data in both ways but trends in stomach fullness and in percent empty stomachs are not apparent in our present data (Fig. 9-10). Squid stomach data, in general and especially where squid must be caught via attraction to food, contains a lot of variability and trends are not easily detected. There does appear, however, to be a decrease in the number of fish found in stomach of squid caught to the south of the front (Fig. 11). We suspect that these data are a surrogate for stomach fullness that is more accurate than the direct measure of the latter as they are less affected by recent feeding.

Identification of squid stomach-contents is not simple. Squids, of course, cut their prey into small pieces and identification of prey from these fragments is difficult. The squids feed almost exclusively on fish and squid, although occasionally shrimp and a few other odd items (i.e., octopod eggs) can be important. We have concentrated on identifying fish by using otoliths and squids by using the remains of beaks. In both cases, identification rests on building a large reference collection of fish otoliths and beaks taken from identified potential prey. We have relied on the large HOKUSEI trawl to obtain these specimens. Unfortunately, during the 1997 cruise the net apparently tangled the otter doors during the first set and tore itself apart. We obtained a fair amount of material, however, from the 1996 tows but are still lacking many groups. Identification of both squid beaks and otoliths requires considerable effort.

We (REY) are developing a data base of squid-beak characters. At present this has been completed for 24 genera using the lower beaks. Study of the upper beaks is a bit further behind. In the latter case, the characters have been provisionally identified and now the squid genera need to be surveyed. Traditionally only lower beaks are used in identification of cephalopods because they have more characteristics. However since we are working with beak fragments, we need species confirmation from both beaks. Commonly only one member of the pair of beaks is present in the stomach. Only a small portion of the samples have been examined for beak identification to date. Nevertheless, a few trends appear to be developing. (1) Squids are less important in the diet than we anticipated. Studies of related squids in the eastern Pacific (Shchetinnikov, 1992, J. Mar. Biol. Ass. U.K., 72: 849-860) showed that diet of large adult squid was about 20-30% of the total and that the squid eaten were rather large (ca. 40% of the predator ML). We have found about 1 squid for every 3.5 fish in the stomachs (based on eye lenses) and the squids are mostly small. The only large squids taken are those that are virtually undigested and presumably a result of aberrant feeding. (2) Of the squids eaten, we expected that the large red squid, which invades the habitat of its smaller close relative, tobi-ika (*Sthenoteuthis oualaniensis*), during the winter would feed heavily on this squid. Thus far, disregarding fresh remains in the stomachs, we have found no tobi-ika beaks.

Matt Parry has been responsible for identifying otoliths. We have a reference collection of otoliths from 93 fishes representing 24 families. At present we are aiming at identification to the family level only. About 80% of the otoliths (sagitta) taken from the stomachs have been identifiable (by MP). As expected, the most important items in the diet are myctophid fishes. However, a large variety of midwater fishes have been identified and some (e.g. Sternoptychids, Serrivomerids) are not known to migrate vertically. As a result, the squid may be feeding to some extent on midwater animals in

deep water during the day. This has not been previously recognized in oceanic ommastrephid squids, which are generally thought to feed exclusively at night in near-surface waters.

Reproduction. One of our objectives is to determine whether or not the red squid is a multiple spawner. This information is critical to understanding their population dynamics. In conjunction with NMFS personnel we have found that the red squid produces ova continuously and not in a batch or batches (Fig. 12). Ova are stored in the oviducts and the fullness of the oviducts can provide an indication whether or not they spawn repeatedly. Single spawners should show a gradual increase in oviduct fullness as size increases. In the data we have examined, so far, such a trend is not apparent (Fig. 13). These data, however, are not conclusive since there may be variation in (1) squid length at the start of ova production and (2) rates of ova production, which could obscure a trend. Our data, also, show that the nidamental glands vary in weight with the fullness of the oviducts suggesting that the nidamental glands cycle in weight as the oviducts are filled and emptied in a multiple spawning squid (Fig. 14). The nidamental glands produce the large gelatinous mass into which eggs are placed during spawning. Nidamental glands become enlarged and functional at sexual maturity. A single spawning female should show only a gradual increase in nidamental-gland size with increasing ML. This data is compromised, but not as seriously, by the same problems that compromised the oviduct fullness data. We have obtained tissue from the tips of the gland to learn if cycling can be confirmed histologically. However, we have yet to do the histology.

At this point, the evidence favors multiple spawning. If so, the northward "migration" of the red squid probably functions primarily to build size by placing the squid in superior feeding grounds while the southern migration places the squid on the spawning grounds. Spawning, however, would then be mostly fueled by feeding on the spawning grounds. Ultimately (if multiple spawning occurs) we will need to know how frequently squid spawn and over how long a time. We have proposed to examine statoliths of females for clues to the solution of this problem. We have removed the statoliths from many of the females, but have not yet obtained access to a confocal microscope.

Coordination with related programs: We maintain close contact with NMFS research on the broadbill swordfish. The HOKUSEI MARU '96 cruise and the TOWNSEND CROMWELL cruise of Feb.-March '96 were coordinated to provide as much overlap in areal sampling as possible. The sampling plan for the HOKUSEI MARU '97 was based largely on results obtained by the May '96 CROMWELL cruise. The CROMWELL cruise

deployed squid driftline gear borrowed from us. Squids with intact stomach that have been eaten by swordfish are passed to us for analysis. During the May '97 CROMWELL cruise stomachs of captured red squid were frozen and sent to us for analysis.

#### **RESEARCH PLAN FOR 1998:**

Research for 1998 will involve (1) laboratory work based on material collected during 1996, 1997 and 1998 and (2) a 15-day cruise (Feb. 5-20) on the FTS HOKUSEI MARU.

Laboratory work. We will continue efforts to identify material from the stomachs of the red squid. We expect to extend the collection of otoliths and beaks used for identification primarily through collections made aboard the 1998 HOKUSEI MARU cruise. In addition we will complete the data base for identification of cephalopod beaks upper beaks and identify beak remnants in all stomachs obtained to date. We will also begin to quantify the identification of otoliths (we presently rely on matching otoliths from stomachs to photographs of otoliths from known fishes). We will also process stomach contents and other materials taken during the 1998 cruise. We will look for histological variation in the nidamental glands and try to gain access to a confocal microscope to examine statoliths.

HOKUSEI MARU '98 cruise. In Feb. 1998 we plan to run a transect from 21° N to 31° N along 165 W Long. This transect will begin well south of the Archipelago, pass through the Archipelago and proceed north well past the subtropical front. We will be looking for differences in catches north and south of the Archipelago as well as very close to the Archipelago. We will use a 2 m<sup>2</sup> plankton net to obtain better paralarval samples. This is not a trivial change since plankton sampling from this ship is challenging. Most other sampling will be as in 1997 (i.e., deploy squid drift lines; run automatic jigging machines; jig by hand with poles; deploy a series of oblique plankton tows at each station and sort samples; obtain micronekton with the HOKUSEI trawl; obtain reproductive data, histological samples of nidamental glands, stomachs and statoliths from captured squid). In addition we plan to (1) deploy a "vertical" drift line from the ship in an attempt to determine the swimming depth of female red squid to the north and south of the subtropical front and (2) deploy an ROV, obtained by the chief scientist (Dr. Yasunori Sakurai) to determine its usefulness in studying swimming and feeding behavior of the red squid and, possibly, the detection of squid egg masses.

## General Project Synopsis

This project examines the general ecology of the red squid *Ommastrephes bartramii* in the central North Pacific near the Hawaiian Archipelago. Our interest in the red squid is based on (1) its considerable potential for a Hawaii-based commercial fishery and (2) its importance in the ecology of the broadbill swordfish which is a major commercial fishery in Hawaii. This project involves strong cooperative aspects with the National Marine Fisheries Service (NMFS), Honolulu Lab and Hokkaido University in Japan.

In order to study this squid, we must have effective sampling methods. For catching adult squid, we have experimented with large trawls, pole and line jigging, automatic jigging machines and squid driftlines. None of the methods have been satisfactory as yet. The squid driftlines, however, seem to have the greatest potential. At present, most of our sampling is done aboard the FTS HOKUSEI MARU from Hokkaido University although we have samples from commercial fishermen and NMFS. For sampling paralarvae we used standard plankton nets aboard the HOKUSEI MARU.

At present we are trying to obtain data on latitudinal trends in feeding, reproductive condition and abundance. Our data, although meager, suggest that squid are most abundant in the vicinity of the subtropical front. Unlike males, females are difficult to capture south of the front, and we suspect this is due to a deeper nighttime habitat in these warmer waters which would make females less vulnerable to our sampling gear.

Paralarvae are caught predominantly south of the front but are very patchy and widely scattered there. Apparently the spawning grounds of this squid constitute a broad area south of the subtropical front. In the Hawaiian region, the squid feed predominately on midwater fishes and other squids. There is some indication that supplemental feeding occurs during the daytime in deep water and that food is more abundant near the subtropical front. Our present evidence suggests that the red squid is a multiple spawner and that spawning is fueled by feeding on the spawning grounds.

Fig. 1. Plot of station positions for HOKUSEI MARU cruises of February 1996 and 1997 and the 19° surface isotherm. Station numbers are recorded at each station position.

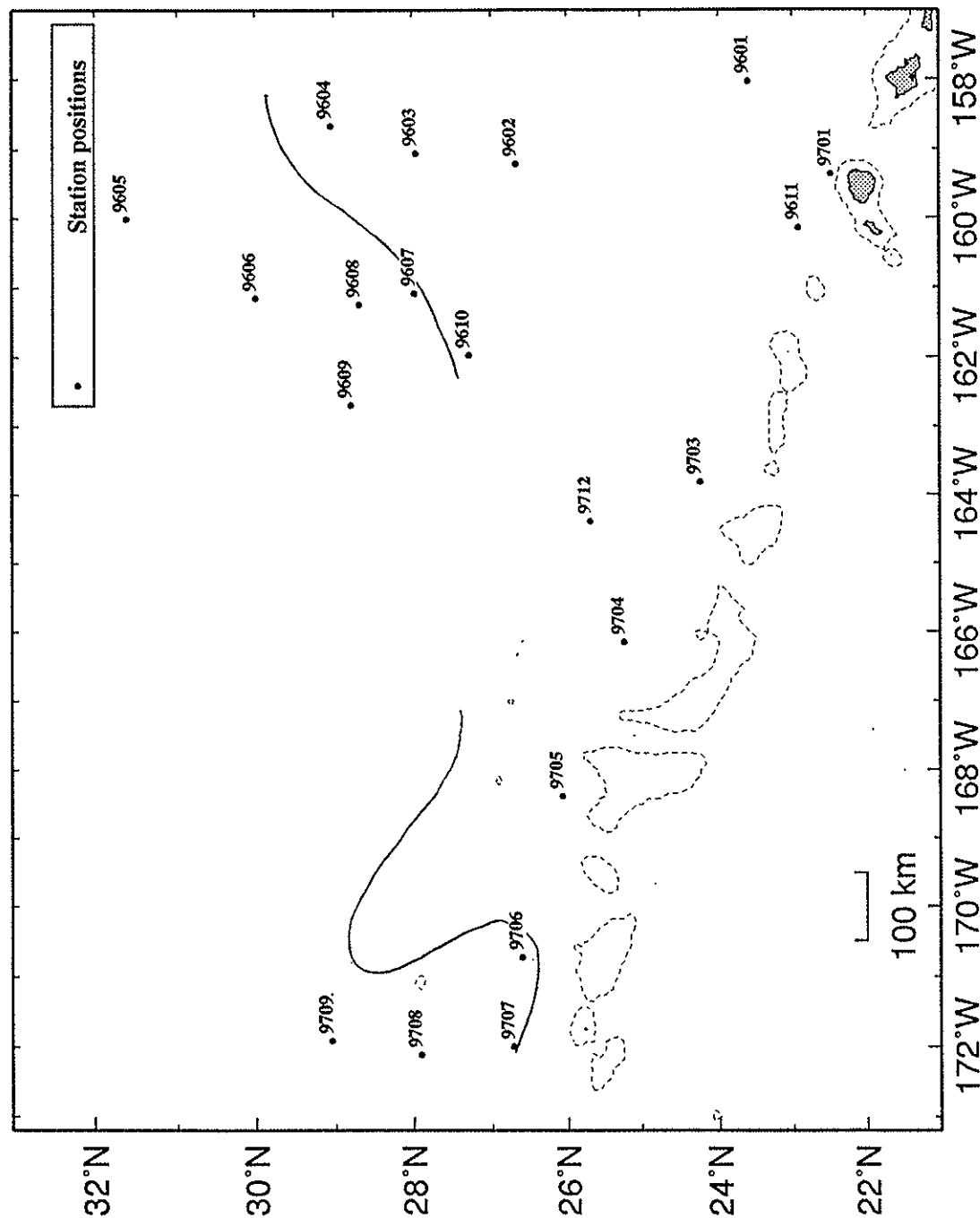
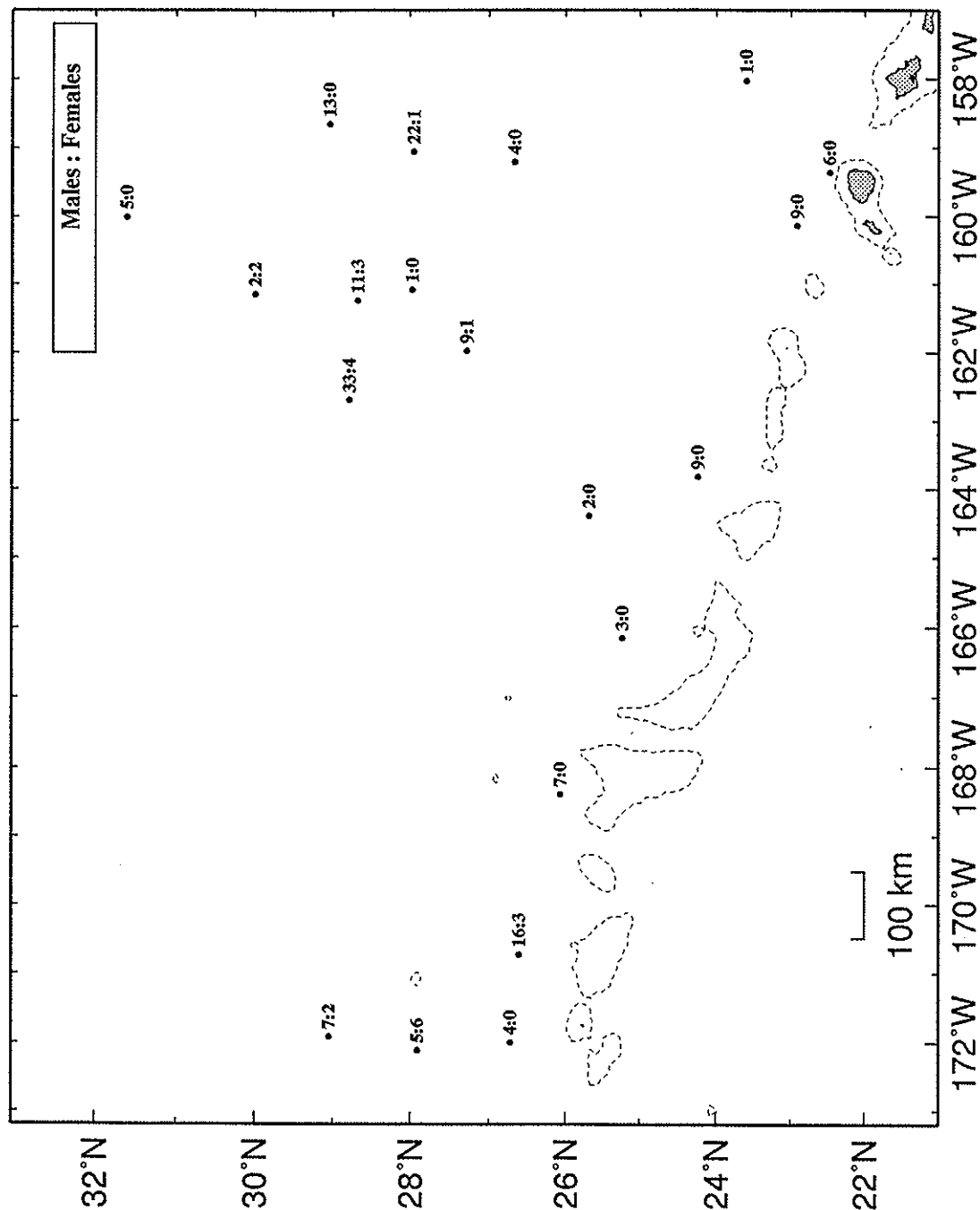


Fig. 2. Geographical plot showing the catch ratio of males to females of *O. barramii* at each station for Feb. 1996, 1997.



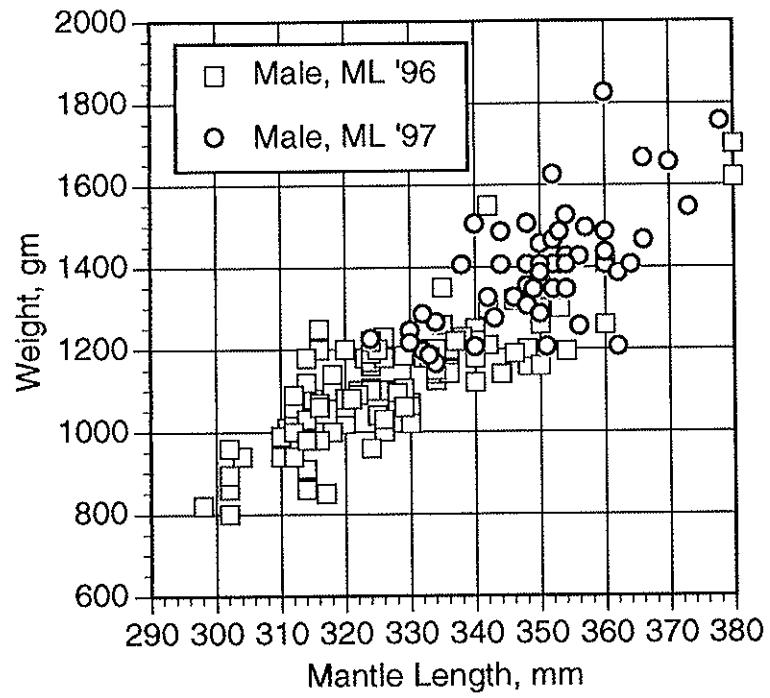


Fig. 3. Length-weight plot of male *O. bartramii* comparing size between 1996 and 1997.

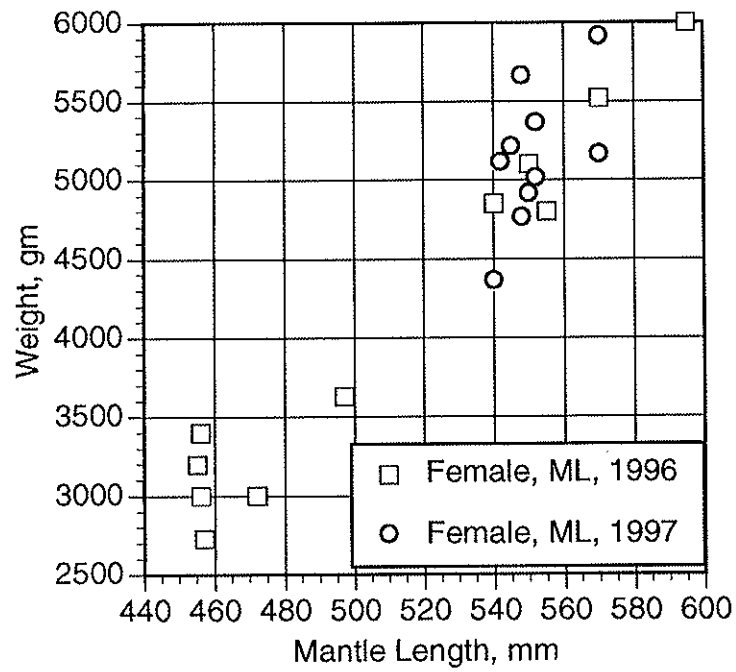


Fig. 4. Length-weight plot of female *O. bartramii* comparing size between 1996 and 1997.

Fig. 5. Geographical plot showing the mean ML/station for male *O. barramii*, in Feb. 1996, 1997

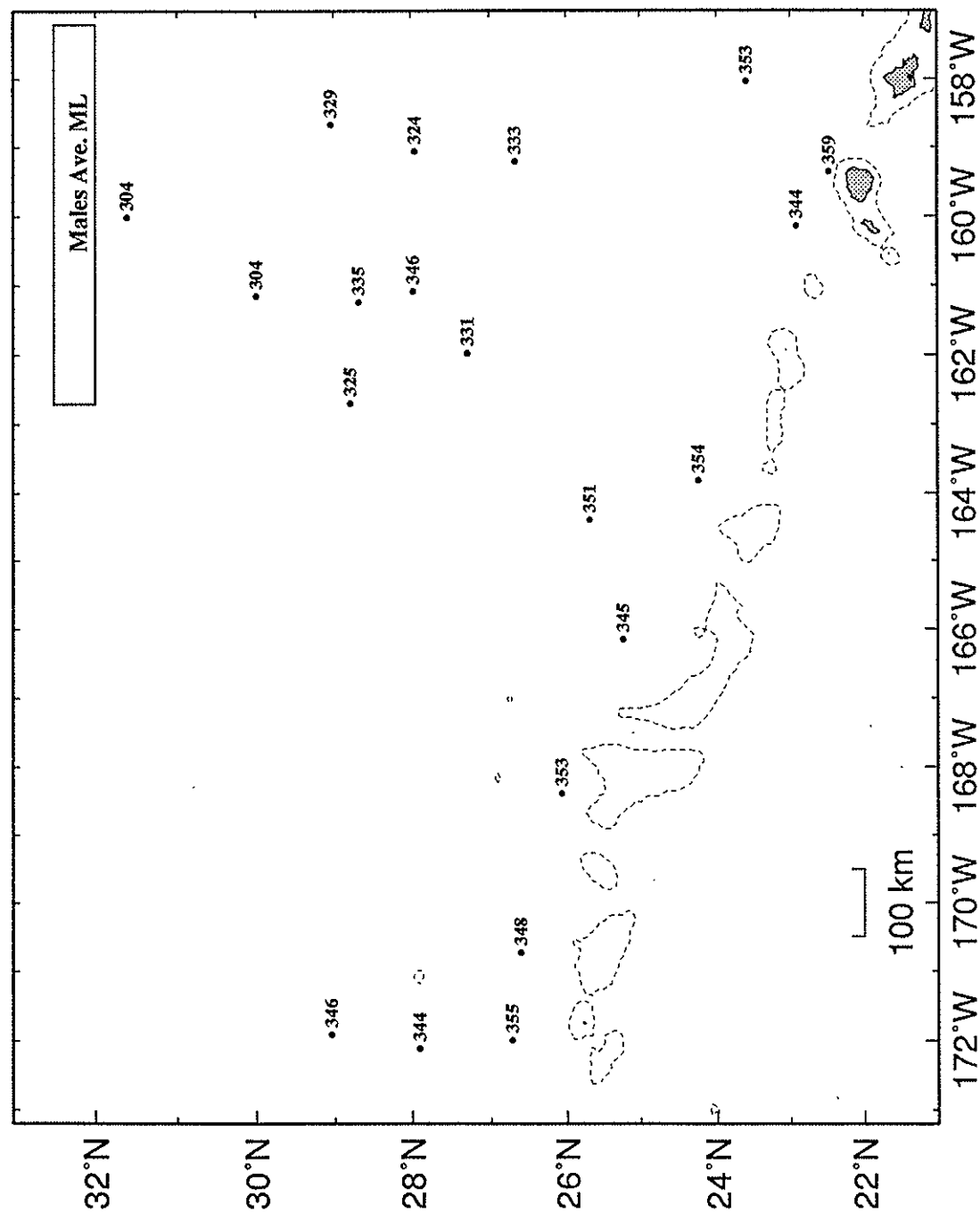
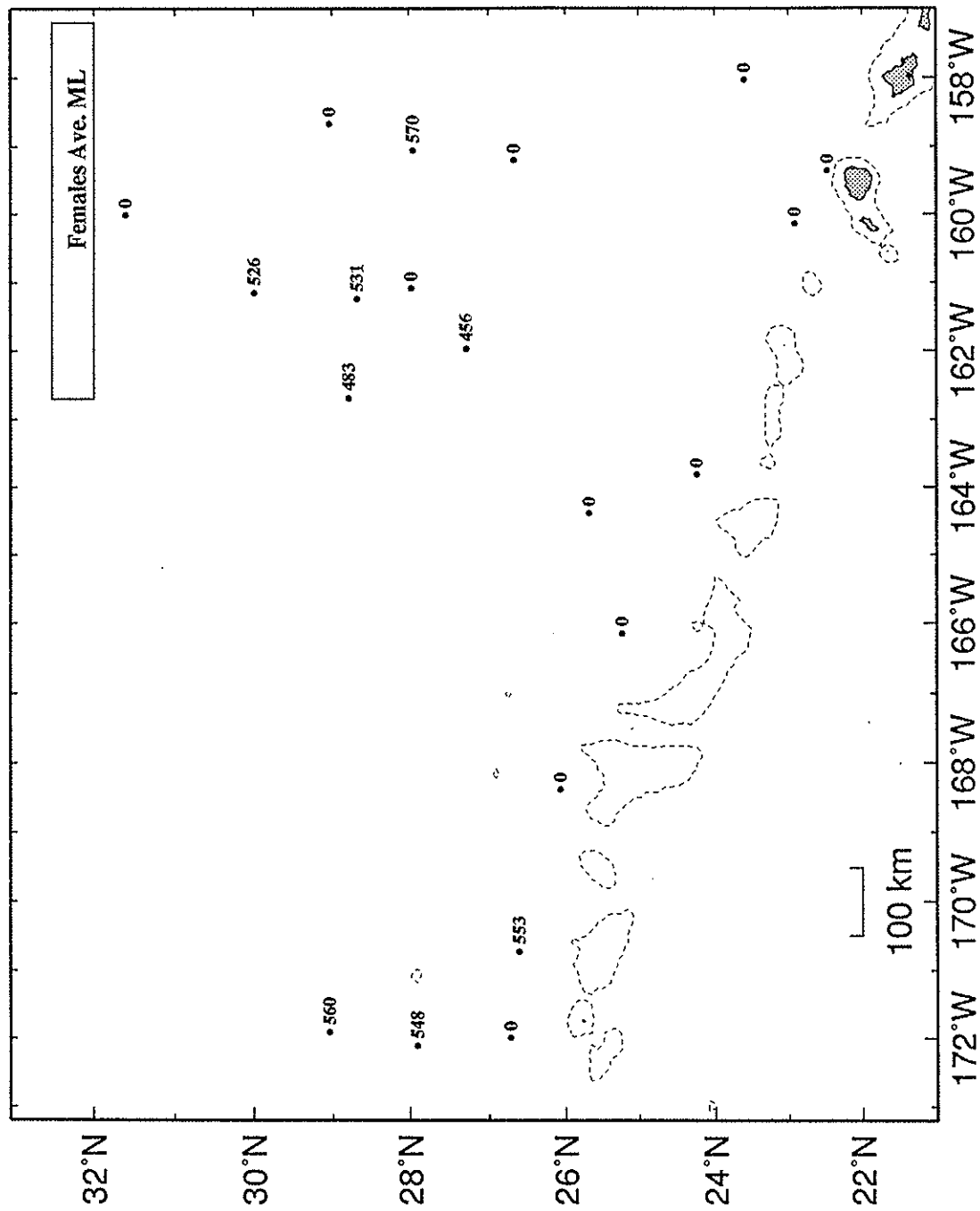


Fig. 6. Geographical plot showing the mean ML/station for female *O. bartramii*, in Feb. 1996, 1997



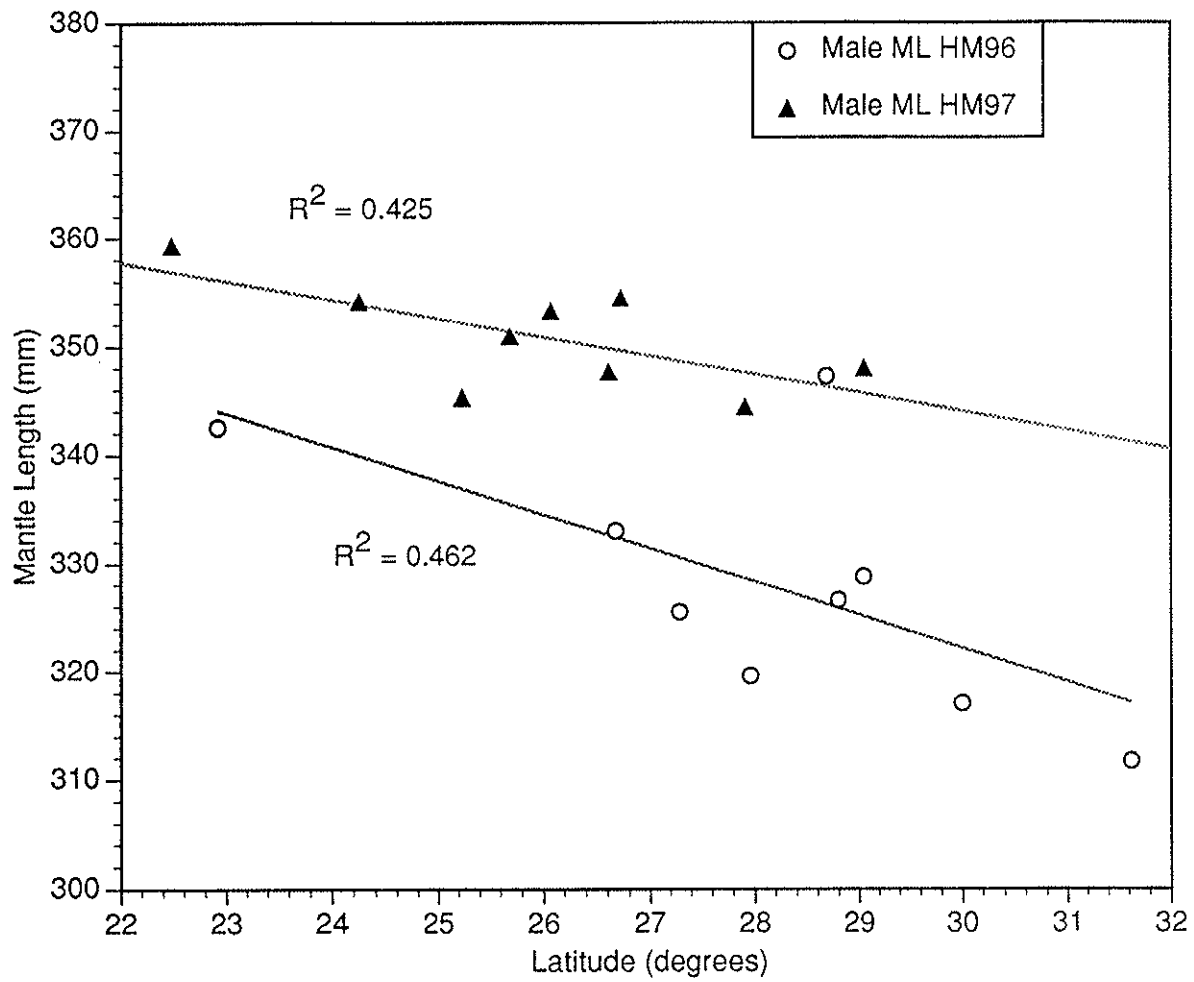


Figure 7. Graph showing the change in mantle length with latitude for *O. bartramii* males.

Fig. 8. Catch rate of *O. bartramii* paralarvae per 25 m<sup>2</sup> of the ocean surface in Feb. 1996, 1997. 25 m<sup>2</sup> approximates the area sampled per tow.

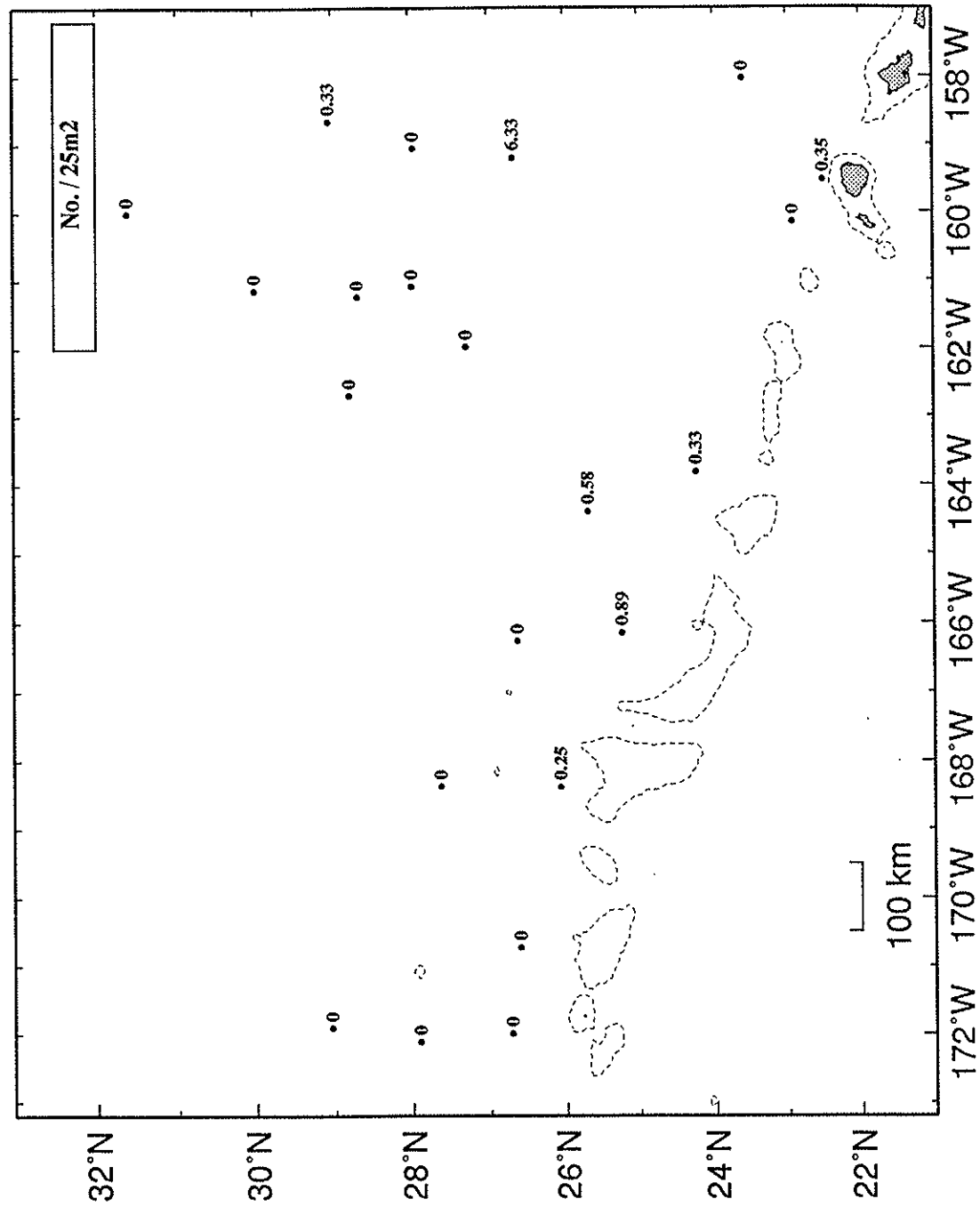


Fig. 9. Plot of mean weight of stomach contents per station normalized to ML (content wt.in gm.\*100/ML) against distance to the 19° surface isotherm for *O. bartramii*. All stomachs included.

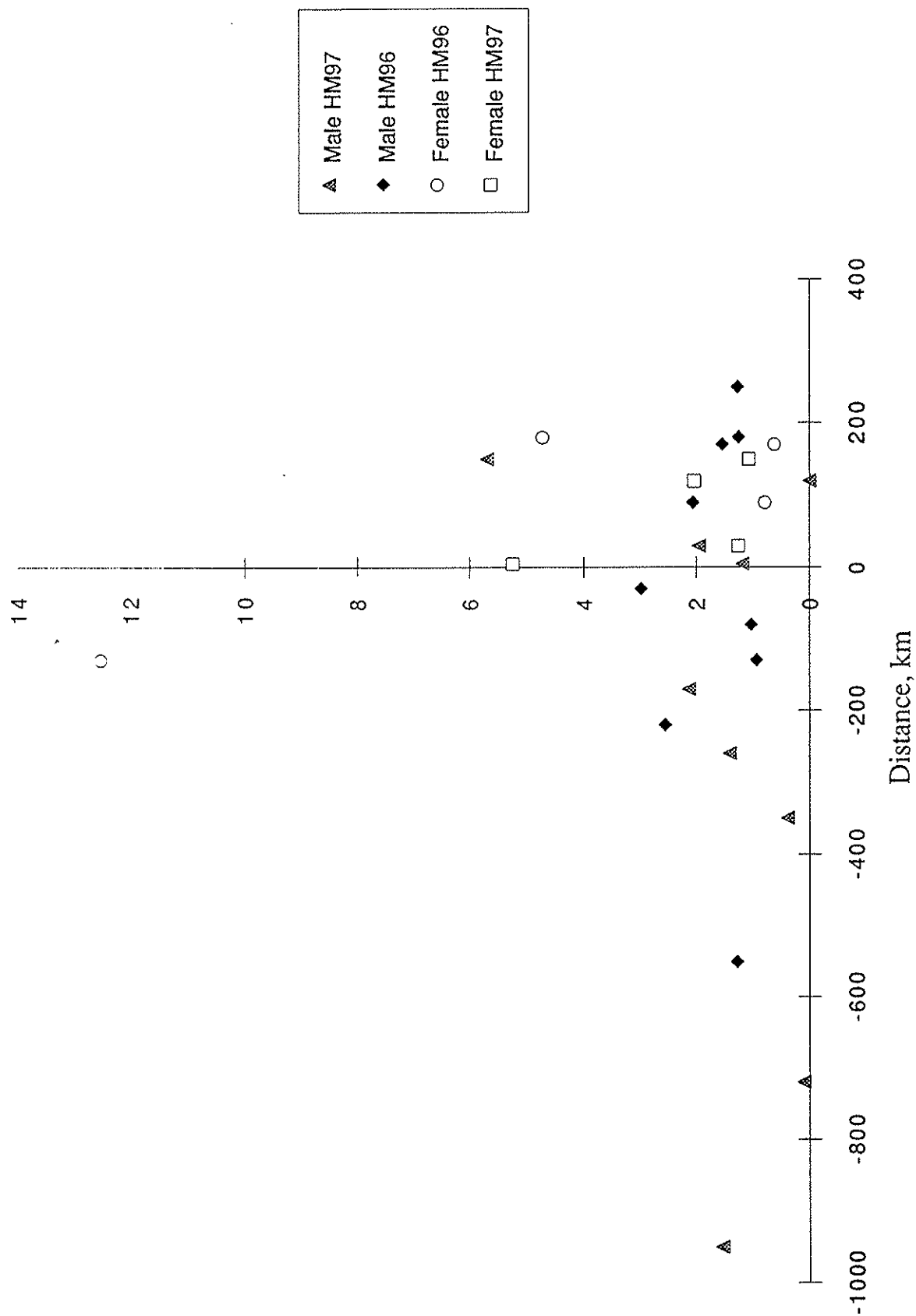
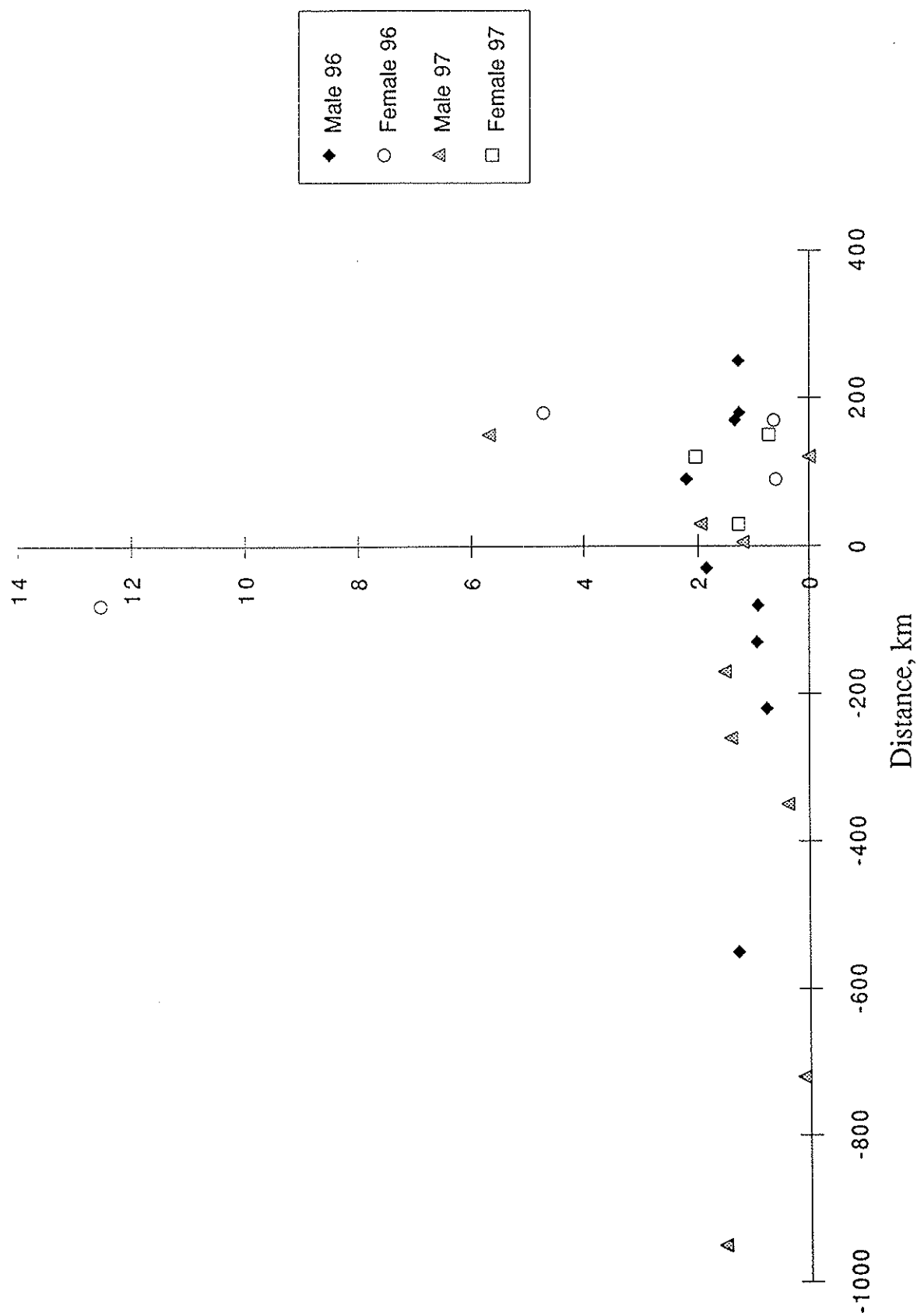


Fig. 10. Plot of mean weight of stomach contents per station normalized to ML (content wt. in gm.\*100/ML) against distance to the 19° surface isotherm for *O. barramii*. Stomach with fresh contents have been eliminated.



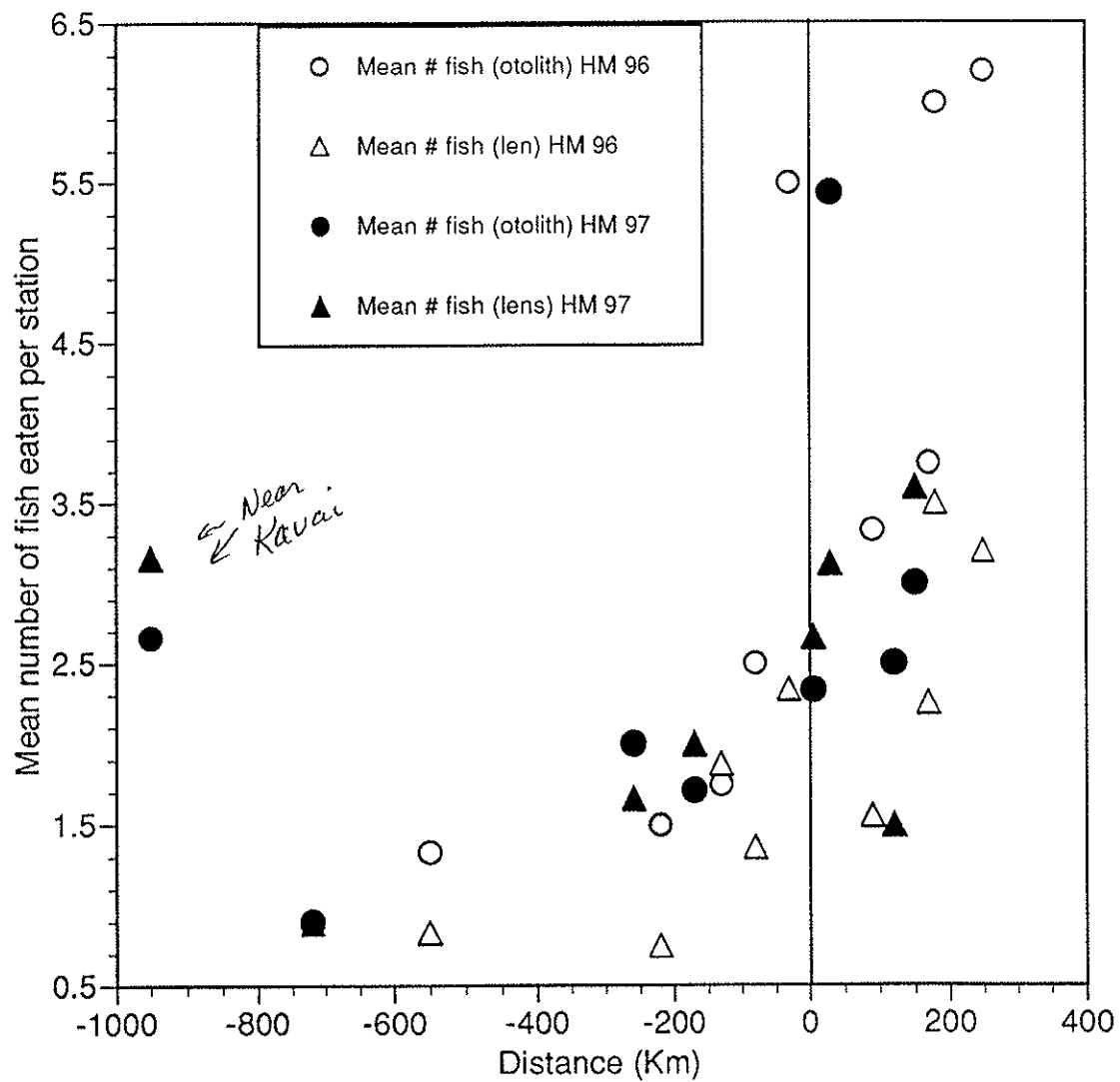


Figure 11. Plot of the mean number of fish eaten per station vs distance from the 19°C surface isotherm for *O. bartramii*. Number of fish estimated from the number of otoliths (sagitta) or eye lenses.

*Ommastrephes bartramii* (N=12)

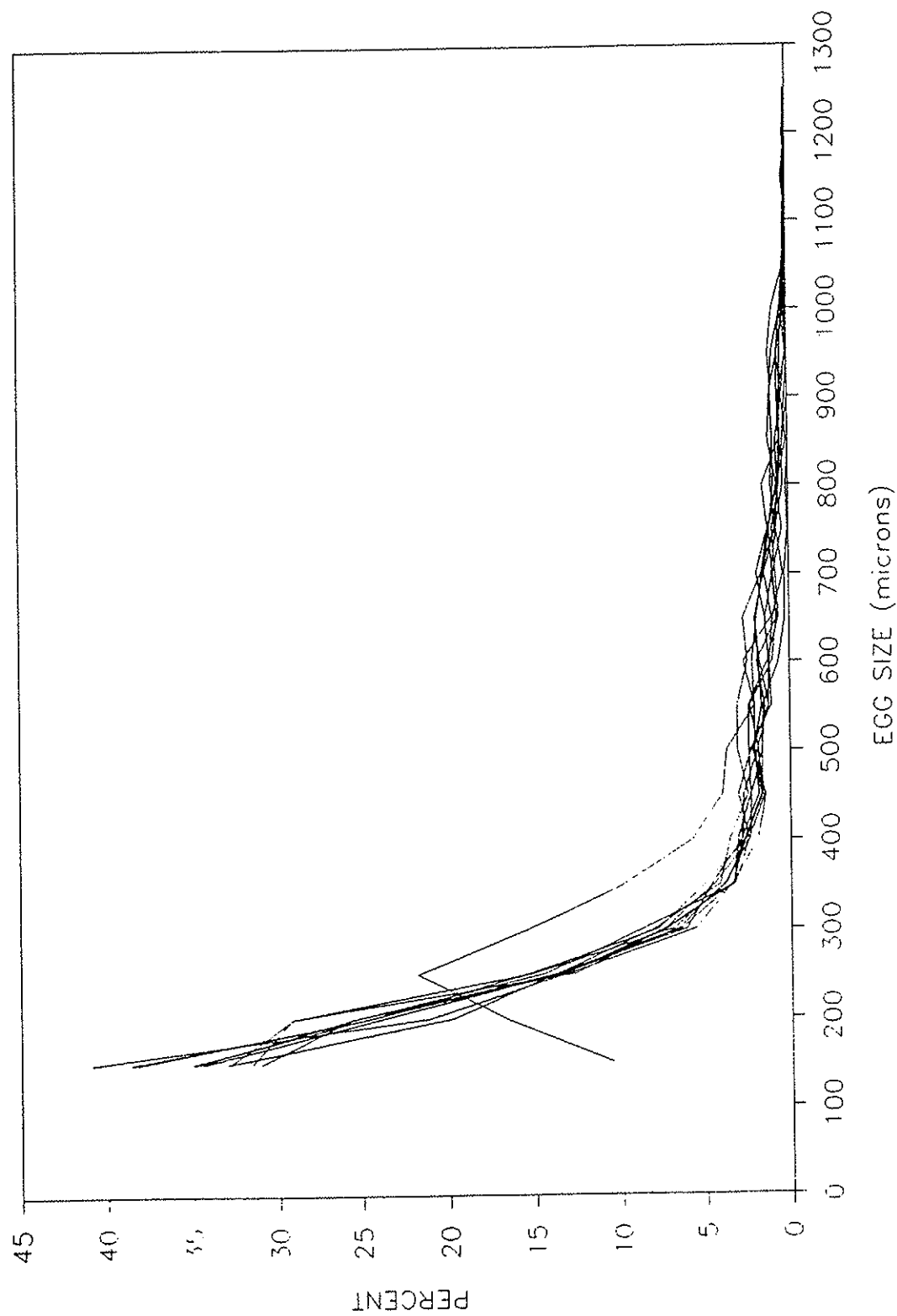


Fig. 12. Size-frequency distribution of oocytes in the ovaries of mature *O. bartramii* indicating continuous production of ova. We suspect that the one offset line resulted from inadvertently changing the calibration of the measuring microscope.

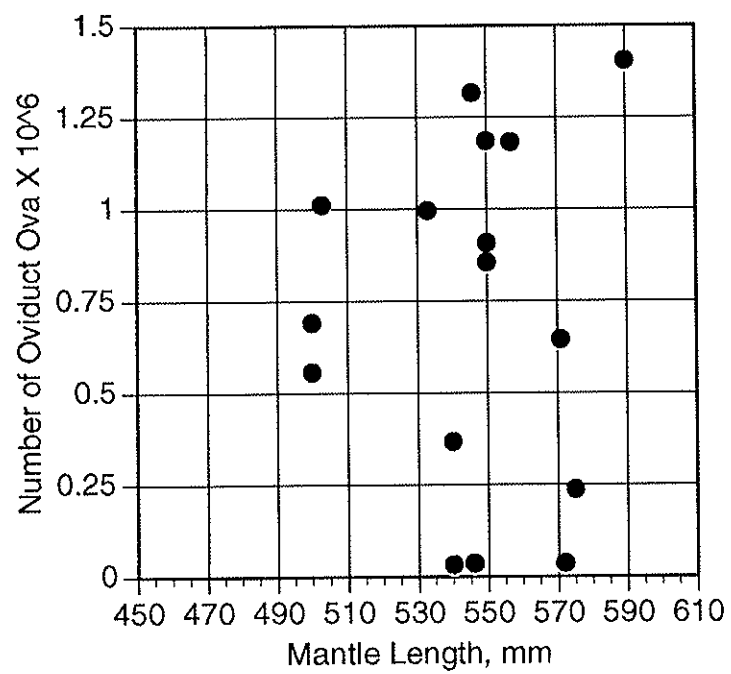


Fig. 13. Graph comparing the number of ova in the oviducts of mature females of *O. bartramii* against ML. Note the lack of a relationship.

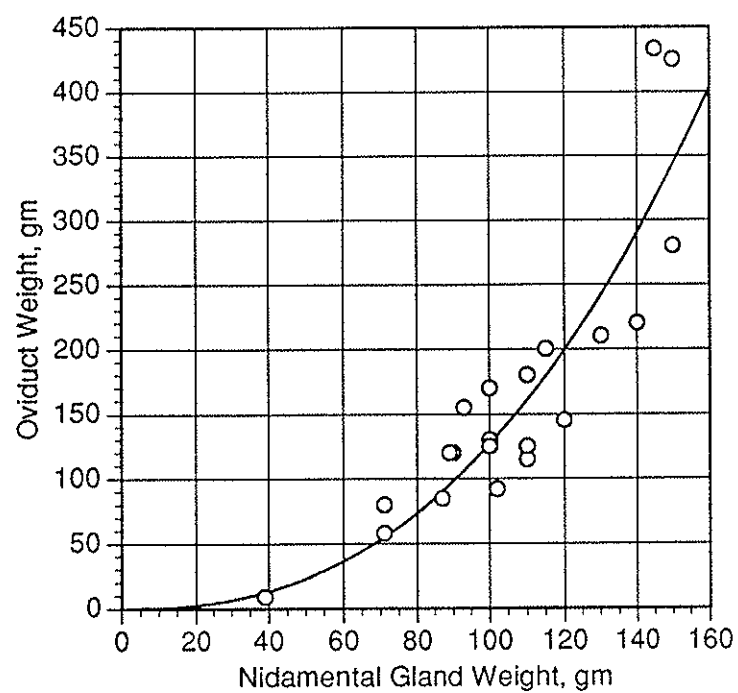


Fig. 14. Relationship between oviduct weight and nidamental gland weight for females captured during the 1996 and 1997 cruises. Best fit power regression is  $y = 0.0016x^{2.45}$ .  $R^2 = 89.7$