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Mercury and selenium content of tropical sharks.

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ABSTRACT

Total mercury, alkyl mercury and selenium concentrations in the muscle tissue of several species of pelagic sharks from northern Australian waters are reported. Mean mercury concentrations ranged between 0.13 mg/kg for *Carcharhinus brevipinna* and 1.94 mg/kg for *C. amblyrhynchoides*. Maximum values exceeded 1.5 mg/kg in nine of the species studied and the highest recorded concentration was 3.7 mg/kg for *Sphyrna mokarran*.

Mercury concentrations were highly dependent on the size of shark, a relationship that was adequately represented by the power function. Males of most of the species studied had significantly higher levels of mercury than females of similar size.

Alkyl mercury composed over 80% of the total muscle mercury in each of the species studied.

Mean selenium concentrations ranged between 0.37 mg/kg for *Negaprion acutidens* and 1.86 mg/kg for *C. dussumieri*. Most of the sharks examined had concentrations of less than 1.0 mg/kg, the maximum concentration determined was 3.4 mg/kg for *C. dussumieri*. There was no correlation between selenium and length and selenium and mercury for most of the species studied.

Implications of the present findings to the developing shark fishery are discussed in respect to Australian standards for mercury.

INTRODUCTION

In recent years considerable attention has been given to the study of mercury in fish and possible relationships with human health. Fish accumulate substantial concentrations of mercury in their tissues and may, therefore, represent an important dietary source of this element. Fish accumulate mercury either directly from the surrounding water (Burrows and Krenkel 1973; MacLeod and Pessah 1973; Cember *et al.* 1978) or from the diet (Jernelöv and Lann 1971).

Most of the mercury present in the edible flesh of fish is organic or alkyl (methyl-, ethyl- and butyl-) mercury, with methyl mercury comprising over 90% of the alkyl component (Kumagai and Saeki 1978). This is significant since methyl mercury is the most toxic form of the element. Most studies of mercury content of fish have been directed at total mercury, comparatively few have reported organic mercury levels.

Fish also accumulate significant quantities of selenium and may be an important dietary source of this essential micronutrient. In a number of studies on fish, correlations between selenium and mercury concentrations have been reported (Ganther *et al.* 1972; Ganther and Sunde 1974; Mackay *et al.* 1975; Leonzio *et al.* 1982), in some cases both elements are present in epimolar amounts. These findings have led to the suggestion that selenium may be important in protecting these animals against the toxic effects of accumulated mercury. There is also considerable evidence available to indicate that selenium present in or added to diets acts to decrease the toxicity of methyl mercury (Ganther *et al.* 1972; Ganther and Sunde 1974; Stoewsand *et al.* 1974; Chang and Suber 1982). It may thus be appropriate to consider selenium content when defining safe mercury levels in fish used for human consumption. This consideration is, however, complicated since the actual mechanism of the interaction is not yet fully understood.

In Australia, the National Health and Medical Research Council (NH & MRC) has recommended that the mean concentration of mercury in fish and fish products should not exceed 0.5 mg/kg (based on a prescribed sampling procedure), with a maximum permissible level of 1.5 mg/kg for any individual sample. These recommendations have been implemented by the Australian Bureau of Customs and all States and Territories except South Australia and Tasmania, which have legislated for a mean of 1.0 mg/kg.

As a group, sharks are particularly predisposed to the accumulation of high concentrations of mercury and, as a result, mercury legislation has especially affected shark fisheries. Results of exploratory fishing surveys (Church 1981; Lyle and Timms 1984) have indicated that considerable potential exists for the development of an Australian-based shark fishery in northern Australia. It is a multispecies resource, with some twenty species of shark recorded in catches. It was recognised that assessment of the mercury content in the edible flesh of the sharks would be very pertinent to the future development of the fishery. In an earlier study of mercury levels in seven of the more frequently occurring species (Lyle 1984) it was established that all but *Carcharhinus sorrah* (sorrah shark) included individuals that exceeded the NH & MRC standard for mercury. The present study was designed to complement the previous work through evaluation of mercury concentrations in the rarer species and to include investigations of alkyl mercury and selenium concentrations.

MATERIALS AND METHODS

Sampling

Sharks were collected over the period September 1982 to April 1984 from various localities around the Northern Territory coast, principally between Anson Bay (13°30'S,130°00'E) and the Goulburn Islands (11°30'S,133°30'E). With few exceptions sharks were caught by gillnet.

Species, sex and fork length (FL) of each shark collected were recorded. Fork lengths rather than total lengths (TL) were utilized because fork length is an easier and more accurate measurement to obtain. Since previous studies have reported total lengths (eg. Lyle 1984), total lengths were also measured in subsamples of each species to facilitate comparisons between studies.* Regression equations describing fork length - total length relationships are given in Table 1.

Samples of axial muscle tissue for chemical analyses were removed from the region anterior to the first dorsal fin and placed in sealed polyethylene bags and frozen at -20°C or lower. Sharks were deliberately selected over the observed size ranges of each species to ensure representation of all size groups. Muscle tissue samples were also taken from a small number of intra-uterine embryos.

Chemical analyses

Samples of tissue were partially thawed, any skin removed and the residual tissue homogenized to a fine paste. The homogenate was stored in sealed polyethylene bags at -20°C until required for analysis.

Each tissue sample was analysed for total mercury concentration and where possible, approximately 10 samples of each species were analysed for alkyl mercury and selenium concentration.

* Total length was determined by extending the upper caudal fin parallel to the body axis.

Total mercury

Total mercury was determined using the method described by Hatch and Ott (1968) and reported by Lyle (1984). Tissue samples were digested in a nitric-sulphuric acid mixture, the mercury present in the digest was then reduced to mercury vapour with stannous chloride and estimated by cold-vapour atomic absorption spectrophotometry.

Accuracy of chemical analyses was checked by reference to National Bureau of Standards (NBS) Research and Reference Materials. Determination of total mercury on NBS Research Material 50 (Albacore tuna) gave a mean of 0.94±0.04 mg/kg for seven determinations, the mercury concentration of this material is given (not certified) as 0.95±0.10 mg/kg. Further checks were made by determination of mercury on NBS Standard Reference Material 1566 (Oyster) which gave a mercury concentration of 0.054 mg/kg compared with the certified value of 0.057±0.015 mg/kg.

Alkyl mercury

The method employed for alkyl mercury determination was essentially that described by Collett *et al.* (1980). Alkyl mercury was extracted from a solution of the tissue in alkali by steam distillation, and converted by acid persulphate digestion to inorganic mercury which was determined by cold-vapour atomic absorption spectrophotometry.

Analysis of duplicate samples of NBS Research Material 50 gave a mean value of 0.78±0.02 mg/kg, equivalent to 82% of the value for total mercury concentration. Work reported by NBS has suggested that 80-90% of the mercury content is present as methyl mercury.

Selenium

Selenium analysis was based on the method of Flanjak (1978) with some minor modifications. Selenium was converted to selenium hydride after acid digestion of the tissue to

destroy all organic matter and subsequent reaction with sodium borohydride. The selenium hydride was passed through a heated quartz tube and selenium determined by atomic absorption spectrophotometry.

Four determinations of selenium on NBS Research Material 50 gave a mean concentration of 3.8±0.1 mg/kg, the selenium concentration of this material is given (not certified) as 3.6±0.4 mg/kg

Duplicate analyses were performed in about 10% of the samples analysed for total and alkyl mercury and on about two thirds of the samples analysed for selenium.

RESULTS

Total Mercury

Total mercury concentrations were determined in the muscle tissue of twenty species of shark and results are summarised in Table 2. Mean mercury concentrations ranged widely, from 0.13 mg/kg for *C. brevipinna* (spinner shark) to 1.94 mg/kg for *C. amblyrhynchoides* (grey whaler shark). In fact other than *C. brevipinna*, only *C. sorrah*, *C. macloti* (milk shark), *C.dussumieri* (black spot shark), *Negaprion acutidens* (lemon shark), *Hemipristis elongatus* (fossil shark) and *Triaenodon obesus* (blunt nose shark)* had mean concentrations of less than 0.5 mg/kg. Maximum concentrations exceeded 1.5 mg/kg in one half of the species examined and were over 3 mg/kg in *C. limbatus* (black tip shark), *C. melanopterus* (black fin reef shark), *C. amboinensis* (grey whaler shark) *C. amblyrhynchoides* and *Sphyrna mokarran* (great hammerhead).

Mercury concentrations in three *C. limbatus* embryos ranged between 0.07 0.21 mg/kg (equal to approximately 10% of the maternal muscle concentration), 0.72 and 0.82 mg/kg in two *C. melanopterus* embryos (about 27% of the maternal value) and 0.29 and 0.39 mg/kg in two *S. mokarran* embryos (about 9% of the maternal value).

Length-mercury relationships

Plots of mercury concentration against length for those species not previously reported by Lyle (1984) are given in Figure 1. For each of these species there was considerable variation in mercury concentrations, even amongst individuals of similar size. In spite of this variation, mercury concentrations tended to increase as the sharks became larger. The relationship between length (FL) and mercury concentration (Hg) was adequately

* Based on a single specimen only

described by the power function:

$$Hg=aFL^{b}$$

where 'a' and 'b' are constants and 'a' includes a correction factor for biases caused by logarithmic transformation of Hg and FL used to estimate the constants (Beauchamp and Olson 1973; Hancock *et al.* 1977). Confidence limits on the corrected estimates of mean mercury concentrations were determined using Cox's direct method (Land 1972).

Length-mercury relationships for males and females of each species were determined separately (Table 3). Analysis of covariance, based on linear regressions of ln(FL) and ln(Hg), was used to test the effect of sex on these relationships. Significant differences in either slope or elevation were apparent between males and females of each of the species except *C. brevipinna*, *C. dussumieri* and *N. acutidens* (Table 4). Length-mercury relationships for these latter species can thus been determined independently of sex (Table 3). Note, the length-mercury relationship determined for male *Rhizoprionodon taylori* (milk shark) does not include three outlying values which have been indicated in Figure 1 and which exerted considerable influence on the significance of the length-mercury relationship (refer to Table 3). Curves, with confidence limits, relating mercury concentration and length are represented in Figure 1.

Lengths that correspond to mean mercury concentrations of 0.5 and 1.0 mg/kg are given in Table 5. For those species with significant differences in length-mercury relationships between the sexes, it is evident that males attain specified mercury concentrations at smaller sizes than females.

Alkyl mercury

Results of paired analyses of total and alkyl mercury for seventeen shark species are given in Table 6. In each case, most of the mercury (82-110%) was present as alkyl mercury. Values that exceed 100% presumably indicate limits in analytical precision , such errors associated with determinations of mercury have been discussed by Walker (1977).

Selenium concentrations

Selenium concentrations were determined in seventeen species of shark and results are summarised in Table 7. Mean values ranged between 0.37 mg/kg for *N. acutidens* and 1.86 mg/kg for *C. dussumieri*, although most fell between 0.6 0.84 mg/kg. Maximum observed concentrations exceeded 1.0 mg/kg in nine of the species examined, the highest value recorded being 3.4 mg/kg for *C. dussumieri*.

Interestingly, the selenium concentration in the muscle tissue of a pregnant *S. mokarran* (292 cm FL) was 0.45 mg/kg which compared with concentrations of 2.10 and 2.20 mg/kg in muscle tissue of two of its pups (both 48 cm FL).

Correlations between selenium concentration and length and selenium and mercury concentrations have been examined and correlation coefficients are given in Table 8. Selenium and length were significantly correlated in only five species, and of these, selenium was positively correlated with length in *C. amboinensis*, *C. macloti* and *S. blochii* (handle bar hammerhead) and negatively correlated in *C. limbatus* and *C. brevipinna*. With the exceptions of *C. cautus* (mangrove shark) and *S. blochii* no significant correlations between selenium and mercury concentrations were detected.

DISCUSSION

Warm-water sharks appear to accumulate higher concentrations of mercury and obtain specified concentrations at slightly smaller sizes compared with cool-water sharks (Denton and Breck 1981; Lyle 1984). This may be related, in part at least, to the effect of high ambient water temperatures on bioaccumulation rates for mercury. For instance, laboratory studies on teleosts which have demonstrated that bioaccumulation rates increase more or less exponentially with rising water temperature (MacLeod and Pessah 1973; Cember *et al.* 1978). No data on mercury levels in the waters adjacent to the Northern Territory or in likely prey organisms could be located but in the absence of polluting industry the comparatively high concentrations of mercury found in this and an earlier study (Lyle 1984) may be regarded as natural accumulations.

Mercury concentration was found to be highly dependent on the size of shark. It can be inferred from coefficients of determination (r^2) that, depending on the species considered, between 35 and 92% of the total variation in mercury concentration could be attributed to differences in length. The applicability of the power function in describing relationships between length and mercury is well documented for other species of shark (Forrester *et al.* 1972; Walker 1976; Hancock *et al.* 1977; Caputi *et al.* 1979; Taguchi *et al.* 1979; Ueda and Takeda 1983; Lyle 1984).

Circumstantial evidence presented by Taguchi *et al.* (1979) for *Squalus* and Ueda and Takeda (1983) for and *Mustelus* suggests that the actual rate of mercury accumulation may remain reasonably constant with time, such that mercury concentration increases more or less linearly with age. The differences in length-mercury relationships noted between males and females of *C. limbatus*, *C. sorrah*, *C. fitzroyensis* (sand shark), *C. amblyrhynchoides* and *S. blochii* (Lyle 1984) and determined here for *C. melanopterus*, *C. cautus* *C. amboinensis*, *C. macloti*, *R. acutus* (milk shark) and *R. taylori* may thus reflect differences in growth rates between the sexes. For example, preliminary analysis of length-at-age and growth rates for *C. limbatus* from northern Australian waters has

indicated that females grow faster than males (S. Davenport personal communication). If similar patterns apply for other shark species and if, as implied above, the accumulation rate for mercury is more or less constant with time, it follows that at a given size males would be older than females and have accumulated more mercury. Conversely males would be expected to attain specified concentrations of mercury at smaller sizes then females (refer to Table 5). Taguchi *et al.* (1979) found that while there were significant differences in length-mercury relationships for male and female *Squalus mitsukurii*, the sex effect was not apparent when mercury concentrations were expressed as a function of age. It is possible that similar growth and accumulation patterns may apply for many of the shark species found in northern Australian waters.

Walker (1976) has suggested transfer of mercury to ova and embryos may also reduce the concentrations of mercury in females. The presence of detectable levels of mercury in near-term embryos of *C. limbatus*, *C. melanopterus* and *S. mokarran* indicates some deposition of mercury to embryos. Forrester *et al.* (1972), Childs *et al.* (1973) and Taguchi *et al.* (1979) for *Squalus* spp. and Ueda and Takeda (1983) for *Mustelus* spp. have also reported detectable mercury concentrations in intra-uterine embryos, but in each instance mercury levels were well below 0.1 mg/kg. Squalids are ovoviviparous and nutrients are derived from an associated yolk sack, whereas carcharhinids and sphyrnids are typically viviparous and there is a direct interchange of nutrients (and presumably mercury) between the mother and embryo via the placenta. This may account for the comparatively high concentrations of mercury in embryos reported in this study.

The high selenium content in *S. mokarran* embryos (nearly five times the concentration in the maternal tissue) is difficult to explain and is in apparent contrast to *Mustelus* where embryos were found to have selenium concentrations comparable to those of the mother (Ueda and Takeda 1983).

Alkyl mercury represented over 80% of the total muscle mercury content in each of the species studied here, which is in good agreement with reported values for other shark species (Walker 1976; Ueda and Takeda 1983) and teleosts (Kamps *et al.* 1972; Rivers *et al.* 1972; Bebbington *et al.* 1977; Cappon and Smith 1981).

Selenium concentrations in the muscle tissue of elasmobranchs (Glover 1979; Braddon and Sumpter 1981; Olsen 1983; Ueda and Takeda 1983) and teleosts (Bebbington *et al.* 1977; Itano *et al.* 1977; Luten *et al.* 1980; Cappon and Smith 1981) generally lie below 1.0 mg/kg. Whilst approximately one half of the shark species examined in this study included some individuals with selenium concentrations that exceeded 1.0 mg/kg (NH & MRC recommended maximum), individuals within this group represented only 15% of the total number of samples analysed for selenium and mean concentrations in all but three species - *C. cautus*, *C. dussumieri* and *S. blochii* - were less than 0.84 mg/kg. The maximum value of 3.4 mg/kg determined for *C. dussumieri* is comparable to maximum reported values of 4.3 mg/kg for black marlin (Mackay *et al.* 1975) and 3.0 mg/kg for pike (Speyer 1980).

The absence of obvious correlations between size and selenium concentrations for most of the species studied here suggests that selenium is accumulated in a homeostatic manner rather than by cumulative deposition as for mercury. Similar findings have been reported for length-selenium relationships in *Mustelus* (Ueda and Takeda 1983), several scombrid species (Itano *et al.* 1977) and pike (Speyer 1980) but differ in the case of black marlin where selenium concentration was positively correlated with size (Mackay *et al.* 1975). Selenium and mercury were significantly correlated in only two species, which apparently contradicts the concept that there may be a causal relationship between both elements. More work is required in this area before the situation can be fully clarified.

IMPLICATIONS

It is apparent from this and an earlier study (Lyle 1984) that many of the pelagic shark species that occur off northern Australia may include individuals that accumulate unacceptably high levels of mercury in their flesh. If the significance of these findings to the developing commercial shark fishery is to be assessed, species (and sex) and size composition data from the commercial fishery are required. These data are not currently available, however, detailed catch information was collected as part of a gillnet fishing survey (using commercial gear) conducted in Northern Territory coastal waters (Lyle and Timms 1984). Weighted mean mercury concentrations of the total catch of each species can be calculated in the following manner:

$$\sum_{l=s}^{t} Hg_l W_l n_l \Big/ \sum_{l=s}^{t} W_l n_l$$

where s and t are the lengths of the smallest and largest individuals respectively, Hg_l is the concentration of mercury, W_l is the weight and n_l the number of individuals in the catch of length l. Weights have been determined from length-weight relationships reported by Lyle and Timms (1984) and mercury concentrations were determined from relationships given in Table 3 and by Lyle (1984). Weighted mean concentrations for *C. sorrah*, *C. macloti* and *C. dussumieri* were less than 0.5 mg/kg, means for all of the remaining species except *R. taylori* exceeded 1.0 mg/kg (Table 9). The weighted mean mercury concentration for the combined catch was 1.27 mg/kg, which clearly exceeds the NH & MRC standard.

Whilst it is beyond the scope of the present report to propose a management strategy based on regulations for mercury, it is evident that it will be necessary to control the levels of mercury in shark catches that are marketed within Australia. One such approach is to constrain the mean mercury concentration of the entire catch to a nominated level. An appropriate method to achieve this is to impose size restrictions on the capture and sale of large sharks that exceed the nominated mercury standard.

An example of this is the partial ban on the sale of school shark (*Galeorhinus australis*) that exists in Victoria. It would be impractical to adopt different maximum sizes for each species because of the multispecies nature of the shark fishery and difficulties in species recognition . A further consideration is that most sharks caught in northern Australia waters will be marketed interstate and/or overseas where various different standards for mercury apply. As an interim measure, fishermen have been advised that:

1. shark that exceed 100 cm total length should not be sold for human consumption in States or Territories that have adopted the NH & MRC standard for mercury;

2. shark over 135 cm total length should not be sold for human consumption in States that have adopted a mercury standard of 1.0 mg/kg; and

3. hammerheads should not be sold for human consumption.

Based on these recommendations it is evident from Table 9 that, whilst reasonably effective in constraining the weighted mean concentration of the combined catch to the desired limits, concentrations for individual species do vary considerably. At maximum sizes equivalent to 100 or 135 cm total length, 41 or 73% respectively of the total catch weight would be retained for Australian markets.

This analysis does not take into account the fact that standards for mercury in Australia include a maximum allowable concentration of 1.5 mg/kg in any individual sample. It is thus necessary to examine the extent of the scatter of mercury values for each species. To ensure that no shark exceed this maximum, with a high degree of certainty, it may also be appropriate to consider the size at which the upper 95% confidence limit on the data equals 1.5 mg/kg. It is clear from Figure 1 and results presented by Lyle (1984) that at total lengths of 100 and 135 cm there is a possibility some sharks may exceed 1.5 mg/kg.

It would seem then, that the mercury issue can be expected to significantly influence the future development of the shark fishery in northern Australia, particularly in the establishment of markets for the product.

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TABLE 1: Fork length - total length relationships for several species of shark from northern Australian waters. TL is total length (cm), FL is fork length (cm) and r is the correlation coefficient.

SPECIES	NUMBER	RELATIONSHIP	r
Carcharhinus limbatus	536	TL = 1.903 + 1.242 FL	0.999**
C. sorrah	344	TL = 7.831 + 1.175 FL	0.997**
C. fitzroyensis	175	TL = 4.168 + 1.194 FL	0.998**
C. amblyrhynchoides	90	TL = 1.763 + 1.235 FL	0.998**
C. melanopterus	38	TL = 4.356 + 1.160 FL	0.997**
C. cautus	54	TL = 2.992 + 1.164 FL	0.994**
C. amboinensis	173	TL = 0.783 + 1.269 FL	0.999**
C. macloti	132	TL = 5.153 + 1.160 FL	0.989**
C. dussumieri	50	TL = 4.441 + 1.144 FL	0.990**
C. brevipinna	14	TL = 1.696 + 1.233 FL	0.999**
Rhizoprionodon acutus	330	TL = 6.057 + 1.144 FL	0.984**
R. taylori	200	TL = 1.638 + 1.173 FL	0.986**
Negaprion acutidens	14	TL = -3.666 + 1.229 FL	0.999**
Sphyrna lewini	188	TL = 0.167 + 1.321 FL	0.999**
S. mokarran	89	TL = 1.799 + 1.318 FL	0.997**
S. blochii	263	TL = 2.823 + 1.313 FL	0.998**

** $p<0.01$

TABLE 2: Total mercury concentrations for several species of shark from northern Australian waters. SD is standard deviation

SPECIES	NUMBER	FORK LENGTH (cm) MEAN	FORK LENGTH (cm) RANGE	TOTAL MERCURY (mg/kg) MEAN	TOTAL MERCURY (mg/kg) RANGE	SD
Carcharhinus limbatus	66	105.7	53.2-171.0	1.23	0.17-3.60	0.87
C. sorrah	30	77.9	54.7- 98.5	0.34	0.06-0.68	0.19
C. fitzroyensis	10	81.8	66.7- 96.5	0.90	0.15-1.60	0.51
C. amblyrhynchoides	12	93.0	64.2-129.2	1.94	0.55-3.50	0.96
C. melanopterus	43	83.4	55.0-104.8	1.43	0.26-3.10	0.83
C. cautus	50	76.7	44.6- 94.0	1.19	0.12-2.30	0.53
C. amboinensis	56	88.5	55.1-183.0	1.07	0.49-3.30	0.59
C. macloti	61	62.2	51.8- 70.9	0.25	0.03-0.62	0.16
C. dussumieri	47	62.6	45.0- 71.0	0.34	0.08-0.56	0.13
C. brevipinna	21	80.5	59.4-114.0	0.13	0.03-0.30	0.07
C. amblyrhynchos	1	120.8		1.40		
Galeocerdo cuvieri	6	163.0	97.5-203.0	0.77	0.39-1.10	0.27
Negaprion acutidens	22	115.1	71.3-214.0	0.49	0.28-1.10	0.20
Hemipristis elongatus	3	75.0	62.0- 88.0	0.23	0.11-0.39	
Triaenodon obesus	1	67.8		0.48		
Rhizoprionodon acutus	40	64.6	42.0- 72.6	1.01	0.16-2.00	0.58
R. taylori	55	42.5	32.2- 51.7	0.51	0.03-1.20	0.30
Sphyrna lewini	11	94.4	45.0-152.4	1.16	0.25-2.80	0.88
S. mokarran	14	159.8	51.8-280.0	1.52	0.19-3.70	1.11
S. blochii	61	83.2	46.5-116.7	0.83	0.11-1.90	0.51

TABLE 3: Relationships between length and mercury concentration for several species of shark from northern Australian waters. Hg is mercury concentration (mg/kg) and FL is fork length (cm) and r is the correlation coefficient based on linear regression of ln (Hg) and ln (FL).

** $p<0.01$, *$p<0.05$

SPECIES	NUMBER	SEX	RELATIONSHIP	r
Carcharhinus melanopterus	16	♂	$Hg=(2.58\times10^{-12})FL^{6.147}$	0.930**
	27	♀	$Hg=(2.34\times10^{-8})FL^{3.999}$	0.915**
C. cautus	25	♂	$Hg=(2.27\times10^{-11})FL^{5.719}$	0.840**
	25	♀	$Hg=(1.54\times10^{-7})FL^{3.591}$	0.961**
C. brevipinna	11	♂	$Hg=(5.28\times10^{-5})FL^{1.797}$	0.728**
	10	♀	$Hg=(2.98\times10^{-8})FL^{3.476}$	0.836**
	21	♂ε♀	$Hg=(1.01\times10^{-6})FL^{2.679}$	0.782**
C. amboinensis	29	♂	$Hg=(1.43\times10^{-2})FL^{0.984}$	0.680**
	27	♀	$Hg=(2.28\times10^{-2})FL^{0.832}$	0.595**
C. dussumieri	28	♂	$Hg=(1.75\times10^{-9})FL^{4.617}$	0.607**
	19	♀	$Hg=(8.43\times10^{-9})FL^{4.209}$	0.881**
	47	♂ε♀	$Hg=(8.36\times10^{-9})FL^{4.227}$	0.778**
C. macloti	33	♂	$Hg=(1.68\times10^{-20})FL^{10.711}$	0.788**
	28	♀	$Hg=(1.49\times10^{-13})FL^{6.753}$	0.696**
Rhizoprionodon acutus	25	♂	$Hg=(4.66\times10^{-11})FL^{5.738}$	0.843**
	15	♀	$Hg=(2.26\times10^{-19})FL^{10.158}$	0.584*
R. taylori	21	♂+	$Hg=(6.18\times10^{-14})FL^{8.183}$	0.717**
	31	♀	$Hg=(3.15\times10^{-12})FL^{6.767}$	0.680**
Negaprion acutidens	10	♂	$Hg=(1.78\times10^{-3})FL^{1.189}$	0.955**
	12	♀	$Hg=(2.72\times10^{-3})FL^{1.091}$	0.807**
	22	♂ε♀	$Hg=(2.63\times10^{-3})FL^{1.100}$	0.887**

+ Excludes 3 outlying values, with these points relationship is:
$Hg=(8.20\times10)FL^{-1.324}$ $r=-0.096$ (not significant)

TABLE 4: Effect of sex on length-mercury concentration relationships for several species of shark from northern Australian waters, using analysis of covariance [based on linear regression of ln(FL) against ln(Hg)]

	t-values for comparison of:	
SPECIES	SLOPES	ELEVATIONS
Carcharhinus melanopterus	2.596**	
C. cautus	2.111*	
C. brevipinna	1.740	0.776
C. amboinensis	0.495	2.139*
C. dussumieri	0.318	1.072
C. macloti	1.909	2.746**
Rhizoprionodon acutus	1.312	3.530**
R. taylori	0.545	5.612**
Negaprion acutidens	0.372	0.637

* $p<0.05$

** $p<0.01$

TABLE 5: Fork (and total) lengths that correspond to mean concentrations of 0.5 mg/kg and 1.0 mg/kg (determined from length-mercury relationships) for various species of shark found in northern Australian waters. Figures in parentheses represent total lengths.

SPECIES	SEX	LENGTH (CM) AT MERCURY CONCENTRATION OF: 0.5 mg/kg	1.0 mg/kg
Carcharhinus melanopterus	♂	69 (84)	77 (94)
	♀	68 (83)	81 (98)
C. cautus	♂	64 (77)	73 (88)
	♀	65 (79)	79 (95)
C. brevipinna	♂&♀	A	A
C. amboinensis	♂	B	75 (96)
	♀	B	94 (120)
C. dussumieri	♂&♀	69 (83)	A
C. macloti	♂	65 (81)	70 (86)
	♀	71 (87)	A
Rhizoprionodon acutus	♂	56 (70)	63 (78)
	♀	64 (79)	68 (84)
R. taylori	♂	38 (46)	41 (50)
	♀	45 (54)	51 (61)
Negaprion acutidens	♂&♀	120 (144)	A

A Predicted length exceeds largest individual sampled in this study

B Predicted length below smallest individual sampled in this study

TABLE 6: Total mercury, alkyl mercury and percentage of mercury present as alkyl mercury in several species of shark from northern Australian waters. SD is standard deviation.

		TOTAL MERCURY		ALKYL MERCURY		% ALKYL MERCURY	
SPECIES	NUMBER	MEAN	RANGE	MEAN	RANGE	MEAN	SD
Carcharhinus limbatus	22	1.02	0.12-3.60	0.95	0.14-2.90	93.1	9.0
C. sorrah	20	0.33	0.06-0.68	0.32	0.07-0.57	98.6	10.7
C. fitzroyensis	9	0.90	0.15-1.60	0.87	0.15-1.40	102.0	16.3
C. amblyrhynchoides	8	1.90	0.55-3.30	1.75	0.55-3.30	93.7	6.0
C. melanopterus	11	1.59	0.36-3.10	1.33	0.30-2.50	86.1	9.1
C. cautus	10	1.14	0.34-2.30	0.95	0.28-1.80	88.3	12.7
C. amboinensis	12	1.51	0.55-3.30	1.41	0.46-3.60	90.3	9.3
C. macloti	8	0.23	0.09-0.52	0.21	0.10-0.45	94.2	11.6
C. dussumieri	3	0.35	0.15-0.51	0.30	0.15-0.47	87.7	
C. brevipinna	8	0.14	0.06-0.23	0.14	0.09-0.26	110.4	24.9
Galeocerdo cuvieri	3	0.77	0.39-1.10	0.59	0.37-0.82	82.1	
Negaprion acutidens	2	0.50	0.46-0.55	0.56	0.48-0.64	110.4	
Rhizoprionodon acutus	10	1.01	0.28-1.80	0.81	0.25-1.50	80.2	7.7
R. taylori	9	0.58	0.07-1.10	0.49	0.09-0.99	88.9	16.2
Sphyrna lewini	9	1.21	0.25-2.80	1.20	0.28-2.60	99.8	8.5
S. mokarran	14	1.52	0.19-3.70	1.45	0.15-3.70	98.2	16.7
S. blochii	10	0.58	0.14-1.70	0.52	0.11-1.30	90.2	12.8

TABLE 7: Length and selenium concentrations of several species of shark from northern Australian waters. SD is standard deviation.

		FORK LENGTH (cm)		SELENIUM (mg/kg)		
SPECIES	NUMBER	MEAN	RANGE	MEAN	RANGE	SD
Carcharhinus limbatus	21	98.3	53.2-171.0	0.78	0.37-1.10	0.22
C. sorrah	20	76.1	54.7- 98.5	0.61	0.40-1.00	0.18
C. fitzroyensis	10	78.6	59.4- 96.5	0.61	0.25-0.92	0.20
C. amblyrhynchoides	8	91.3	64.2-129.2	0.84	0.41-1.60	0.40
C. melanopterus	11	85.7	68.3-103.5	0.70	0.28-1.40	0.33
C. cautus	10	76.0	56.8- 92.2	1.12	0.49-2.10	0.48
C. amboinensis	12	111.0	55.1-183.0	0.66	0.39-1.00	0.18
C. macloti	7	62.8	58.5- 68.3	0.69	0.48-0.88	0.16
C. dussumieri	3	63.8	57.0- 69.3	1.86	0.48-3.40	
C. brevipinna	8	85.1	65.5-114.0	0.61	0.40-0.98	0.21
Galeocerdo cuvieri	3	162.5	97.5-203.0	0.48	0.34-0.71	
Negaprion acutidens	2	110.4	85.3-135.6	0.37	0.34-0.40	
Rhizoprionodon acutus	10	66.3	59.7- 72.6	0.72	0.44-1.30	0.28
R. taylori	7	43.4	32.2- 51.7	0.46	0.32-0.65	0.12
Sphyrna lewini	9	96.6	45.0-152.4	0.81	0.46-1.50	0.32
S. mokarran	14	148.8	51.8-280.0	0.79	0.33-1.90	0.47
S. blochii	10	75.2	46.5-109.7	1.13	0.61-1.90	0.47

TABLE 8: Correlation analysis comparing selenium concentration with fork length and mercury concentrations in several species of shark from northern Australian waters.

	CORRELATION OF SELENIUM AND:	
SPECIES	FORK LENGTH	TOTAL MERCURY
Carcharhinus limbatus	-0.475 *	-0.295
C. sorrah	-0.251	-0.127
C. fitzroyensis	0.171	0.537
C. amblyrhynchoides	0.183	0.193
C. melanopterus	0.185	0.249
C. cautus	0.335	0.723 **
C. amboinensis	0.510 *	0.469
C. macloti	0.943 **	0.656
C. brevipinna	-0.694 *	-0.243
Rhizoprionodon acutus	-0.543	-0.139
R. taylori	0.327	0.129
Sphyrina lewini	0.431	0.392
S. mokarran	0.170	0.108
S. blochii	0.836 **	0.803 **

* $p<0.05$
** $p<0.01$

TABLE 9: Weighted mean mercury concentrations (mg/kg) based on exploratory fishing survey gillnet catches (Lyle and Timms 1984)* and calculated for different maximum lengths. Values in parentheses represent the sample sizes of sharks measured for length frequency.

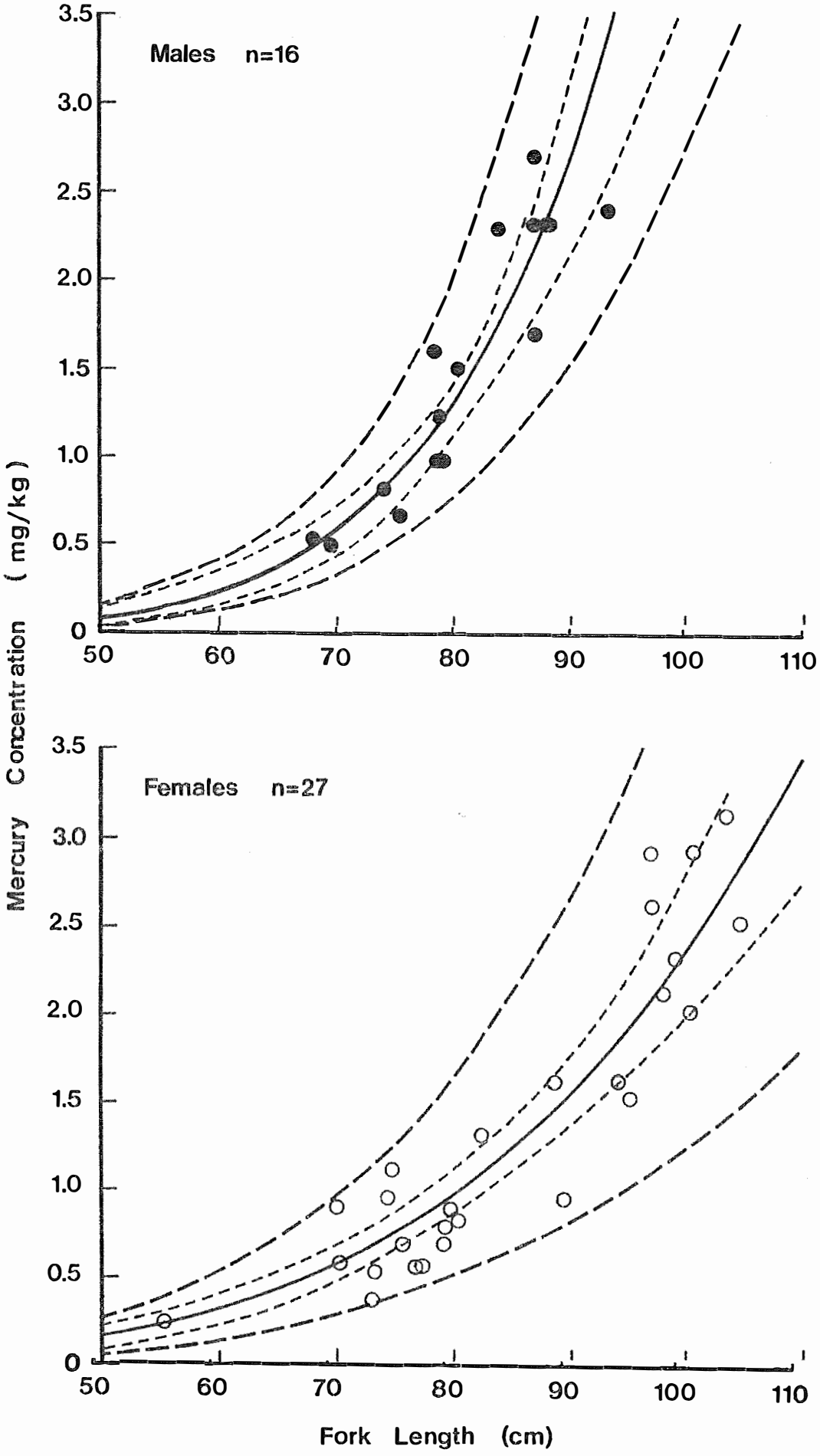
SPECIES	TOTAL CATCH	MAXIMUM TOTAL LENGTH 100 cm	135 cm
Carcharhinus limbatus	1.47 + (2377)	0.49 + (1613)	1.01 + (2152)
C. sorrah	0.45 + (2071)	0.38 + (1713)	0.45 + (2071)
C. fitzroyensis	1.12 + (167)	0.79 + (126)	1.12 + (167)
C. amblyrhynchoides	2.79 + (100)	1.02 + (23)	2.62 + (99)
C. amboinensis	1.31 (202)	0.83 (109)	0.97 (162)
C. macloti	0.35 (202)	0.33 (201)	0.35 (202)
C. dussumieri	0.39 (40)	0.39 (40)	0.39 (40)
Rhizoprionodon acutus	1.08 (705)	1.08 (705)	1.08 (705)
R. taylori	0.67 (104)	0.67 (104)	0.67 (104)
Sphyna lewini	1.67 + (286)	0.59 + (140)	0.82 + (211)
S. mokarran	3.17 + (91)	0.54 + (17)	0.88 + (46)
S. blochii	1.13 + (266)	0.36 + (84)	0.90 + (241)
SPECIES COMBINED	1.27 (6611)	0.53 (4875)	0.85 (6200)

* Based on 'commercial' gillnet catches:gillnet was 1200 m long, with 150 mm stretched mesh monofilament and 100 mesh drop.

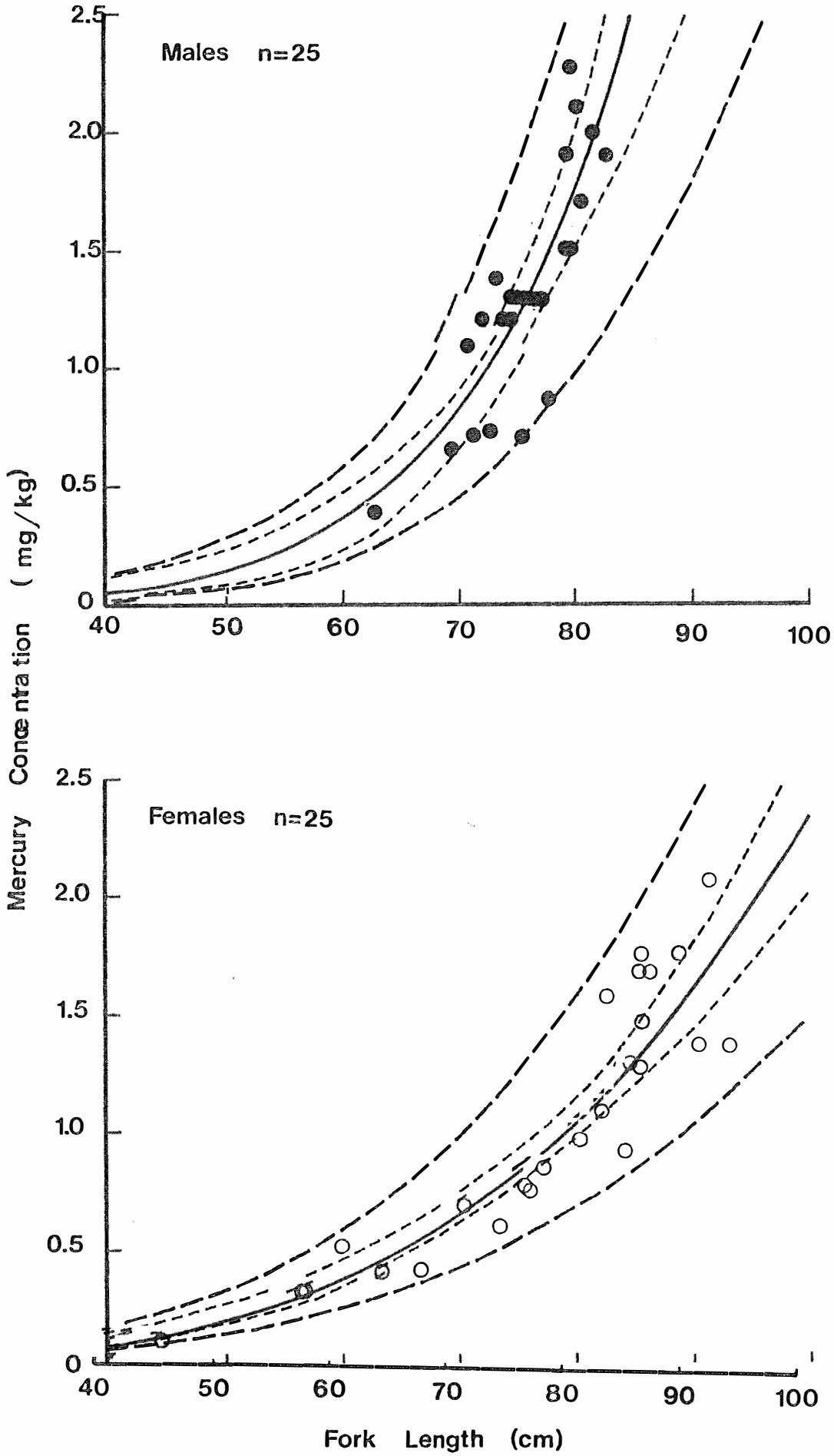
\+ Determined using length-mercury relationships reported by Lyle (1984).

FIGURE 1: Relationships [with 95% confidence limits on the mean curve (------) and individual data (————)] between mercury concentrations and length for (a) *Carcharhinus melanopterus*; (b) *C. cautus*; (c) *C. amboinensis*; (d) *C. macloti*; (e) *C. dussumieri*; (f) *C. brevipinna*; (g) *Rhizopriondon acutus*; (h) *R. taylori* and (i) *Negaprion acutidens* (● males; O females; ■ male values excluded from regression analysis; n represents sample size).

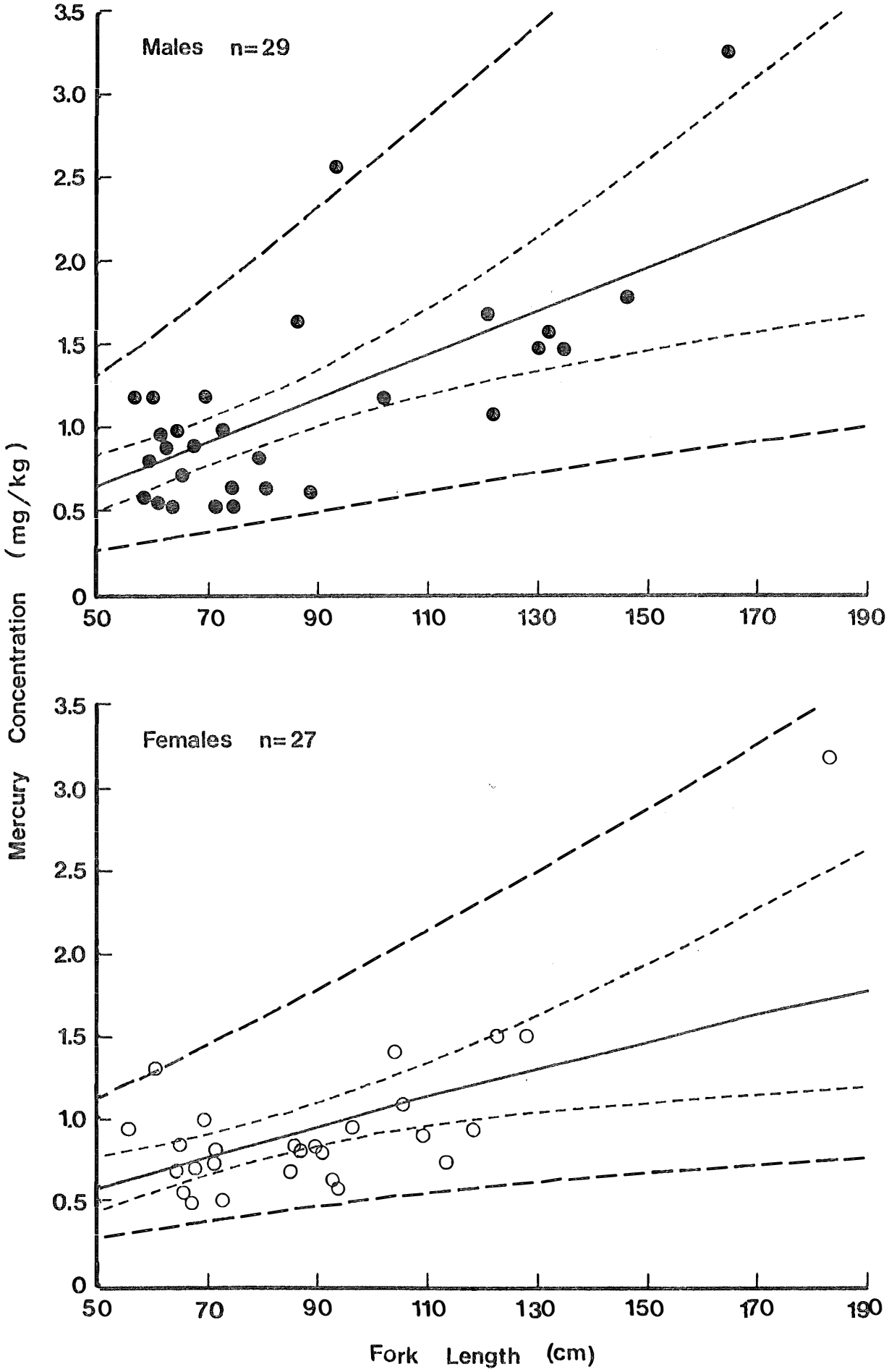
(a) *C. melanopterus*



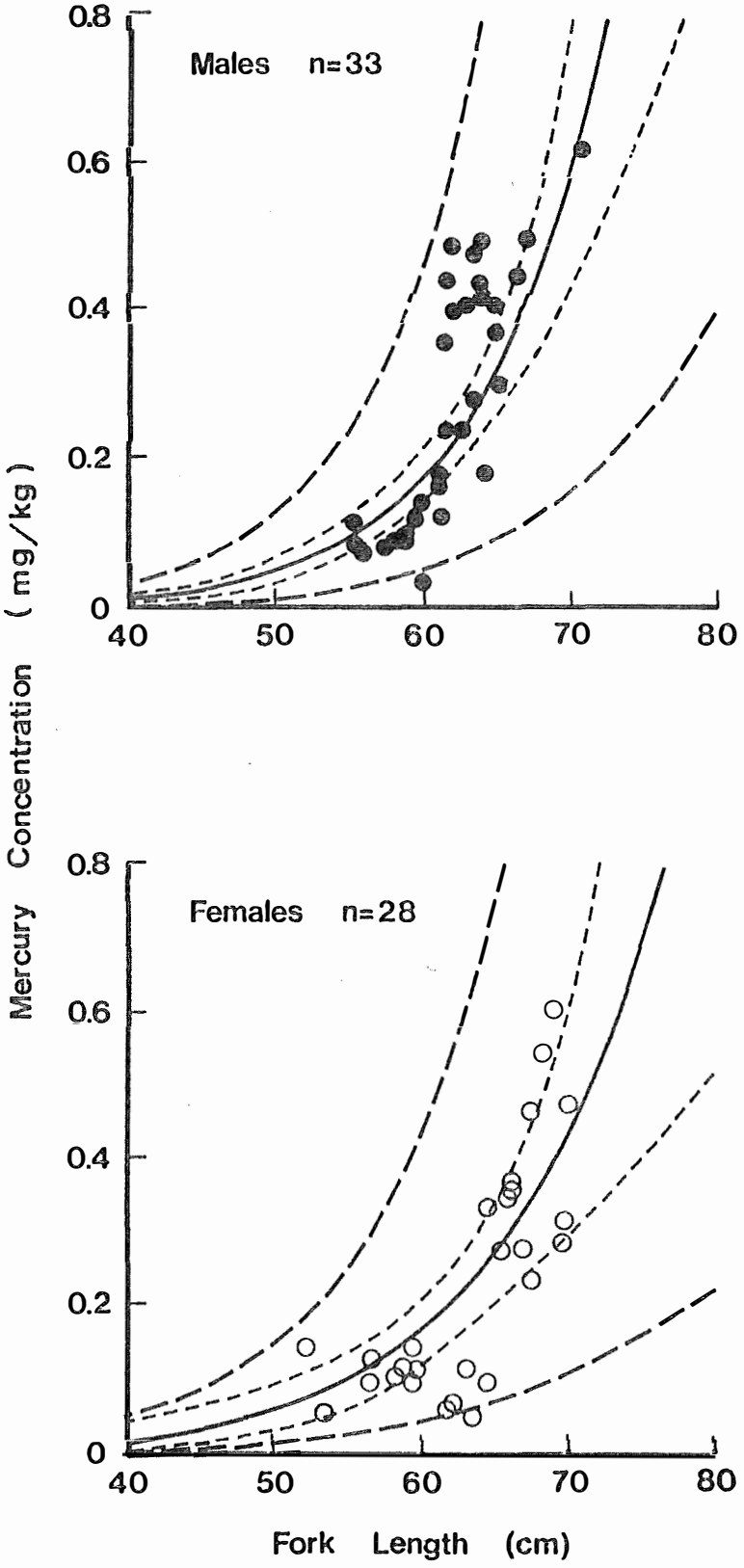
(b) *C. cautus*


Males n=25
Females n=25
Mercury Concentration (mg/kg)
Fork Length (cm)
0
0.5
1.0
1.5
2.0
2.5
40
50
60
70
80
90
100

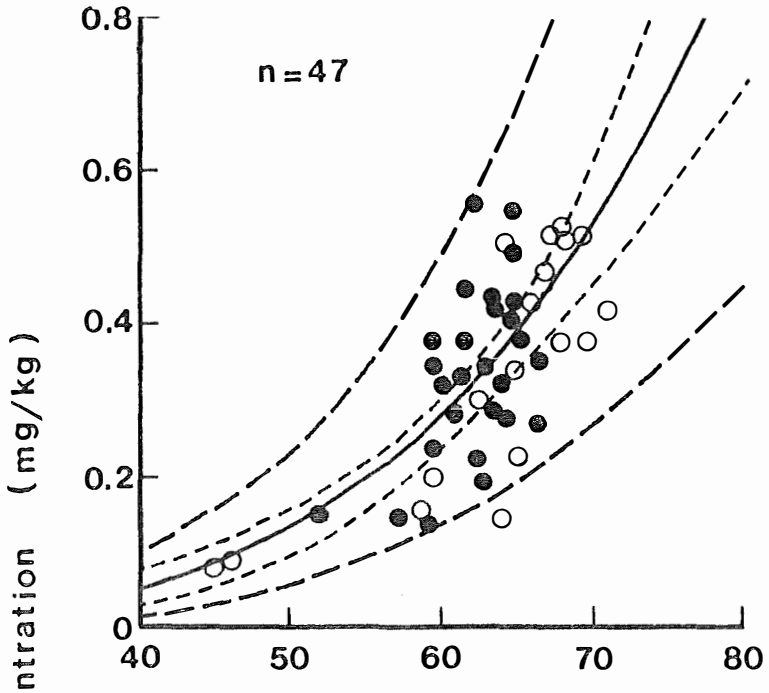
(c) *C. amboinensis*



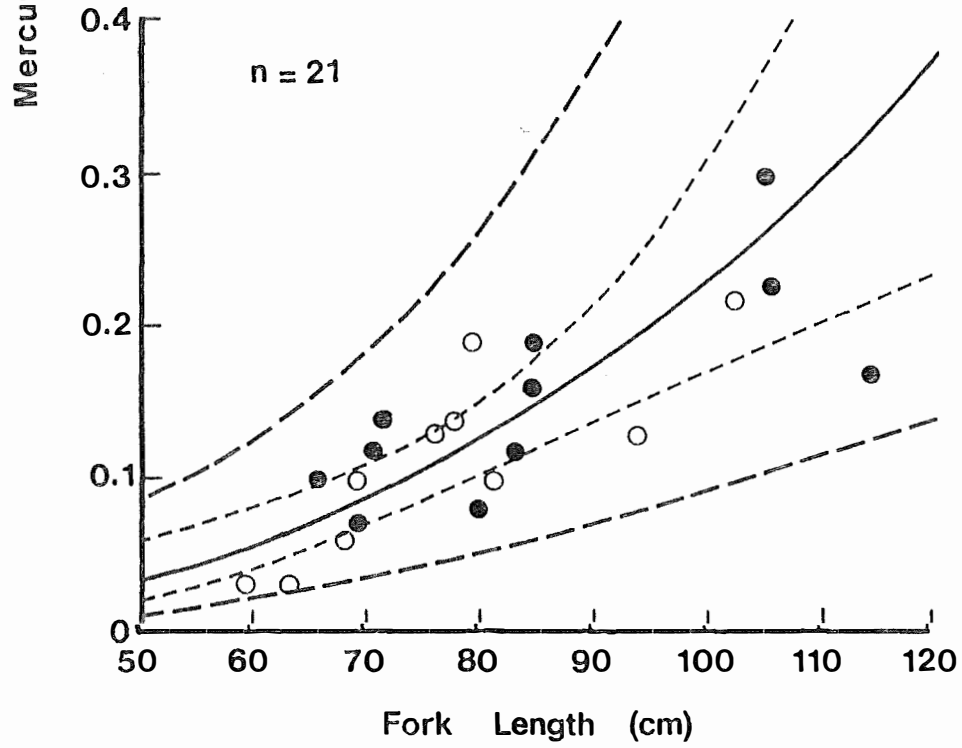
(d) *C. macloti*


Males n=33
Females n=28
Mercury Concentration (mg/kg)
0.8
0.6
0.4
0.2
0
40
50
60
70
80
Fork Length (cm)

(e) *C. dussumieri*

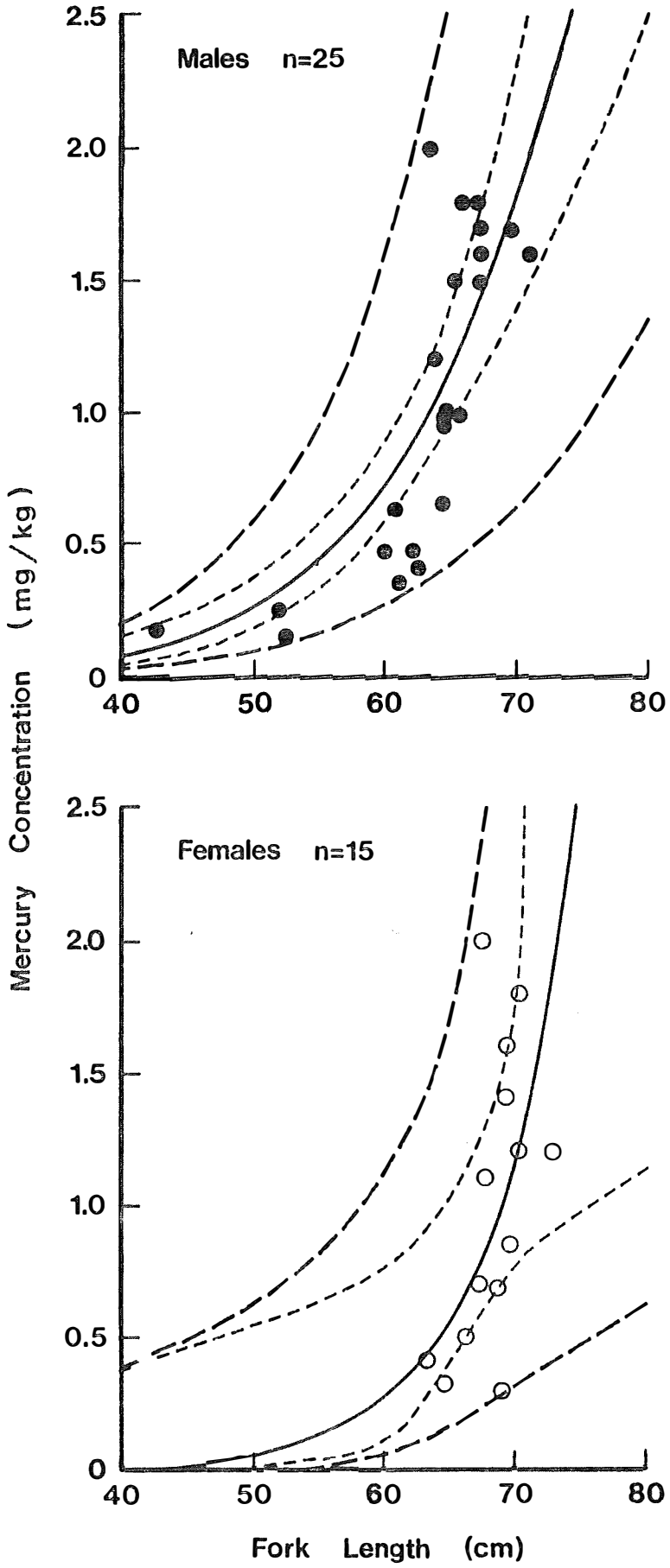


(f) *C. brevipinna*

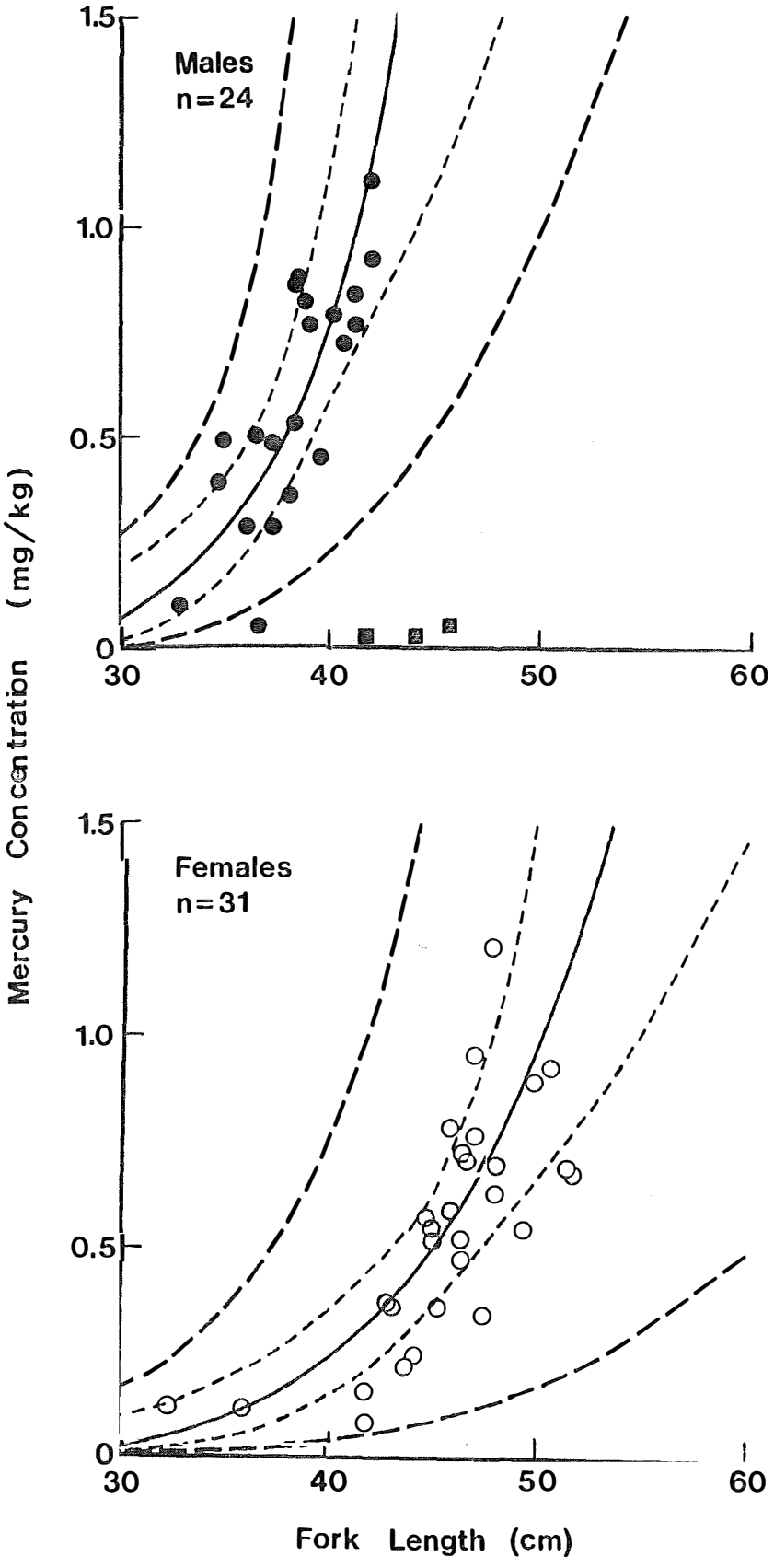


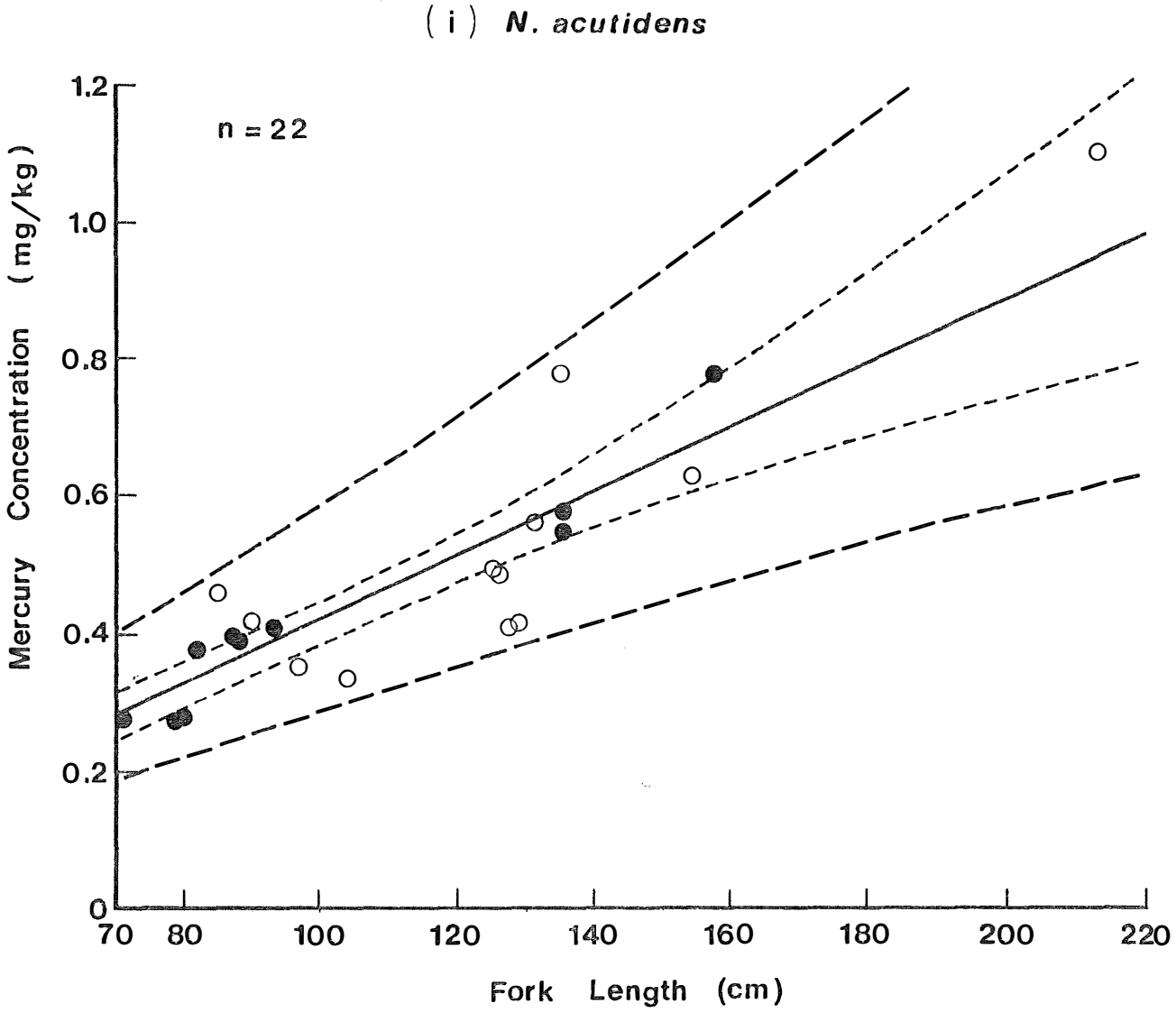
Mercury Concentration (mg/kg)

(g) *R. acutus*


Males n=25
Females n=15
Mercury Concentration (mg/kg)
Fork Length (cm)
0
0.5
1.0
1.5
2.0
2.5
40
50
60
70
80

(h) *R. taylori*


Males
n=24
Females
n=31
Mercury Concentration (mg/kg)
Fork Length (cm)
0
0.5
1.0
1.5
30
40
50
60


(i) N. acutidens
n = 22
Mercury Concentration (mg/kg)
1.2
1.0
0.8
0.6
0.4
0.2
0
70
80
100
120
140
160
180
200
220
Fork Length (cm)