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ESTIMATED BODY SIZE AT SEXUAL MATURITY OF SLIPPER LOBSTER *SCYLLARIDES SQUAMOSUS* AT MARO REEF AND NECKER ISLAND (NORTHWESTERN HAWAIIAN ISLANDS), 1986-97

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ABSTRACT

Body size at sexual maturity was evaluated for slipper lobster *Scyllarides squamosus* at two banks (Maro Reef, Necker Island) in the Northwestern Hawaiian Islands (NWHI), using research and commercial catch data collected during the 12-yr period from 1986 to 1997. Using available research data, estimated size at median maturity of NWHI slipper lobster is about 49-50 mm tail width, equivalent to about 66-67 mm carapace length. Size at maturity was further compared between banks and among years to evaluate whether bank- or time-specific estimators might be warranted. Sizes at median maturity at Maro Reef and at Necker Island were similar during the period of sampling, although maturity distributions among size classes differed between banks. The data also weakly suggest that size at maturity declined at both banks between 1986 and 1997. Median size of the slipper lobsters caught on research cruises did not change during this period. Observed results to date suggest that both bank and exploitation exerted over time influence size at maturity in NWHI slipper lobster.

The inconstancy of the size at maturity estimates suggests that future re-characterizations are justified. The present level of sampling effort on research cruises, however, is likely insufficient to provide adequately precise estimates on an annual basis. Means of circumventing research data limitations are discussed.

INTRODUCTION

The slipper lobster, *Scyllarides squamosus*, has historically contributed a minor portion of the Northwestern Hawaiian Islands (NWHI) commercial lobster fishery (Pooley and Kawamoto, in prep.). Prior to the 1997 commercial fishing season, the spiny lobster (*Panulirus marginatus*) was consistently targeted by the fishery. In 1997, however, several commercial vessels targeted slipper lobster at Maro Reef, one of two NWHI banks (the other being Necker Island) that have been heavily exploited by the fishery in recent years.

To date, only spiny lobster life history parameters have been used as input to stock assessments for the NWHI lobster fishery. This has been acceptable in the past because spiny lobster has been a nearly exclusive target species.

With slipper lobster developing as a newly targeted species, and with stock management by bank or region a future possibility, species- and bank-specific estimates of body size at sexual maturity and other key life history parameters are becoming essential in assessments of NWHI lobster stocks. Prior characterizations of size at maturity (Polovina, 1989) and size-specific fecundity (DeMartini et al., 1993) of spiny lobster have discovered bank-specific and temporal variations. The present evaluation therefore considers the possible effects of bank and time on size at maturity of slipper lobster.

METHODS AND MATERIALS

Data Used

At least some fishery-independent research data are available for most years during the period from 1984 to 1997. Research data were collected aboard the NOAA ship *Townsend Cromwell* on annual assessment cruises conducted during 1984-88 and 1990-97. In 1995 and 1997, additional (fishery-dependent) data for slipper lobster were collected by National Marine Fisheries Service (NMFS), Southwest Region (SWR) observers aboard commercial vessels. Research or commercial data were collected at Maro Reef as well as Necker Island in most years, although the number of female slipper lobster sampled has varied among years (Table 1). Historical research stations sampled only a small fraction of bank areas fished commercially in most years. In 1997 at Maro Reef, however, the area of research sampling was expanded to partially overlap commercially fished areas. No data are available for 1989 because the research cruise series was temporarily suspended then.

Sexual maturation in female slipper lobster was indexed by egg presence on pleopods ("berried" condition). All stages of egg development (scored aboard ship by egg color) were treated equivalently as evidence of spawning. Berried condition was used as an imperfect index of sexual maturity, which scaled to a maximum proportion berried less than 1.0 due to a preponderance of mature but inactively reproductive females, because no other measure (such as histological evidence of ovarian development) was available. Data on berried condition of slipper lobsters was not recorded on the fall 1984-85 cruises; hence, our evaluation was limited to 1986 onward. Most assessment data were collected during May-August (primarily June-July) when the incidence of berried spiny lobster peaks. Although substantial commercial catch data were collected in September-October 1995, the data analyzed were limited to May-August of all years to minimize the effect of seasonal variability on berried condition. Incidence of berried slipper lobster appears to peak in May, slightly earlier than spinys in the NWHI (“Narrative Report” of *Townsend Cromwell* cruise TC-79-02, on file in the Editorial Office, Honolulu Laboratory, F/SWC2).

Tail width (TW3, defined as the straight line distance across the tail measured as the widest spot between the first and second tail segments) was used as the primary body size metric because it is the standard used for lobster in the Crustacean Fishery Management Plan (FMP) for the NWHI lobster fishery (FMP Amendment 5). TW3 was converted to carapace length (CL), using matched TW3-CL data collected on research cruises, in order to provide a more conventional size metric for comparison with other lobster fisheries. Data were initially recorded in millimeters (either 0.01 or 0.1 mm), then classified by 1-mm bins to the nearest 0.1 mm.

Statistical Analyses

Body size at sexual maturity was estimated by fitting the fraction berried (Y) among all sample females (N) against TW3 using the hyperbolic tangent model of Polovina (1989). The model,

$$Y = A(1 + \mathrm{Tanh}[B(TW3-C)]), \qquad (1)$$

was fit using weighted nonlinear regression. Both the square root of the number of females per size class and the inverse of the variance [N/(Y + 0.05)(1 - Y)] of the fraction berried per size class were evaluated as weighting factors. Size or tail width at median sexual maturity ($TW3_{50}$, referred to as "size at the onset of sexual maturity" by Polovina, 1989) was estimated as the inflexion point on the curve at which the parameter C is the tail width where the fraction of berried females equals one-half the asymptotic level, 2A.

As a check on size at maturity estimates provided by the hyperbolic tangent method, $TW3_{50}$ was also estimated separately for Maro Reef and Necker Island samples, using research data for all years combined, and fit to a three-parameter logistic model giving proportion berried (*P*) as a function of TW3,

$$P = a/\{1 + [(4b/a) \cdot EXP(TW3_{50} - TW3]\}, \qquad (2)$$

where *a* is the asymptotic proportion berried, *b* is the slope of the logistic function at the inflection point, and $TW3_{50}$ is the tail width at the inflection point (size at 50% of asymptote).

Nonparametric estimates of *P* as a function of TW3 were obtained by fitting binomial family General Additive Models (GAMs) to binary data on individual animals, coded as 1 (berried) or 0 (not berried).

The possible effects of time (either year or more than one year pooled to increase sample size) on body size at median maturity were evaluated by rank correlation of $TW3_{50}$ and sample year.

Conventional statistical tests and estimates of size at median sexual maturity using the hyperbolic tangent model were made using PC SAS v. 6.04 (SAS Inst. Inc., 1990). Parameter estimates of the logistic model were obtained by a nonlinear fitting procedure which maximizes a binomial log-likelihood function. The procedure was constructed using AD Model Builder (Anon., 1993). GAM models were fit using Splus software (Chambers and Hastie, 1992).

RESULTS

Size at Sexual Maturity

General

Using all available research data on TW3 and fraction berried, $TW3_{50}$ in NWHI slipper lobster was estimated as 49.5 mm TW3 by the hyperbolic tangent model (Table 2). Using either the square root of sample size or the inverse variance as a weighting factor produced $TW3_{50}$ estimates that differed only slightly and without pattern; hence, all estimates using the hyperbolic tangent model presented herein use inverse variance weightings.

Bank Effect

Estimates of $TW3_{50}$ using the hyperbolic tangent model were identical (49.8 mm TW3) at both Maro Reef and Necker Island, if evaluated using research data for the entire sampling period from 1986 to 1997 (Table 2). Estimates of $TW3_{50}$ from the logistic model were similar for Maro Reef and Necker Island (49.0 and 48.9 mm, respectively), but were slightly less than the estimate provided by the less conventional, hyperbolic tangent model.

If research data for 1986-97 are pooled, the GAM models of proportion berried for each bank (Figs. 1A, B) describe qualitative differences between banks in the distributions of berried females among size classes. A maximum likelihood (ML) chi-square can be used to test whether banks differed in fits to the logistic model. The maximum likelihood for the logistic model, fit to combined Maro and Necker research data, was significantly less than the sum of likelihoods for separate models fit to research data from each bank (ML chi-square = 11.72, $df = 3$, $P = 0.008$). This suggests the possibility that maturation schedules differ between banks.

Slipper lobsters caught by the commercial fishery in 1997 were larger-bodied (Table 1) and had a larger median size at maturity (Table 2) than slippers caught on research cruises in years other than 1997, when commercial areas were added to the research sampling grid (G. DiNardo, personal commun.). The maturity distributions of slippers also differed between research and commercial catches at Maro Reef in 1997 (ML chi-square = 21.28, $df = 3$, $P < 0.0001$; Fig. 2A,B). These results for 1997, when catches were sufficient to compare research and commercial data, justify not pooling commercial samples with research data to evaluate a bank effect.

Temporal Effect

The research data weakly suggest that size at maturity of slipper lobster declined at both Maro Reef and Necker Island from 1986 to 1997 (Spearman's rank correlation: $r_s = - 0.41$; $N = 11$ bank-years; $P = 0.21$; Table 2; Fig. 3). Estimates of median maturity for research and commercial samples at Maro Reef in 1997, although deleted from the time series analyzed, are included in Figure 3 to illustrate the contrasting sizes of slipper lobster in the 1997 research-commercial and other years' research samples.

CL-TW3 Relation

The CL-to-TW3 relation for 1984-96 research samples, fit by linear least squares regression, is best described by the equation,

$$CL = 4.31 + 1.2530 \cdot TW3, \quad r^2 = 0.942, \tag{3}$$

$\underline{N} = 4{,}167$,
$\underline{P} < 0.001$,

where both size metrics are expressed in millimeters. Based on this relationship, 66-67 mm CL would be the equivalent of a 49-50 mm TW3 at median maturity for slipper lobster in the NWHI (Table 2).

DISCUSSION

Comparisons with Spiny Lobster

Only spiny lobster size-at-maturity estimates were available for previous assessments of NWHI lobster stocks. The only estimates of body size at sexual maturity for spiny lobster are those provided by Polovina (1989) for carapace length (CL at onset of maturity ranging from about 6.8 cm at Maro Reef in 1977 to 5.8 cm at Necker Island during 1985-86) and by Polovina and Moffitt (1989) for tail width (TW3 at onset of maturity ranging from 5.1 cm at Maro Reef in 1977 to 3.9 cm at Necker Island in 1988). In terms of tail width, slipper lobster are larger at onset of sexual maturity (4.8-6.1 cm TW3, this study) than spiny lobster. However, the difference between spinys and slippers in CL-at-maturity is less (slippers: 6.5-8.1 cm CL; Table 2). The apparent discrepancy between size metrics obviously reflects shape differences between species (slipper or "squat" lobster are wider at a given length, although about the same carapace length as spinys).

Polovina (1989) demonstrated that temporal changes in the size at maturity of spiny lobster occurred between 1977 (prior to development of the fishery) and 1988 (after a half-dozen years of intense exploitation). Polovina's (1989) analysis also suggested that different, bank-specific maturation schedules might exist for spinys. No further decline in size at maturity of spinys is evident from research catch data for the period 1990-95 (W. Haight, unpubl.) during which heavy exploitation continued except for a 1-year closure of the commercial fishery in 1996.

Bank and Time Effects on Maturity in Slippers

The currently available data suggest that bank and perhaps time affect size at maturity in NWHI slipper lobster. That bank might affect size at maturity of slipper lobster is not surprising. Because of differences in shelter and foraging resources, the standing stocks and productivities of spiny lobster vary appreciably among banks throughout the NWHI (Parrish and Polovina, 1994).

The observed decrease in the incidence of large, berried females (at Necker Island only) possibly reflects a bank-specific difference in senescence of old individuals. More likely, the decrease represents differences among size (age) classes in the timing of spawning that vary between Maro Reef and Necker Island because of differences between banks in seasonality related to latitude. If so, we would expect these differences to diminish or disappear if both banks were consistently sampled during their respective peak spawning period.

If real, the observed temporal changes in size at maturity within banks are less explicable for slipper lobster. The median body sizes of slippers caught at Maro and at Necker did not change (decline) over the period from 1986 to 1997, which might be expected if stocks were fished down to densities at which compensatory growth or maturation might occur (Polovina, 1989; DeMartini et al., 1993). Summaries of commercial logbook data (Pooley and Kawamoto, in prep.) indicate that catches of slippers between 1983 and 1997 totaled about one-third those of spinys, arguably sufficient to induce a compensatory change in the growth or maturation of slippers. The lack of change in median body size of slippers caught by research catches during 1986-97, during which time the types of traps used were changed, further suggests that the presence/absence of escape vents (developed for spinys) has minor influence on the numbers of small slippers caught.

CONCLUSIONS AND RECOMMENDATIONS

Berried condition provides an inexact proxy of maturity in lobsters. Improved estimates of sexual maturity are needed for both slippers and spinys. One option to increase the precision of size at maturity estimates for individual years is to increase sampling effort (measure greater numbers of lobsters at additional stations). Because this is probably not feasible on research cruises, another option might be to increasingly rely on the large sets of data collected by observers aboard commercial vessels. In 1995 and 1997, for example, the numbers of slipper lobster sampled by observers were 85% and 275% greater than those sampled on the respective year's research cruise (Table 1). Although commercial catches sample a different size spectrum of lobsters than research catches, commercial catches could provide their own time series of samples over larger, more representative areas of the fishery.

Another option might be to use an estimator of sexual maturity that provides more direct evidence of maturity than does the presence of eggs on pleopods. Houssain (1978), for example, describes the use of an external morphological criterion (ratio of the lengths of endopodites to exopodites on pleopods) to estimate size at sexual maturity in both males and females of the slipper lobster *Thenus orientalis*. An analogous, more detailed study of the spiny lobster *Panulirus japonicus* is described by Minagawa and Higuchi (1997). Prescott (1984) stated that allometric growth of walking legs can be used to estimate size at sexual maturity in the Hawaiian spiny lobster, *P. marginatus*, although specifics were not provided. If an analogous morphological marker occurs in *Scyllarides squamosus*, leg or pleopod samples collected at sea (without undue additional effort) could later be measured ashore. Even typically small research samples (several hundred female slipper lobsters) might then provide adequately precise size-at-maturity estimates if unberried but mature females could be distinguished from immature females.

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Table 1.--Fraction berried and numbers of berried, unberried, and total female lobsters sampled at Maro Reef and Necker Island (NWHI) each sampling year during the period 1986-97. Data collected by fishery-independent research (res) cruise of the NOAA ship *Townsend Cromwell* are distinguished from fishery-dependent data collected by NMFS, SWR observers aboard commercial (com) fishing vessels (1995 and 1997 only, in bold type).

			Female Slipper Lobster				
			TW3		Number		
Bank	Year(s)	Type data	Median	Range	Berried	Total	Proportion berried
Maro	1986	res	64.4	44-81	28	260	0.108
Maro	1987	res	60.6	43-79	68	276	0.246
Maro	1988	res	57.9	43-80	44	137	0.321
Maro	1990	res	62.2	43-77	107	220	0.486
Maro	1991	res	60.8	29-80	86	293	0.294
Maro	1992	res	60.8	39-79	164	368	0.446
Maro	1993	res	58.2	29-77	157	607	0.259
Maro	1994	res	59.6	29-78	310	442	0.701
Maro	**1995**	**com**	**59.3**	**47-77**	**90**	**1008**	**0.089**
Maro	1995	res	59.8	31-80	231	503	0.459
Maro	1996	res	61.3	34-79	119	585	0.203
Maro	**1997**	**com**	**67.3**	**47-90**	**515**	**1911**	**0.269**
Maro	1997	res	60.4	33-83	128	735	0.174
Maro, all years[a]		res	60.3	29-83	1442	4426	0.326
Necker	1986	res	61.3	46-78	32	133	0.241
Necker	1987	res	61.3	41-83	40	163	0.245
Necker	1988	res	62.7	46-76	73	199	0.367
Necker	1990	res	59.1	44-75	16	62	0.258
Necker	1991	res	60.8	45-71	9	52	0.173
Necker	1992	res	59.9	46-76	28	112	0.250
Necker	1993	res	59.6	32-73	53	160	0.331
Necker	1994	res	59.5	47-72	75	145	0.517
Necker	**1995**	**com**	**61.3**	**47-73**	**20**	**188**	**0.106**
Necker	1995	res	62.2	43-76	45	143	0.315
Necker	1996	res	60.7	29-78	77	172	0.448
Necker	**1997**	**com**	**62.2**	**48-79**	**405**	**1669**	**0.243**
Necker	1997	res	61.0	48-75	97	221	0.439
Necker, all years[a]		res	60.7	29-83	545	1562	0.349
Both banks, all years[a]		res	60.5	29-83	1987	5988	0.332

[a]Excluding commercial data

Table 2.--Estimated body sizes at median sexual maturity ($TW3_{50}$) for slipper lobster at Maro Reef and Necker Island (NWHI) during the period 1986-97. $TW3_{50}$ was estimated by the hyperbolic tangent model of Polovina (1989), with inverse variance weighting. Rankings are provided for the 11 bank-years of research data[a] with estimable $TW3_{50}$'s (excluding 1997 at Maro Reef). Commercial data are bold type. Body size is expressed as both tail width (TW3 in mm) and carapace length (CL in mm; see Methods).

			Sizes at sexual maturity		
Bank	Year(s)	Type data	$TW3_{50}$	Rank	CL
Maro	1986-87	res	57.1	1	75.9
Maro	1988	res	50.8	7	68.0
Maro	1990-92	res	54.8	2	73.0
Maro	1993	res	50.4	8	67.5
Maro	1994	res	48.6	10	65.2
Maro	**1995**	**com**	**--**	**-**	**--**
Maro	1995	res	51.2	6	68.5
Maro	1996	res	52.2	3	69.7
Maro	**1997**	**com**	**67.9**	**-**[b]	**89.4**
Maro	1997	res	61.3	-[c]	81.1
Maro, all years[a]		res	49.8	n/a	66.7
Necker	1986-87	res	51.8	4	69.2
Necker	1988	res	51.3	5	68.6
Necker	1990-92	res	50.2	9	67.2
Necker	**1995,97**	**com**	**--**	**-**	**--**
Necker	1993-97	res	48.1	11	64.6
Necker, all years[a]		res	49.8	n/a	66.7
Both banks, all years[a]		res	49.5	n/a	66.3

[a]Excluding commercial data

[b]Commercial catches at Maro reef in 1997 were excluded from the analysis of year effects on median maturity.

[c]Research cruise samples in 1997 included commercially fished regions of Maro Reef (G. DiNardo, personal commun.); these samples were excluded from the analysis of year effects.

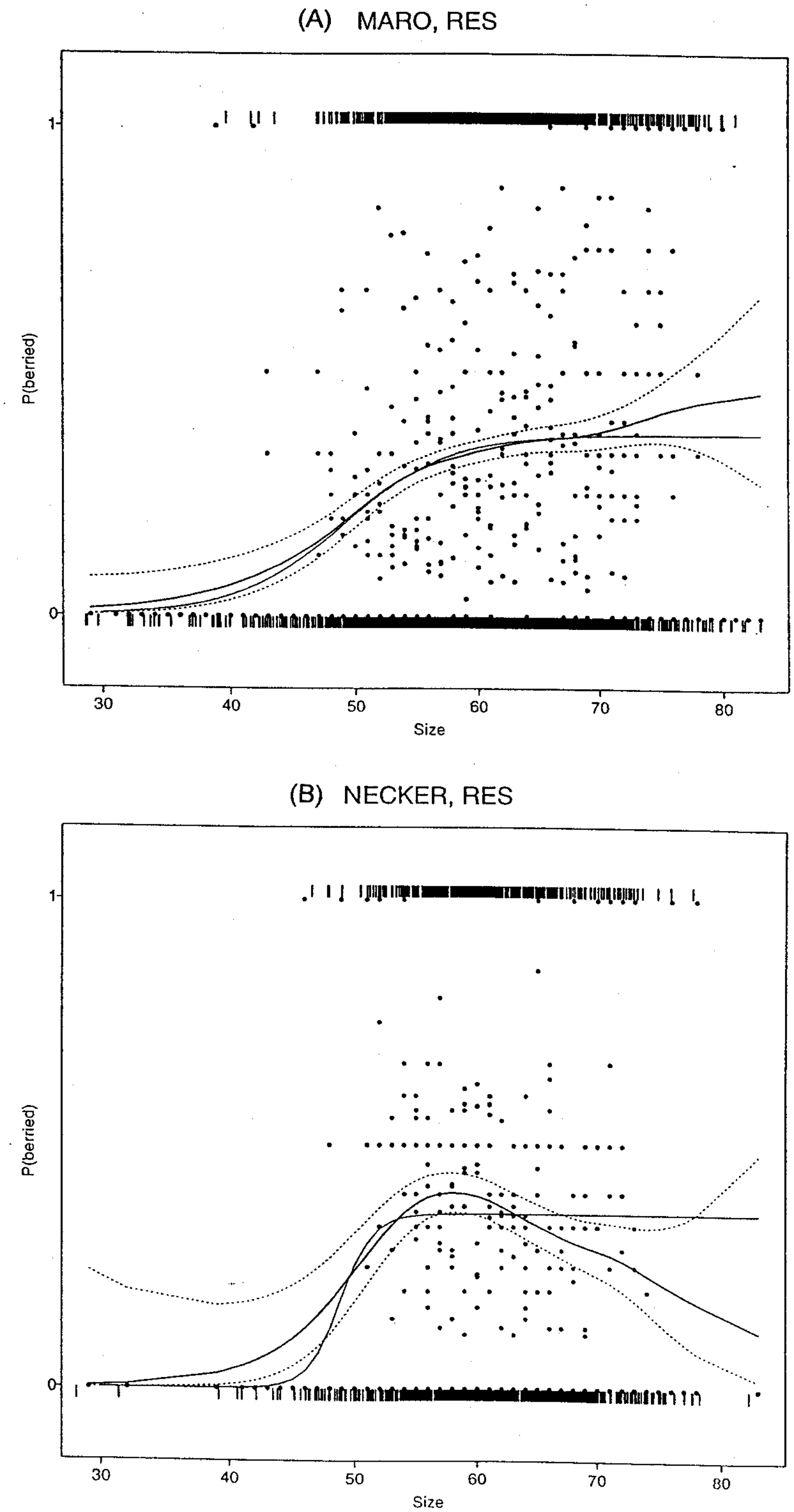

Figure 1.--GAMs and logistic models for research data from (A) Maro Reef and (B) Necker Island. The GAM model, depicted by the bold line enclosed by approximate 95% confidence bounds, was fit to binary data given by "rug" plots at P = 1 (berried) and P = 0 (not berried). The logistic model is the thin sigmoid line, fit to the data points of proportion berried.

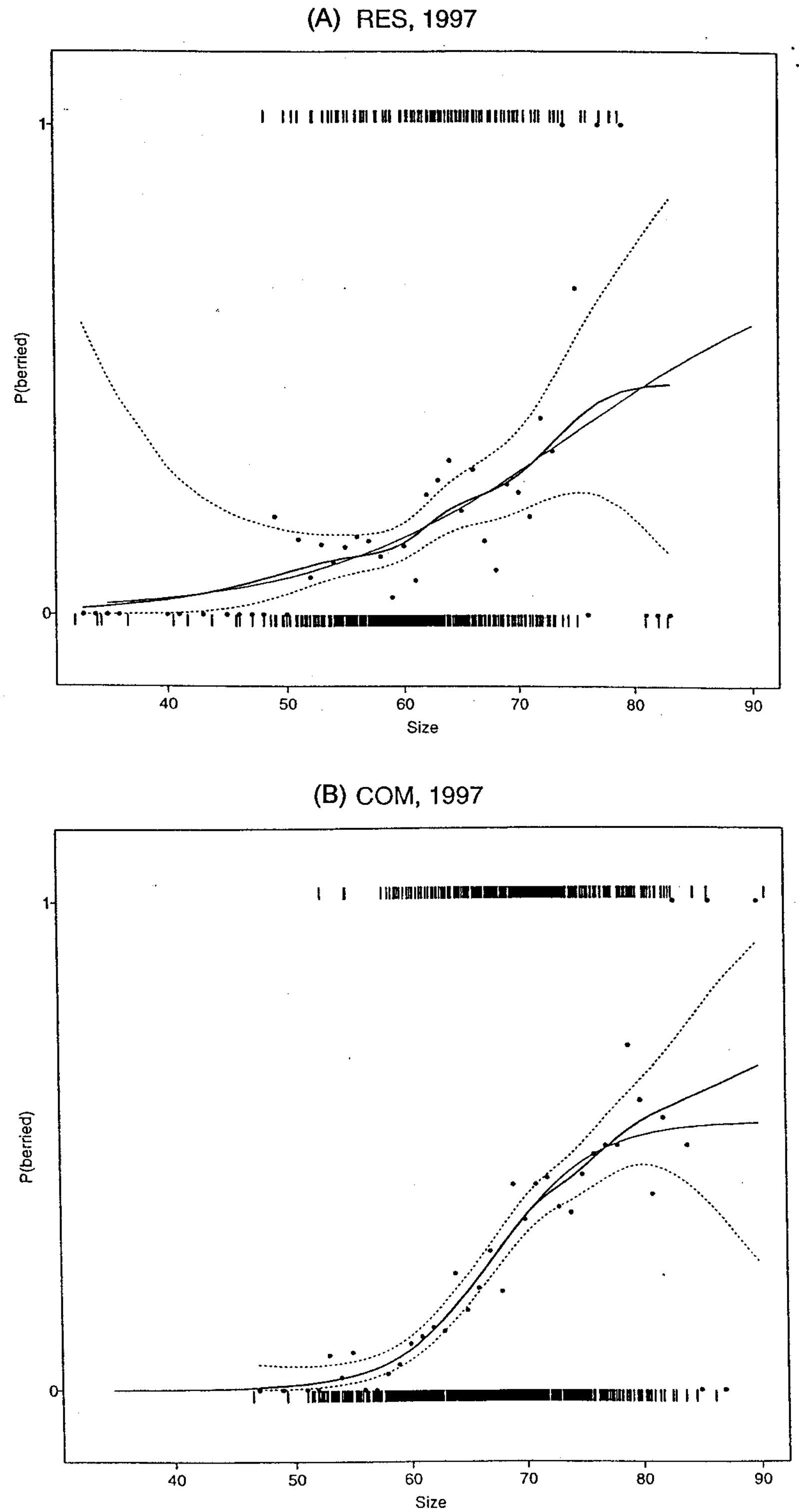

Figure 2.--GAMs and logistic models for (A) research data and (B) commercial data at Maro Reef in 1997. The GAM model, as the bold line enclosed by approximate 95% confidence bounds, was fit to binary data given by "rug" plots at P = 1 (berried) and P = 0 (not berried). The logistic model is the thin sigmoid line, fit to the data points of proportion berried.

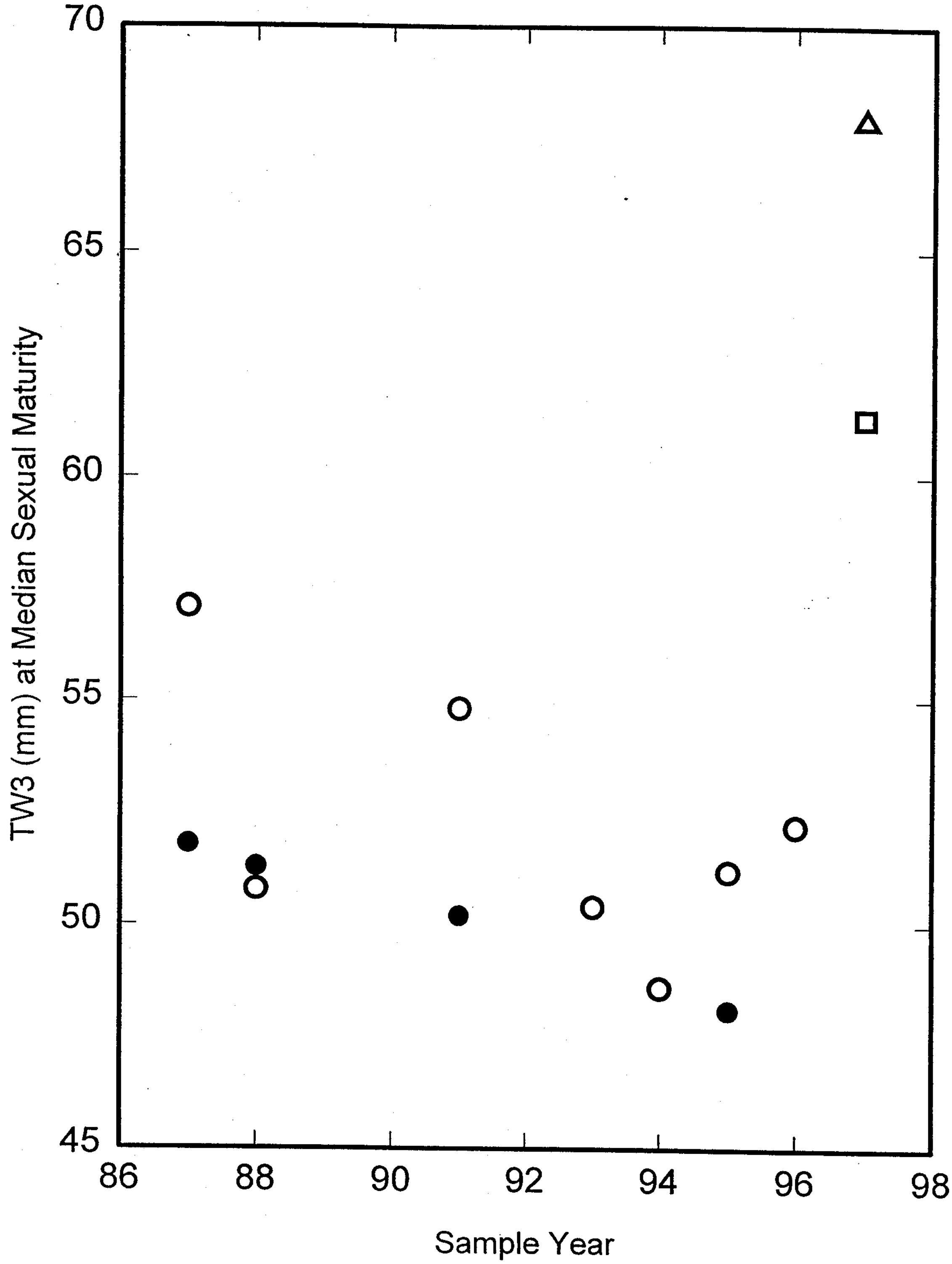

Figure 3.--Scatterplot of tail width at median sexual maturity for research samples at each bank (Maro Reef: hollow circles; Necker Island: solid circles) versus sample year during 1986-97. Median maturity ($TW3_{50}$, in mm) was estimated by the hyperbolic tangent model. For Maro Reef in 1997 only, commercial (hollow triangle) as well as research data (hollow square) are shown.