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COMPREHENSIVE (1986-2001) CHARACTERIZATION OF SIZE AT SEXUAL MATURITY FOR HAWAIIAN SPINY LOBSTER *(Panulirus marginatus)* AND SLIPPER LOBSTER *(Scyllarides squammosus)* IN THE NORTHWESTERN HAWAIIAN ISLANDS

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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ABSTRACT

Body size (tail width, TW) at which 50% of females attain functional sexual maturity (TW_{50}) is characterized for two species of lobsters historically important to the Northwestern Hawaiian Islands (NWHI) commercial trap fishery. Characterizations use an extensive time series of research catch data spanning 16 years (1986-2001). For one species, the slipper lobster (*Scyllarides squammosus*), of recent growing importance to the fishery at Maro bank, maturity was gauged by ovigerous (berried) condition of females. The TW_{50} of slipper lobster was estimated by fitting a 3-parameter logistic equation to percentage berried versus TW; TW_{50} was best described as 50.0 ± 0.83 (SE) mm for all survey-years pooled at Maro bank. For the other species, the endemic Hawaiian spiny lobster (*Panulirus marginatus*), the longstanding dominant targeted by the fishery at Necker bank, the maturation of females could be described based on presence of a spermatophoric (sperm) plate as well as berried condition. For spiny lobster, a more accurate estimate of TW_{50} was possible by fitting a 2-parameter logistic equation. Estimated TW_{50} of spiny lobster at Necker bank differed between the 1986-88 and 1990-2001 surveys and was best described as 38.1 ± 0.46 mm and 35.1 ± 0.15 mm for the two respective periods.

No prior published data on size at maturity exist for slipper lobster, and the estimate of median maturation size provided herein represents the first available as input to a stock assessment for slippers. Prior published estimates of body size at sexual maturity (based on percentage berried alone) exist for spiny lobster during pre-exploitation (1977-81) and peak-exploitation (1986-87) periods of the fishery. Our estimated TW_{50} of 40.9 mm for 1987 (based on a 3-parameter logistic fit to percentage berried) was indistinguishable from a previous estimate for 1987 (60.8 mm carapace length, equivalent to 41.4 mm TW), derived using a different fitting function (hyperbolic tangent). Our primary estimator of TW_{50} for spiny lobster using a 2-parameter fit to percentage mature, with maturation gauged on presence of a sperm plate if the female was not ovigerous, averaged 1.4 mm smaller than that based on percentage berried alone. We suggest that the latter, more accurate and precise, 2-parameter estimate be adopted as the best estimate available for input to contemporary stock assessments of Hawaiian spiny lobster.

INTRODUCTION

The commercial lobster trap fishery in the Northwestern Hawaiian Islands (NWHI) began in 1977 and targeted the Hawaiian spiny lobster (*Panulirus marginatus*) through the mid-1990s (Polovina, 2000), with landings and CPUE that declined fivefold during the late 1980s to early 1990s and that remained low during the mid- to late-1990s (DiNardo et al., 2002; DeMartini et al., 2003, in press). By the mid-1990s, the slipper lobster (*Scyllarides squammosus*) previously of secondary importance, was increasingly targeted and by 1998 contributed as much as 64% and 44% of the landed catch and ex-vessel value, respectively, of the total NWHI lobster catch (DeMartini and Williams, 2001). The fishery was closed in 2000 because of increasing uncertainties in the population models used to assess stock status.

Estimates of body size at sexual maturity provide key input to the management of sustainable capture fisheries wherever size-structured models are used to estimate allowable catch. In particular this is true for crustacean fisheries for which management guidelines often use estimates of size-specific egg production as a means of describing egg-per-recruit relationships. Lengthy time series of such data are needed to describe productivity cycles and other long-term patterns and distinguish these from short-term (e.g., interannual) variations, particularly for long-lived species.

Body size at sexual maturity of Hawaiian spiny lobster was previously estimated for two periods (1977-81, 1986-87) at the start and during the peak of the fishery (Polovina, 1989). More recent published estimates for the species do not exist. DeMartini and Kleiber[1] provided a preliminary description of size-at-maturity patterns for slipper lobster based on research and commercial catches from 1984 through 1997.

Our objectives in this paper are to estimate body size at sexual maturity for Hawaiian spiny lobster and slipper lobster using all available fishery-independent research catch data from 1986 through 2001. Estimates are partitioned by year and series of consecutive years (as sample sizes allow). Estimates of the body size (tail width, TW) at which 50% of the females in the population were mature (TW_{50}) are based on one (slipper lobster) or two (spiny) gross external morphological features (described in the Methods) that were consistently scored during the entire 16-yr series of surveys. More efficient morphometric descriptors of sexual maturity (pleopod metrics) have been developed for slippers; unfortunately, data are available for only 1997-2001 (DeMartini et al.)[2], cannot be extrapolated to the majority of years in the time series and are not considered herein.

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[1]DeMartini, E. E., and P. Kleiber. 1998. Estimated body size at sexual maturity of slipper lobster *Scyllarides squammosus* at Maro Reef and Necker Island (Northwestern Hawaiian Islands), 1986-97. Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Southwest Fish. Sci. Cent. Admin. Rep. H-98-02, May 1998, 14 p.

[2]DeMartini, E. E., M. L. McCracken, and R. B. Moffitt. Unpubl. ms. Relative pleopod length as estimator of size at sexual maturity in two lobsters (*Panulirus marginatus*, *Scyllarides squammosus*): validation and comparison with other methods. Mar. Ecol. Prog. Ser.

METHODS AND MATERIALS

All specimens of spiny lobster used in this study were trapped by research ship from Necker bank surrounding Necker Island (23°34'N, 164°42'W), NWHI. All slipper lobsters were similarly trapped from Maro bank, located about 600 km northwest of Necker at 25°25'N, 170°35'W. All specimens used in this study were collected mid-spring to mid-summer, primarily in June and July (May: 1994; May-June: 1988; June: 1992-93, 1999; June-July: 1990, 1995-98, 2000, 2001; July: 1987, 1991; July-August: 1986). Maro and Necker banks were the targeted focus of the NWHI commercial trap fishery for *S. squammosus* and *P. marginatus*, respectively, prior to closure of the fishery in 2000. Lobsters used in this study were trapped from bank terraces at median depths of 15 fm (slippers, Maro) and 17 fm (spinys, Necker) using molded plastic (Fathom Plus®) traps baited with 1 kg of mackerel (*Scomber japonicus*), fished with a standard (overnight) soak.

Shipboard Processing

All specimens were processed alive within minutes of trap retrieval. Tail width (TW) and/or carapace length (CL), each as defined by DeMartini et al. (2003, in press), were measured for most specimens. Berried (ovigerous) females were noted and scored for egg developmental stage using a gross visual proxy (brooded eggs noted as either orange or brown to the unaided eye). Female spiny lobsters were also scored for presence/absence and condition ("smooth" = unused, "rough" = partly used) of a spermatophoric (sperm) plate; female slipper lobster in almost all cases lacked a sperm plate. Starting in 1997, various measures of pleopod size (length, width) were measured for both species aboard ship and in the laboratory to evaluate whether pleopod size might provide an accurate morphological proxy for maturity. Exopodites on first left pleopods have been routinely measured aboard ship for representative samples of live berried and unberried females of each species since 2000 (DeMartini et al.)[2].

Statistical Analyses

Maturity was related to the TW metric; TW for specimens lacking that datum was estimated from the CL datum for that specimen using the TW-to-CL relationship described for spiny lobster by DeMartini et al. (2003, in press) and for slipper lobster by DeMartini and Kleiber[1]. Body size at sexual maturity was characterized based on estimates of the TW (hereafter referred to as TW_{50}) at which 50% of females were functionally mature (DeMartini et al.)[2]. Specimens were partitioned by 1-mm TW size class, and the percentage mature per class was fit to one of two forms of logistic equation. The conventional 2-parameter logistic equation was used for spiny lobster because data on presence/absence of a sperm plate on the sternum of females could be used to complement information on ovigerous condition when scoring individuals for maturity. The 2-parameter model we used was:

$$P = 100/\{1 + \exp[-a(TW-b)]\},$$

where P = percentage mature, *a* and *b* are constants, and TW is tail width in mm. A 3-parameter logistic equation (DeMartini and Kleiber)[1] was necessary to estimate size at maturity of slipper lobster. Our inability to distinguish immatures from mature but unberried females introduced a large proportion of artifactual "indeterminates" whose presence prevented standardization to 100% mature without the use of a third parameter. The 3-parameter model we used was

$$P = 100a / \{1 + \exp[(4b/a)(c - TW_{50})]\},$$

where *a* is the asymptotic proportion berried, *b* is the slope of the logistic function at the inflection point, and TW_{50} is the tail width at the inflection point (size at 50% of asymptote). For comparison with results of the 2-parameter fit for spiny lobster, the 3-parameter model also was fit to the percentage berried data for spinys. Parameters of the various models (and their asymptotic SEs) were estimated using the maximum-likelihood nonlinear curve fitting procedure proc NLIN of PC SAS for Windows v. 8 (SAS Institute Inc., 1999). All nonlinear regressions were weighted by the square root of sample sizes.

TW_{50} was estimated by survey-year. Possible differences among survey-year estimates were evaluated by comparisons of the residual sums of squares (RSS; of the above-described 2- and 3-parameter logistic equations) for the sum of all 15 individual years and for all 15 years pooled. The specific hypothesis tested was whether the RSS summed over all individual years was different (by *F*-test) than the RSS for all years pooled, which would be expected if the estimate for one or more years differed from the others.

RESULTS

Size and Sex Composition of Catches

Using data collected during 15 trapping surveys spanning 16 years (no survey was conducted in 1989) from 1986 to 2001, inclusive, measurements of 43,244 spiny lobsters and 21,711 slipper lobsters were available for evaluation of size and sex composition. The contribution of females to total trap catches averaged 46.4% and 40.2% for spiny and slipper lobsters, respectively (Table 1a,b). Female and male spiny lobster exhibited similar size distributions for samples pooled over the entire survey period; body size distributions differed between the sexes for slipper lobster, however (Kolmogorov-Smirnov 2-sample test, $P \ll 0.001$), with females averaging 5 mm greater TW than males (Fig. 1). Overall estimates of percentage berried were 32.9% for spinys and 33.7% for slippers (Table 1a,b).

Body Size at Sexual Maturity

Spiny lobster

Overall 91.6% of all female spinys were classified as mature based on either the presence of a sperm plate (either unused or any degree of use) or berried condition (eggs of any developmental stage). Nearly 90% of all berried females had a sperm plate and about one-third of those with a sperm plate were berried. Estimates of TW_{50} based on the 2-parameter model differed among survey years, with a suggestion of generally smaller median sizes at maturity beginning in 1990 ($F_{28,659} = 1.40$; $P = 0.1$; Fig. 2A). Pooling within series of years, TW_{50} was 38.1 ± 0.46 (SE) mm during 1986-88 ($r^2 = 0.85$) and 35.1 ± 0.15 mm during 1990-2001 ($r^2 = 0.98$; Fig.2A). There was a weak ($r^2 = 0.27$; $P = 0.08$) indication of an increasing trend in size at maturity over the 1990-2001 time period, consistent with a pattern of increasing minimum size of berried females during the same period ($0.47\ \text{mm} \cdot \text{yr}^{-1}$ from about 33 mm in 1990 to 37.5 mm in 2001; $r^2 = 0.59$; $P = 0.004$). If, for heuristic reasons, the data for all 15 years are pooled, the TW_{50} estimate becomes 35.4 ± 0.19 mm ($r^2 = 0.97$; Fig. 3). If the 3-parameter model is used to fit percentage berried versus TW as a gross proxy for maturity using the same specimens, TW_{50} was 39.5 ± 1.15 mm and 36.4 ± 0.61 mm, respectively, for the two time periods and 36.8 ± 0.62 mm ($r^2 = 0.76$; Fig. 3) for the entire time series.

Slipper lobster

For this species only 7 of 8,728 females (< 0.1%) carried a sperm plate. Using percentage berried (eggs of any stage) as the maturity metric, estimates of TW_{50} differed among 12 testable survey-years ($F_{33,434} = 8.33$; $P < 0.001$) but without monotone temporal trend ($P = 0.69$; Fig. 2B). To provide a working estimate for stock assessment, estimates were pooled over years: TW_{50} averaged 50.0 ± 0.83 mm for the 15 survey-years pooled ($r^2 = 0.78$; Fig. 4).

DISCUSSION

Sex, Size, and Maturity Composition

Males numerically dominated the research trap catches of both species; only slipper lobster differed between the sexes in the size composition of trap catches. The size and sex composition of trap catches might not represent those in the natural population, however. Possible reasons trap catch and population parameters might differ include trap selectivity, particularly if the sexes differ in size composition. Sexual differences in the size composition of catches can result from sexually dimorphic growth or mortality schedules. No data on age and growth are available for slipper lobster, so sexual differences in growth rate, longevity, or both cannot be evaluated as the cause(s) of the observed sexual differences in size composition. We do not know whether the unequal proportions of male and female slipper lobsters in research trap catches reflect trap selectivity or population sex structure, but we caution that if size selectivity is influencing our estimates of TW_{50} it is likely more important for slipper than for spiny lobster. Comparisons between commercial and research catch data collected in 1997 (DeMartini and Kleiber)[1], for which TW_{50}s differed by over half a centimeter, exemplify the potential influence of size structure on TW_{50} estimates for slippers.

Size at Sexual Maturity

Spiny lobster

The general pattern for spinys is a smaller body size at sexual maturity consistent with reduced lobster densities under heavy exploitation. Our overall TW_{50} estimates (2-parameter model) for 1986-88 and 1990-2001 comprised survey estimates that ranged from 32.8 to 39.7 mm. All of the latter are smaller than Polovina's (1989) estimated size at "onset of sexual maturity" of 60.8 mm carapace length (CL; equivalent to TW = 41.4) for spinys at Necker in 1987 (the only exploitative phase year analyzed in both his and our paper), which in turn is significantly smaller than his estimate of CL = 67.8 mm (TW = 45.7 mm) for spinys at Necker prior to exploitation in1977. Polovina's 41.4 mm TW estimate for 1987 is indistinguishable from our estimate for 1987 (40.9 ± 1.10 mm TW) based on a different fitting function (3-parameter logistic) for the same series of specimens. (Our 3-parameter logistic estimates and Polovina's (1989) estimates based on a hyberbolic tangent model both used percentage berried as the sole maturity criterion.) Our 2-parameter estimates for 1990-2001 are significantly smaller than estimates for the period from 1986 to 1988, regardless of model. This suggests that the compensatory decrease in size at maturity of spinys induced by early heavy exploitation (Polovina, 1989) in fact ratcheted further downward in the early 1990s and has persisted at lower (but increasing) values throughout the period of heavy exploitation and lower oceanic productivity that followed until the fishery was closed in 2000.

Our primary (2-parameter) model estimate for spinys used additional important information on the presence of a sperm plate and hence is more accurate than the 3-parameter model. As first suggested by DeMartini and Kleiber[1] for slipper lobster, using percentage berried as the sole indicator of sexual maturity inflates the error variance by combining unberried but mature females with immature females. SEs of TW_{50} illustrated in Figure 2 indicate that the 2-parameter model is also more precise than the 3-parameter model for spiny lobster. We therefore believe that our TW_{50} estimate of 35.1 ± 0.15 mm for 1990-2001, based on both sperm plate and berried condition, is the best current reference point for the maturity of spiny lobster at Necker bank.

Slipper lobster

The 50.0 mm estimate of TW_{50}, although acceptably precise (SE = 0.83 mm) when data are pooled over all survey-years, is obviously imprecise for many of the component yearly surveys. During two of the 15 surveys (1986, 1997), SEs exceeded 15% of the estimate and the data for another two surveys (1987, 1996) were inadequate for generating a year-specific size-at-maturity estimate. Clearly, the number of female slippers available for a size-at-maturity characterization, based on the effort and expected average catch of a single research survey, is at best marginally adequate when deducing maturity based on berried condition alone. A direct measure of functional maturity is needed for slipper lobster. A more precise and direct maturity metric has been developed for *S. squammosus* and is described in a companion paper (DeMartini et al.)[2].

ACKNOWLEDGMENTS

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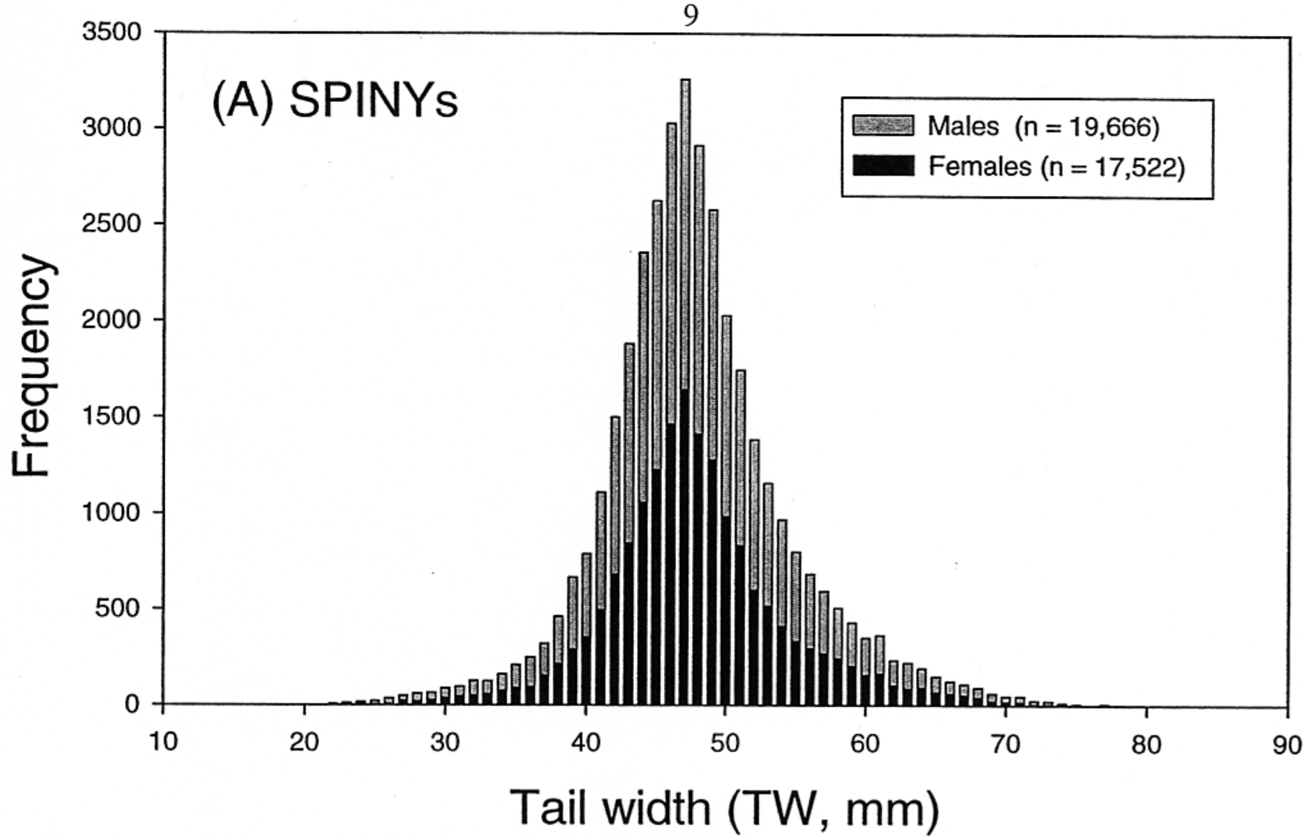
Table 1.--Summary catch statistics for lobster trapped on each research cruise conducted during the period from 1986 through 2001, for (A) Hawaiian spiny lobster (*Panulirus marginatus*) at Necker bank and (B) slipper lobster (*Scyllarides squammosus*) at Maro bank.

(A) Spiny lobster

Year	N (% of total) females	N (% of females) berried	Median (range of) TW (mm) of all females	Median (range of) TW of berried females
1986	1,098 (43.5)	424 (38.6)	47.5 (30.5-80.5)	47.2 (38.0-70.5)
1987	834 (36.0)	271 (32.5)	48.7 (22.4-69.0)	48.7 (36.9-69.0)
1988	1,759 (43.5)	296 (16.8)	47.4 (30.3-76.6)	47.2 (38.5-69.8)
1989	no data	no data	no data	no data
1990	1,249 (43.8)	356 (28.5)	46.5 (24.2-79.7)	46.4 (33.8-69.8)
1991	1,380 (46.8)	563 (40.8)	44.1 (18.7-65.3)	44.4 (30.3-64.8)
1992	1,162 (48.9)	335 (28.8)	45.9 (14.1-84.0)	46.4 (33.9-67.2)
1993	1,708 (50.1)	489 (28.6)	45.6 (22.1-72.7)	45.8 (35.5-72.7)
1994	1,247 (45.1)	360 (28.9)	47.6 (22.0-73.6)	48.7 (36.9-66.5)
1995	1,165 (50.3)	342 (29.4)	46.7 (20.0-71.7)	47.2 (33.8-71.7)
1996	1,151 (47.3)	409 (35.5)	47.6 (24.7-73.0)	48.1 (35.7-68.3)
1997	1,093 (48.7)	421 (38.5)	49.4 (28.4-75.3)	50.2 (36.9-75.3)
1998	917 (57.4)	436 (47.5)	49.2 (28.1-73.1)	49.9 (37.0-72.9)
1999	834 (54.5)	347 (41.7)	50.1 (24.0-72.5)	51.1 (37.8-72.5)
2000	1,114 (48.8)	415 (37.3)	50.3 (21.5-79.6)	51.2 (35.9-71.9)
2001	811 (52.4)	293 (36.1)	50.9 (31.3-73.0)	50.5 (38.2-68.6)
All	17,522 (46.4)	5,757 (32.9)	47.6 (14.1-84.0)	47.8 (30.3-75.3)

(B) Slipper lobster

Year	N (% of total) females	N (% of females) berried	Median (range of) TW of all females	Median (range of) TW of berried females
1986	259 (64.1)	28 (10.8)	64.3 (43.8-81.3)	65.3 (55.3-76.6)
1987	276 (44.9)	68 (24.6)	60.6 (42.9-78.8)	64.8 (43.3-78.0)
1988	272 (34.5)	94 (34.6)	59.1 (43.2-80.4)	60.8 (48.5-76.5)
1989	no data	no data	no data	no data
1990	220 (48.9)	107 (48.6)	62.2 (43.2-77.1)	64.7 (50.9-77.1)
1991	293 (39.6)	86 (29.4)	60.8 (28.4-79.6)	64.1 (42.3-78.1)
1992	512 (40.1)	224 (43.8)	61.7 (39.1-78.6)	61.7 (39.1-76.1)
1993	608 (41.9)	158 (26.0)	58.2 (27.6-76.5)	58.8 (47.1-76.5)
1994	442 (37.3)	310 (70.1)	59.6 (28.7-78.4)	60.0 (48.3-78.4)
1995	503 (41.6)	231 (45.9)	59.8 (30.8-79.6)	60.6 (47.1-79.6)
1996	585 (44.2)	119 (20.3)	61.3 (33.5-79.0)	62.1 (47.9-79.0)
1997	735 (39.6)	128 (17.4)	60.4 (33.2-83.0)	62.9 (49.2-79.0)
1998	1,052 (40.7)	284 (27.0)	65.5 (37.7-85.0)	67.4 (52.4-84.7)
1999	1,058 (43.3)	315 (29.8)	63.5 (42.0-84.2)	65.1 (52.7-80.0)
2000	847 (34.5)	295 (34.8)	61.8 (25.9-80.2)	63.1 (45.0-78.7)
2001	1,066 (36.3)	491 (46.1)	62.1 (33.0-82.2)	63.3 (48.2-81.2)
All	8,728 (40.2)	2,938 (33.7)	61.9 (25.9-85.0)	62.9 (39.1-84.7)



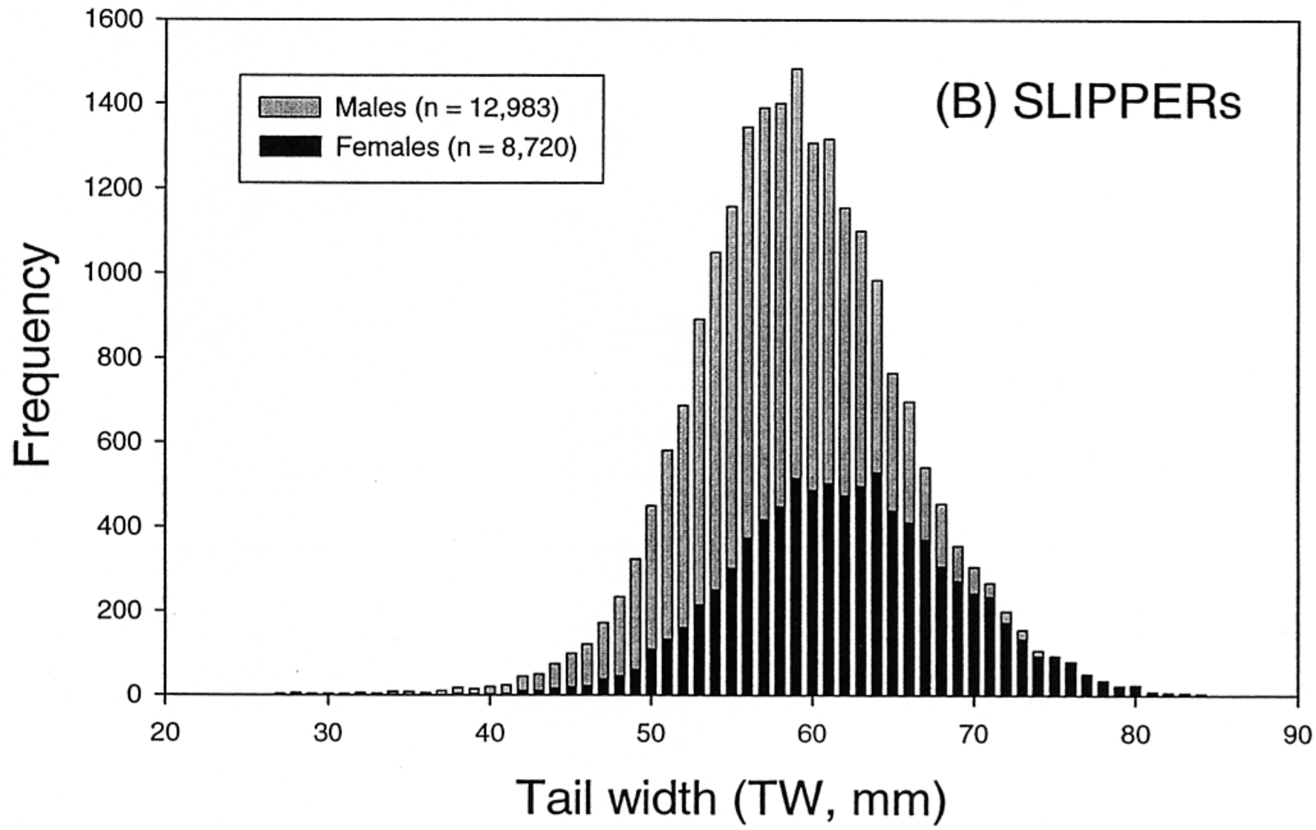


Figure 1.--Histogram frequency distributions of females and males (overlaid on females) of (A) Hawaiian spiny lobster (*Panulirus marginatus*) and (B) slipper lobster (*Scyllarides squammosus*) caught on once-yearly research cruises during the 15-year period (1986-2001) pooled.

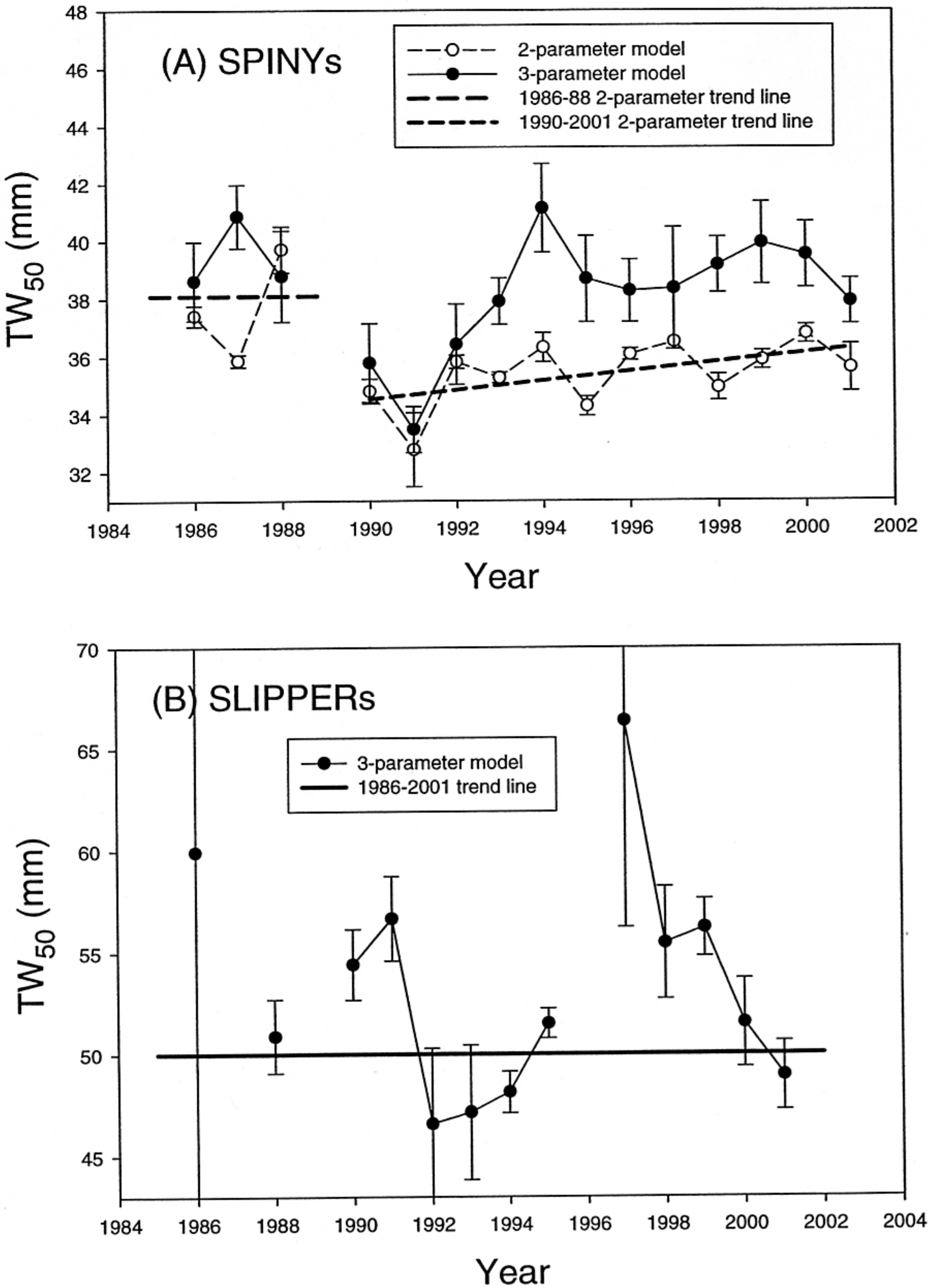


Figure 2.--Scatterplot and fitted trend line for survey-year estimates of the tail width at which 50% of all females were sexually mature (TW_{50}) during the period from 1986 to 2001, for (A) Hawaiian spiny lobster (*Panulirus marginatus*) (estimates based on 3- and 2-parameter logistic functions plotted separately) and (B) slipper lobster (*Scyllarides squammosus*) (3-parameter logistic only). Vertical lines indicate ± 1 SE of the survey-year-specific TW_{50} estimate. Bold lines indicate means of (spiny, 1986-88; slipper, 1986-2001) or trends in (spiny, 1990-2001) TW_{50} estimates.

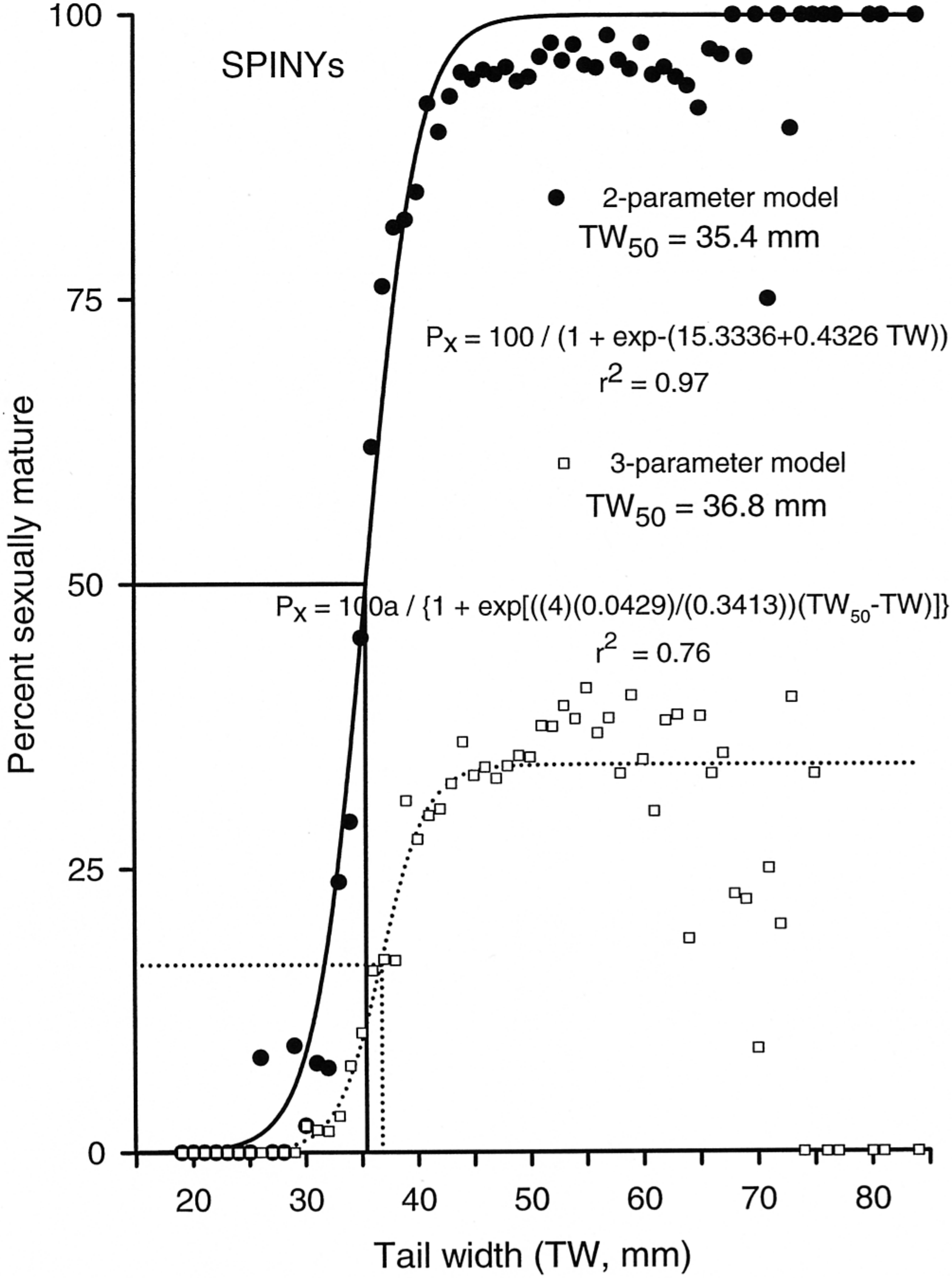


Figure 3.--Spiny lobster (*Panulirus marginatus*): Tail width at which 50% of all females in pooled (1986-2001) research trap catches were sexually mature (TW_{50}) based on fitting a 2-parameter logistic model to percentage mature in 1-mm TW classes. A 3-parameter logistic fit, based on percentage ovigerous (berried) only, is provided as an inset for comparison.

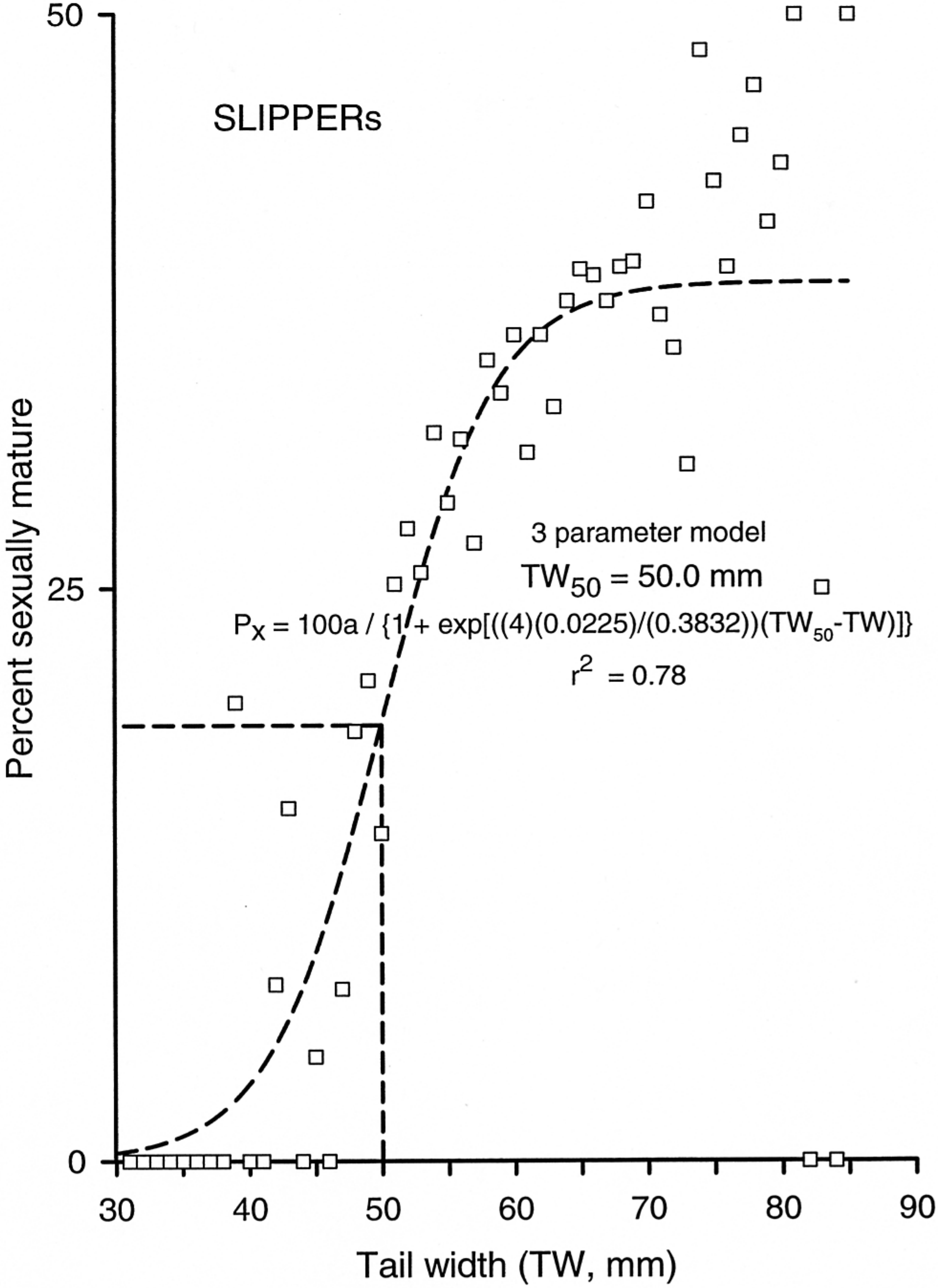


Figure 4.--Slipper lobster (*Scyllarides squammosus*): Tail width at which 50% of all females in pooled (1986-2001) research trap catches were sexually mature (TW_{50}), based on fitting a 3-parameter logistic model to percentage berried in 1-mm TW classes.

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