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Some Preliminary Findings on the Nutritional Status of the Hawaiian Spiny Lobster (*Panulirus marginatus*)[1]

FRANK A. PARRISH[2] AND THERESA L. MARTINELLI-LIEDTKE[3]

ABSTRACT: Data on the nutritional status of spiny lobster (*Panulirus marginatus*) were collected on the commercial trapping grounds of Necker Bank, Northwestern Hawaiian Islands, in the summers of 1991, 1994, and 1995. Glycogen levels measured in abdominal tissue of intermolt males were used as an index of nutritional health of the field population. The range of glycogen sampled from wild lobster was less than half the level measured in captive lobster fed to satiation in a previous study. An analysis of covariance identified significant interannual and spatial effects explaining 46% of the variance in the sample of wild lobsters. Most significant was a decline in lobster glycogen levels between samples collected in 1991 and 1994–1995. Seasonal influences on lobster nutrition are unknown and were identified as an obvious direction for future ecological research.

NUTRITIONAL CONDITION OF lobster, as assessed in the field, could be a valuable tool to provide insight to physiological response of lobster to environmental constraints. The nutritional status of palinurids in the wild has been little studied (Kanciruk 1980). Studies of lobster nutrition have centered on needs associated with rearing and aquaculture (Kanazawa 1994). Only recently have laboratory trials of nutritional indices been applied to address ecological issues (Moss 1994, Robertson et al. 1996). The work reported here used an index of lobster nutritional status on a managed field population to provide some preliminary data on field nutrition and to discuss it in relation to a period of population growth.

A number of nutritional indices were evaluated by Martinelli (1993) using *Panulirus marginatus* in controlled, replicated, month-long laboratory trials. The concentration of glycogen in abdominal muscle was found to be the best index of nutritional status tested for this species (Figure 1). Tests of within-lobster variability indicated that a single sample per lobster was adequate for analysis (Martinelli 1993). The positive linear relationship between recency of feeding and lobster glycogen concentration provided a relational indicator that could be used to document spatial or temporal variation in the nutritional status of field populations.

Blood glucose concentration is controlled by homeostatic mechanisms in many decapod species (Heath and Barnes 1970, Dall 1974). Glucose is held in reserve deposits as glycogen that can be depleted during periods of reduced food consumption to maintain blood glucose concentrations near normal levels. Although the digestive gland is considered the main organ for storage of nutritional reserves in decapods, its importance as a storage organ relative to muscle tissue is variable among species (Armitage et al. 1972, Dall 1981, Barclay et al. 1983, Whyte et al. 1986). When *P. marginatus* is nutritionally stressed, it catabolizes abdominal muscle glycogen reserves (Martinelli 1993). Storage of glycogen in abdominal muscle, like most physiological processes in lobster, is influenced by molt stage (Heath and Barnes 1970).

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[2] Honolulu Laboratory, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, Hawai'i 96822-2396.

[3] U.S. Geological Survey, Biological Resources Division, Columbia River Research Laboratory, 5501A Cook-Underwood Road, Cook, Washington 98605.

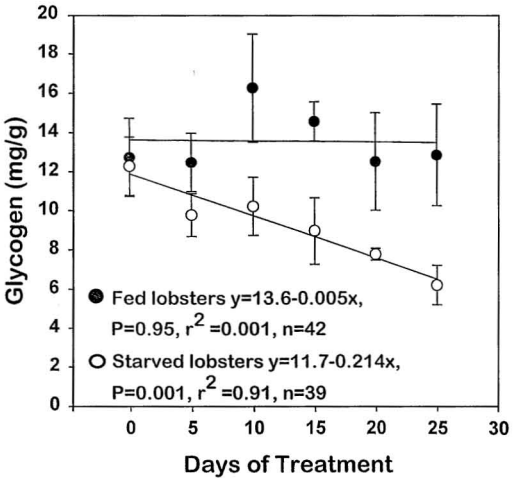

FIGURE 1. Laboratory trials of lobster glycogen concentration plotted relative to days of treatment. Each data point represents multiple lobster (mean = 7, maximum = 9). Filled circles are lobster fed daily and open circles are lobster starved. Confidence intervals (95%) are included for both treatments. A consistent and significant decline is measurable using the glycogen assay to assess starved lobsters. (Source: Martinelli 1993)

The commercial stock of *P. marginatus* occurs in the remote Northwestern Hawaiian Islands (NWHI) and has been fished exclusively by commercial vessels beginning in the early 1970s. Consequently, all fishery effort is documented. In 1991, catch per unit of effort (CPUE) dropped to roughly half the level used to designate optimum sustainable yield (i.e., one lobster per trap), prompting temporary closure of the fishery. Since then, fishing has been restricted by quota and season to permit the stock to recover (Haight and DiNardo 1995). All glycogen sampling occurred during the period of stock recovery. Sampling during a period of increasing population density provided an opportunity to look for an expected density-dependent decline in lobster condition using the glycogen index.

MATERIALS AND METHODS

Lobster were collected as part of the National Marine Fisheries Service (NMFS) Honolulu Laboratory's (HL) lobster assessment cruises. The annual cruise revisits established stations in the NWHI and conducts standardized trap fishing. The annual assessment was conducted just before the commercial season, which was open July–December. This ensured that lobster sampled had not been previously disturbed by the baiting and trapping activities of other fishing vessels. In this paper we make temporal and spatial comparisons of lobsters from the assessment stations of Necker Bank (Figure 2). Stations were selected to represent the range in types of bottom habitat that had been documented in previous surveys (Parrish and Polovina 1994).

Lobster glycogen concentrations were sampled at stations A and B in July 1991, May 1994, and June 1995. For the 1994 and 1995 collections, two additional stations (C and D) were included. At each station, the glycogen levels of at least 25 male lobster representing the size range of the catch were tested. To avoid potential influence of molt stage on glycogen level (Lipcius and Herrnkind 1982), the molt stage of the males was determined using Lyle and MacDonald's (1983) technique to ensure that only lobsters in intermolt were included in the analysis. A sample of abdominal muscle tissue was extracted from each lobster and analyzed for glycogen content (Martinelli 1993). Females were excluded from all analyses to remove any possible effects on nutrition associated with egg production (Herrnkind 1980).

Standard analysis of covariance (ANCOVA) was used with the glycogen data to assess interannual and spatial effects and effects of lobster size. Because of the unbalanced design associated with absence of samples for stations C and D in 1991, the ANCOVA was rerun excluding the 1991 data.

RESULTS

Eleven of the collected lobster were excluded from analysis because they were in premolt condition. Lobster carapace length ranged between 39 and 110 mm. Plotting the size frequency of lobster measurements indicated that distributions were similar for all

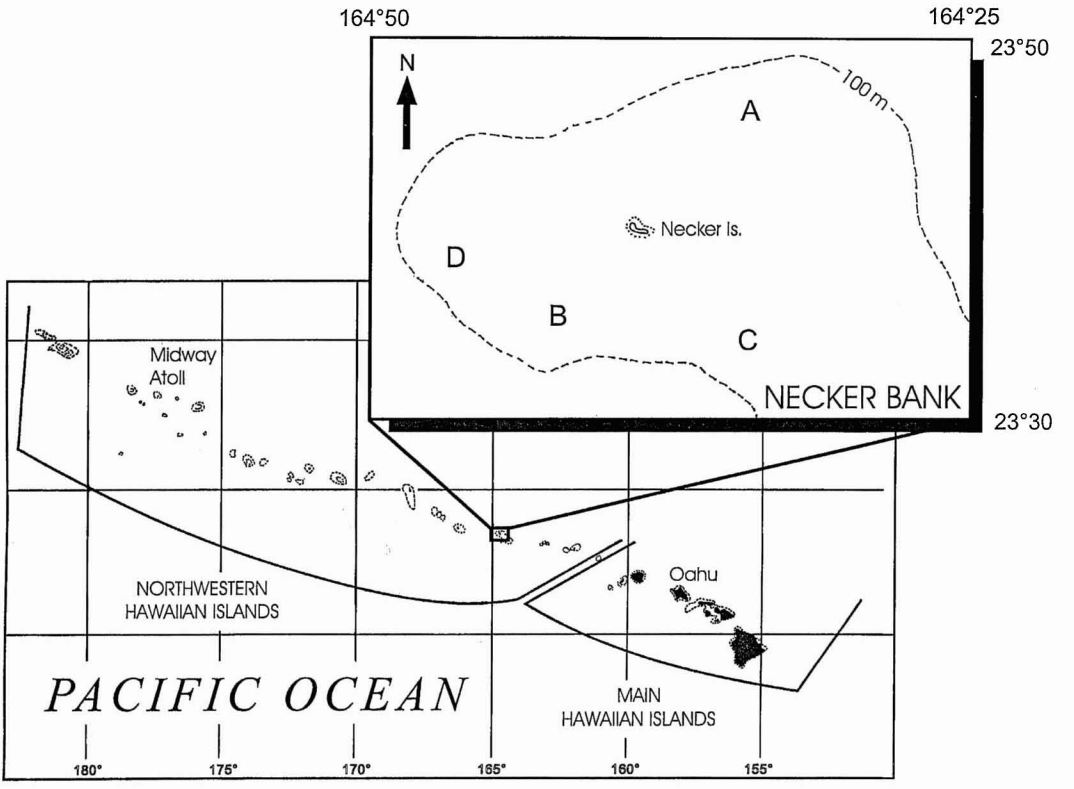

FIGURE 2. Hawaiian Archipelago with an inset of Necker Bank indicating the locations of the four trapping stations.

samples except one (mean CL 8 cm) (Figure 3). The exception was the 1991 sample at station A, which provided smaller lobsters (mean CL 4.5 cm). The ANCOVA identified significant temporal and spatial effects explaining 46% of the sample variance (Table 1). No size-specific differences were identified. Lobsters collected in July 1991 had significantly better nutritional condition (higher glycogen) than the samples of May 1994 and June 1995 (Duncan multiple range test, $P < 0.01$, df = 279). An a posteriori test of spatial effects grouped two stations (A and D) as having lobster in significantly better condition than at the other two stations (Duncan multiple range test, $P < 0.01$, df = 279). The 1991 data were then removed to

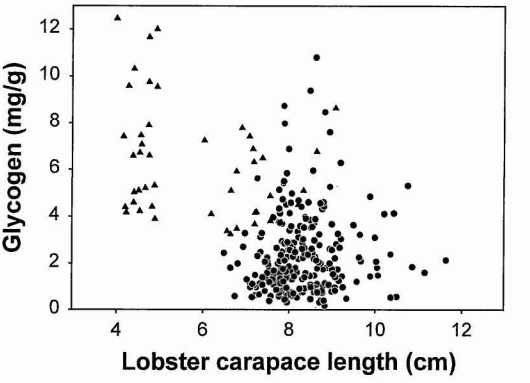

FIGURE 3. Plot of glycogen levels versus carapace length of each lobster sampled. Samples collected in 1991 are indicated with triangles. Circles indicate samples collected during 1994 and 1995.

TABLE 1

ANCOVA TABLE OF LOBSTER GLYCOGEN LEVELS RELATIVE TO LOBSTER SIZE, YEAR OF COLLECTION, AND STATION

VARIABLE	SS	df	MS	*F* STATISTIC	*P* VALUE
Size	0.00018	1	0.0001	0.00	0.99
Year	349.4	2	174.7	59	0.0001
Station	125.8	3	41.9	14.1	0.0001

balance the sampling design and fully focus the analysis on the spatial effects. Without the 1991 data, significance for station A disappeared, and data from station A were lumped with those from stations B and C in overlapping classifications (Duncan multiple range test, $P < 0.01$, $df = 235$). Station D alone was identified as having lobsters in significantly better condition. Even with the 1991 data excluded, weak interannual effects persisted ($P = 0.052$, $F = 3.82$, $R^2 = 0.16$, $df = 1$).

DISCUSSION

The nutritional condition of a lobster is in part dependent on its foraging success. Lobsters foraging in the wild feed as they encounter and capture food. The amount of food, as well as the time between feeding events, varies with local resources and lobster activity. Assessing glycogen concentration permits comparison of relative nutritional states between groups of lobster. The mean glycogen concentrations reported from field animals at Necker ranged from 1.3 to 5.3 mg/g. As expected, this range is considerably lower than the glycogen values of captive lobster, which were fed daily. Lobster fed to satiation had an overall mean glycogen concentration of 12.7 mg/g (Figure 1), and even the lobsters that were starved for 21 days (after being fed to satiation) had higher glycogen values (mean = 6.2 mg/g) than those of field lobsters.

Effect of lobster size was nonsignificant and excluded from the analysis. However, the sampling design was not structured to evaluate size, so the potential influence of size in future nutritional studies should not be dismissed. Size was included in this analysis as a precautionary measure only.

The reason for the significant drop in glycogen levels between 1991 and 1994–1995 is unknown. The change coincides with the closure of the fishery and regrowth of the stock (Haight and DiNardo 1995). The stock recovery leveled in 1994 and 1995 and the fishery continues to be exploited near optimum sustainable yield (e.g., CPUE of 1.0) maintaining a constant population density (DiNardo et al. 1998). The drop in glycogen values from 1991 to 1994–1995 is consistent with a reduction in available resources (e.g., food and shelter) associated with increasing lobster density resulting from the stock recovery. This interpretation parallels findings of other researchers who identified density-dependent responses during declines in the Hawaiian lobster stock (Polovina 1989, DeMartini et al. 1992).

Spatial effects were minor but did persist between years, suggesting that station-specific influences on lobster condition could be present. Different habitats are likely to afford different levels of forage and/or shelter resources. Previous research at Necker Bank linked lobster catch rates with variable scales of habitat relief (Parrish and Polovina 1994). Perhaps greater availability of shelter improves access to forage and results in higher glycogen levels. Enhanced growth in response to improved shelter has been identified by researchers working on other lobster species (Newman and Pollock 1974, Eggleston and Lipcius 1992).

Influences of life history and ecology on lobster glycogen levels should be fully investigated. Because of the logistical constraints on sampling in this study, the observed temporal variability could actually relate more to cyclic seasonal effects than to interannual changes (Dow 1969). Data for our study were collected spanning six summer weeks

(late May to mid-July), which may represent different physiological stages of the lobster. For example, the samples with the highest glycogen levels (1991) were collected latest in the season (mid-July), which may have contributed to their high glycogen values. It is possible that lobster glycogen levels are related to the length of time the lobster have fed on high summer benthic productivity (Doty 1971, Glenn et al. 1990, Martin-Smith 1992). In summer months catch rates improve (Polovina et al. 1995), but it is unknown whether this results from an increase in lobster activity or is caused by calmer weather improving trap catchability (Morgan 1974). For captive *P. japonicus,* a species closely related to *P. marginatus,* Nakamura and Kuramoto (1992) found that the heart rate doubled in summer months and varied in relation to temperature. Peak spawning season for lobster in the Hawaiian Archipelago varies with the latitude of the population, suggesting that lobster may be influenced by environmental cues such as temperature or photic period (McGinnis 1972, MacDonald and Thompson 1987, Polovina and Moffitt 1995). Further work is needed to determine and calibrate the source of glycogen variability in wild lobster. Future ecological research should first focus on detecting any changes in lobster nutrition in relation to season.

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LITERATURE CITED

ARMITAGE, K. B., A. L. BUKEMAN, and N. J. WILLEMS. 1972. Organic constituents in the annual cycle of the crayfish *Orconectes nais*. Comp. Biochem. Physiol. A Comp. Physiol. 41 : 825–842.

BARCLAY, M. C., W. DALL, and D. M. SMITH. 1983. Changes in lipid and protein during starvation and the molting cycle in the tiger prawn, *Penaeus esculentus* Haswell. J. Exp. Mar. Biol. Ecol. 68 : 229–244.

DALL, W. 1974. Indices of nutritional state in the western rock lobster, *Panulirus longipes* (Milne Edwards). I. Blood and tissue constituents and water content. J. Exp. Mar. Biol. Ecol. 16 : 167–180.

———. 1981. Lipid absorption and utilization in the Norwegian lobster, *Nephrops norvegicus* (L.). J. Exp. Mar. Biol. Ecol. 50 : 33–45.

DEMARTINI, E. E., D. M. ELLIS, and V. A. HONDA. 1992. Comparison of spiny lobster *Panulirus marginatus* fecundity, egg size, and spawning frequency before and after exploitation. Fish. Bull. 91 : 1–7.

DINARDO, G. T., W. R. HAIGHT, and J. A. WETHERALL. 1998. Status of lobster stocks in the Northwestern Hawaiian Islands, 1995–97, and outlook for 1998. Honolulu Laboratory, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Honolulu, Hawai'i. Southwest Fisheries Science Center Administrative Report. 35 pp.

DOTY, M. S. 1971. Antecedent event influence on benthic marine algal standing crops in Hawaii. J. Exp. Mar. Biol. Ecol. 6 : 161–166.

DOW, R. L. 1969. Cyclic and geographic trends in seawater temperature and abundance of American lobster. Science (Washington, D.C.) 164 : 1060–1063.

EGGLESTON, D. B., and R. N. LIPCIUS. 1992. Shelter selection by spiny lobster under variable predation risk, social conditions, and shelter size. Ecology 73 : 992–1011.

GLENN, E. P., C. M. SMITH, and M. S. DOTY. 1990. Influence of antecedent water temperatures on standing crop of a *Sargassum* spp.–dominated reef flat in Hawaii. Mar. Biol. (Berl.) 105 : 323–328.

HAIGHT, W. R., and G. T. DINARDO. 1995. Status of lobster stocks in the Northwestern Hawaiian Islands, 1994. Honolulu Laboratory, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Honolulu, Hawai'i. Southwest Fisheries Science Center Administrative Report H-95-03. 17 pp.

HEATH, J. R., and H. BARNES. 1970. Some changes in biochemical composition with

season and during the molting cycle of the common shore crab, *Carcinus meanus* (L.). J. Exp. Mar. Biol. Ecol. 5:199–233.

HERRNKIND, W. F. 1980. Spiny lobsters: Patterns of movements. Pages 349–407 *in* J. S. Cobb and B. F. Phillips, eds. The biology and management of lobster. Vol. 1, Physiology and behavior. Academic Press, New York.

KANAZAWA, A. 1994. Nutrition and food. Pages 483–494 *in* B. F. Phillips, J. S. Cobb, and J. Kittaka, eds. Spiny lobster management. Blackwell Scientific Publications, Oxford.

KANCIRUK, P. 1980. Ecology of juvenile and adult Palinuridae (spiny lobsters). Pages 59–96 *in* J. S. Cobb and B. F. Phillips, eds. The biology and management of lobster. Vol. 2, Ecology and management. Academic Press, New York.

LIPCIUS, R. N., and W. F. HERRNKIND. 1982. Molt cycle alterations in behavior, feeding and diel rhythms of a decapod crustacean, the spiny lobster, *Panulirus argus*. Mar. Biol. (Berl.) 68:241–252.

LYLE, W. G., and C. D. MACDONALD. 1983. Molt stage determination in the Hawaiian spiny lobster, *Panulirus marginatus*. J. Crustacean Biol. 3:208–216.

MACDONALD, C. D., and B. E. THOMPSON. 1987. Characteristics of a recreational fishery for Hawaiian spiny lobsters at the Midway Islands. N. Am. J. Fish. Manage. 7:194–201.

MARTINELLI, T. L. 1993. Nutritional indices for the Hawaiian spiny lobster, *Panulirus marginatus*. M.S. thesis, University of Hawai'i at Mānoa, Honolulu.

MARTIN-SMITH, K. M. 1992. Seasonal variation in tropical benthic *Sargassum* and associated motile epifauna. Proceedings of the 7th International Coral Reef Symposium, Guam 2:881–886.

MCGINNIS, F. 1972. Management investigation of two species of spiny lobsters, *Panulirus japonicus* and *P. penicillatus*. Division of Fish and Game, Department of Land and Natural Resources, State of Hawai'i. 47 pp.

MORGAN, G. R. 1974. Aspects of the population dynamics of the western rock lobster, *Panulirus cygnus* George. II. Seasonal changes in the catchability coefficient. Aust. J. Mar. Freshwater Res. 25:249–259.

MOSS, S. M. 1994. Use of nucleic acids as indicators of growth in juvenile white shrimp, *Penaeus vannamei*. Mar. Biol. (Berl.) 120:359–367.

NAKAMURA, M., and T. KURAMOTO. 1992. Effects of cooling on the heart beat of the Japanese spiny lobster in vivo. Zool. Sci. (Tokyo) 9 (6): 12–16.

NEWMAN, G. G., and D. E. POLLOCK. 1974. Growth of the rock lobster *Jasus lalandii* and its relationship to benthos. Mar. Biol. (Berl.) 24:339–346.

PARRISH, F. A., and J. J. POLOVINA. 1994. Habitat thresholds and bottlenecks in production of the spiny lobster (*Panulirus marginatus*) in the Northwestern Hawaiian Islands. Bull. Mar. Sci. 54:151–163.

POLOVINA, J. J. 1989. Density dependence in spiny lobster, *Panulirus marginatus*, in the Northwestern Hawaiian Islands. Can. J. Fish. Aquat. Sci. 46:660–665.

POLOVINA, J. J., and R. B. MOFFITT. 1995. Spatial and temporal distribution of the phyllosoma of the spiny lobster, *Panulirus marginatus*, in the Northwestern Hawaiian Islands. Bull. Mar. Sci. 56:406–417.

POLOVINA, J. J., W. R. HAIGHT, R. B. MOFFITT, and F. A. PARRISH. 1995. The role of benthic habitat, oceanography, and fishing on the population dynamics of the spiny lobster, *Panulirus marginatus* (Decapoda, Palinuridae) in the Hawaiian Archipelago. Crustaceana (Leiden) 68:203–212.

ROBERTSON, D., M. J. BUTLER, and F. C. DOBBS. 1996. Evaluation of potential indices of nutritional condition of the Caribbean spiny lobster. Page 71 *in* Proceedings of the 24th Annual Benthic Ecology Meeting, Columbia, South Carolina, 7–10 March.

WHYTE, J. N. C., R. R. ENGLAR, B. L. CARSERLL, and K. E. MEDIC. 1986. Influence of starvation and subsequent feeding on body composition and energy reserves in the prawn, *Pandalus platyceros*. Can. J. Fish. Aquat. Sci. 43:1142–1148.