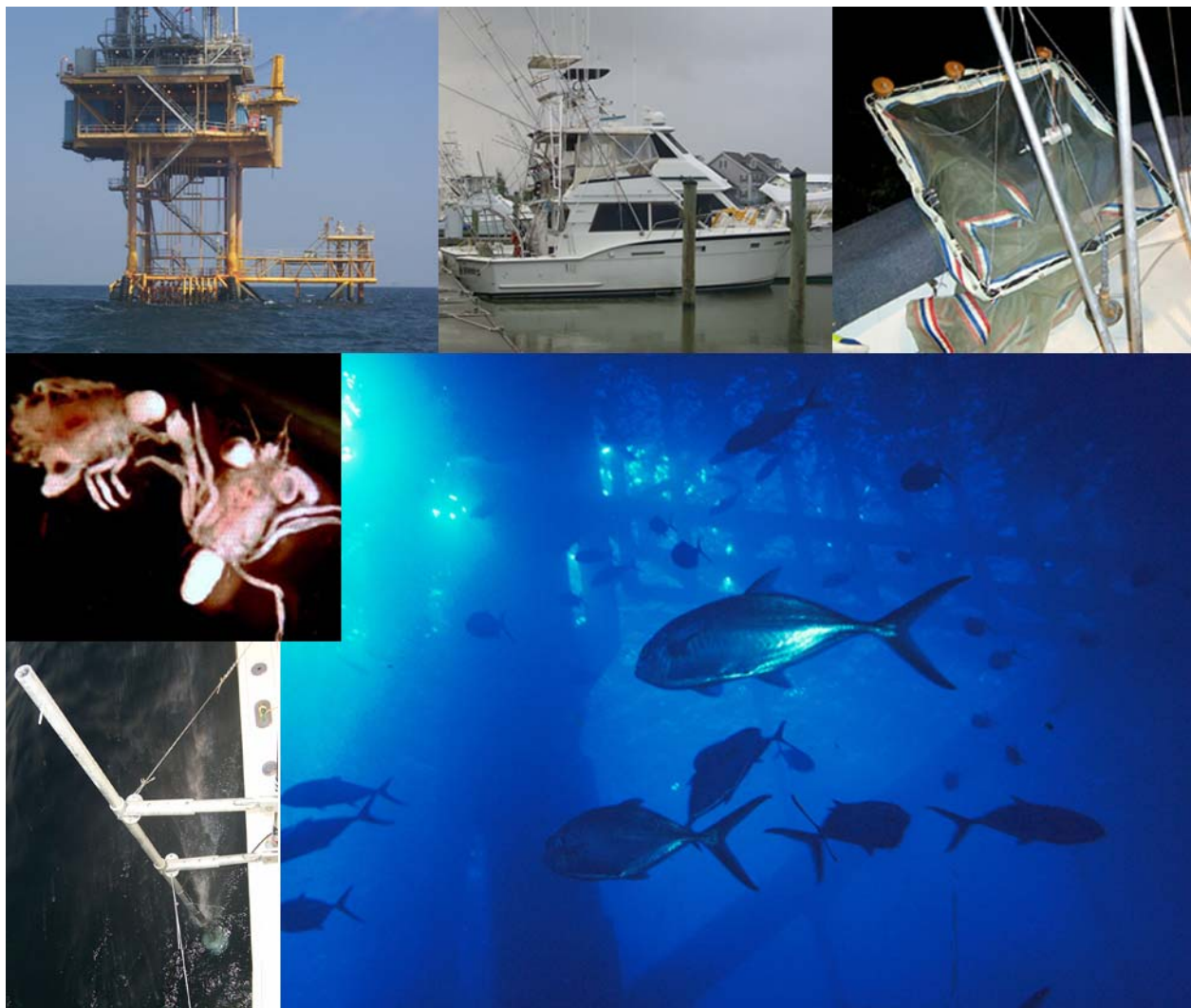**Coastal Marine Institute**

Importance of Zooplankton in the Diets of Blue Runner (*Caranx crysos*) Near Offshore Petroleum Platforms in the Northern Gulf of Mexico

MMS **U.S. Department of the Interior**
Minerals Management Service
Gulf of Mexico OCS Region

LSU **Cooperative Agreement**
Coastal Marine Institute
Louisiana State University

Coastal Marine Institute

Importance of Zooplankton in the Diets of Blue Runner (*Caranx crysos*) Near Offshore Petroleum Platforms in the Northern Gulf of Mexico

Authors

Sean F. Keenan
Mark C. Benfield

July 2003

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS) and the Coastal Fisheries Institute (CFI), Louisiana State University (LSU). This report has been technically reviewed by the MMS and it has been approved for publication. Approval does not signify that the contents necessarily reflect the view and policies of LSU or the MMS, nor does mention of trades names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with the MMS editorial standard.

REPORT AVAILABILITY

Extra copies of the report may be obtained from the Public Information Office (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Public Information Office (MS 5034)
1201 Elmwood Boulevard
New Orleans, Louisiana 70123-2394

Telephone: (504) 736-2519 or
1-800-200-GULF

CITATION

Suggested citation:

ABOUT THE COVER

The underwater photograph of blue runner beneath a platform was provided by Greg Boland, Minerals Management Service, New Orleans, LA.

ACKNOWLEDGMENTS

ABSTRACT

Blue runner (*Caranx crysos*), common around offshore petroleum platforms in the Gulf of Mexico, were found to forage extensively on meso- and macro-zooplankton during the summer months. Larval decapods and stomatopods, hyperiid amphipods, pteropods, and larval and juvenile fishes were common components of their diet. Feeding periodicity results suggest that blue runner around platforms were capable of feeding throughout the night at the same intensity as the day. Size selectivity indicated that larger prey, such as fish were consumed during the night and smaller decapod crustaceans were consumed during the day. Blue runner collected from open waters away from platforms also consumed decapods and larval fish as well as other abundant zooplankton such as chaetognaths. Although certain zooplankton taxa exhibited increased densities near the platform during some cruises, plankton net sampling did not demonstrate consistently elevated densities of zooplankton in proximity to petroleum platforms. Zooplankton density was generally greater during the night samples, however a platform enhancement effect was not observed. Results from ADCP surveys suggested that zooplankton and ichthyoplankton contributed to the measured volume backscattering strength. Diel and between-cruise changes in zooplankton density were correlated with changes in acoustic scattering levels during acoustic surveys conducted around the platforms. These surveys demonstrated the utility of an ADCP to examine small-scale patterns in sound scattering layers in surface waters around platforms, however preliminary analysis did not establish that elevated (or reduced) levels of scattering existed near platforms. Examination of more surveys along with including data on current velocity will provide further insight into the localized effects of these structures. The net and acoustic data collected in this study suggested that more intensive sampling closer to platforms is needed to understand how these structures support large aggregations of fishes such as blue runner.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

Chapter I
General Introduction

The offshore petroleum platforms in the northern Gulf of Mexico have been described as the largest unplanned artificial reef complex in the world (Kasprzak 1998, Stanley and Wilson 2000b). There are over 4,000 platforms (http://www.gomr.mms.gov/homepg/fastfacts/WaterDepth/WaterDepth.html; as of June 2002) in the northern Gulf of Mexico where the majority of substrate is clay, silt, or sand (Parker et al. 1983). Platforms provide an additional 12 km^2 of "reef" habitat (Stanley and Wilson 1997) to the estimated 2,571 km^2 (737 – 6,388 km^2; 95% CL) of natural hard bottom habitat from Pensacola, Florida and Pass Cavello, Texas (Parker et al. 1983). What they lack in surface area, platforms make up with a unique vertical orientation that extends the benthic community into the water column. The three-dimensional structure of platforms provides substrate for encrusting organisms such as corals and sponges as well as habitat for many species of demersal fishes. In addition to the reef community found near platforms, pelagic fish species (i.e., jacks, spadefish, mackerels, and tunas) are often associated with these structures (Seaman et al. 1989) and schools often reach many thousands of individuals (Stanley and Wilson 2000a). How platforms affect fish assemblages remains an important question in understanding how these structures function as productive artificial reefs.

Studies on fish populations around platforms began in the mid 1970's and primarily included qualitative surveys of adult fish and encrusting communities (Hastings et al. 1976; Gallaway 1980; and Sonnier et al. 1976). These studies utilized diver visual surveys to evaluate species composition and abundance. With expansion of underwater video equipment and ROV technology, surveys were conducted over longer time spans and into deeper waters (Seaman et al. 1989; Stanley 1994; Love et al. 1999 and 2000). Love et al. (1999) utilized ROVs to evaluate vertical distribution of platform associated fishes off the California coast to depths of 224 m. Advances over this "snapshot" view of platform-associated fauna came about with the emergence of hydroacoustics (Jennings et al. 2001). Gerlotto et al. (1989) evaluated relative densities of fishes near platforms off Cameroon Africa by using towed hydroacoustics. Stanley (1994) pioneered the use of stationary dual-beam hydroacoustics along with ROV surveys to evaluate fish populations near a platform in the northern Gulf of Mexico. He estimated that between 2,000 and 28,000 fishes covering 19 different species were associated with a given structure at any one time and noted that abundance varied greatly with season. Fish densities were shown to decrease significantly beyond a 16 m radius around the structure and further research by Stanley and Wilson (1997) reported fish densities beyond 30 m were similar to ambient, open-water densities.

In addition to platforms, research has demonstrated increased fish densities near drifting objects (Gooding and Magnuson 1967; Druce and Kingsford 1995), fish attracting devices (FADs; Klima and Wickham 1971; Ibrahim et al. 1996) and artificial reefs (Bohnsack 1989; Lindquist and Pietrafesa 1989). Many hypotheses have been proposed to explain increases in fish abundance near structures. These include shelter from predation, increases in recruitment habitat, increase feeding efficiency, or merely altered behavior leading to attraction (Gooding and Magnuson 1967; Bohnsack 1989). The central question regarding the ecological significance of platforms and other structures pertains to whether structures provide critical habitat needed to

increase productivity or if they simply serve to attract existing fish from surrounding waters (Bohnsack 1989; Shipp 1999). Known as the attraction-production issue, this question remains a debate among reef managers, users, and scientists.

Evaluating trophic dynamics of organisms in proximity to artificial structures is crucial to understanding why these habitats are successful in attracting fishes (Deudero 2001). Enrichment of food resources near floating structures has been hypothesized to explain how these structures attract fishes (Gooding and Magnuson 1967). Observation of diet shifts of fishes near structures may suggest a connection between structure-related productivity and the associated fish community. Studies examining the diets of fishes near artificial reefs and FADs, however, have been inconclusive in demonstrating effects of the structure. For example, the diets of yellowfin tuna (*Thunnus albacares*) showed a shift towards deep-water oplophorid shrimps near Hawaiian FADs in contrast to the piscivorous diet of non-FAD associated tuna (Brock 1985). Brock reported no evidence, however, of an influence from the FAD on the distribution of these shrimp. Ibrahim et al. (1996) compared the epifaunal organisms taken from Malaysian FADs with stomach contents of fish collected near the FADs and concluded that the fish were feeding primarily in the water column and not on encrusting organisms. Donaldson and Clavijo (1994) examined the diet of a pelagic carangid (*Decapterus punctatus*) common on North Carolina artificial reefs and reported these fish did not feed on organisms associated with the reefs but instead on pelagic crustaceans. Studies on trophic relationships of artificial reef and FAD associated fishes remains an important component in developing management strategies based on resource allocation within the reef associated community (Nelson and Bortone 1996). A single study was found on the feeding habits of fishes associated with offshore petroleum platforms in the northern Gulf of Mexico (Gallaway 1980).

Stanley and Wilson (2000b) reported nine out of 26 fish species found near three offshore platforms were carangid jacks and the most abundant of these was the blue runner (*Caranx crysos*). In a study near the Buccaneer platform complex off Texas, Gallaway (1980) described blue runner as "warm-season pelagic predators" attracted solely by the structure. Stanley (1994) also reported blue runner occurring near Louisiana's West Cameron 352 platform primarily during warmer months and that schools reached up to 10,000 individuals. Adult blue runner are considered to be primarily piscivorous (Randall 1967; Christmas et al. 1974), however, the stomach contents of one fish taken near a platform in May 1996 contained large numbers of hyperiid amphipods. The occurrence of small (2–5 mm) zooplankton in the stomach of a fairly large (250 mm standard length) fish suggested a potential trophic linkage between the platform and surrounding fish community. This formed the basis of an Undergraduate Research Opportunities Program grant from the LSU Sea Grant College Program to investigate the relationship between blue runner and zooplankton prey near Louisiana offshore petroleum platforms. The results from that pilot project led to the thesis research presented here.

The subsequent chapters are organized as follows: Chapter 2 describes the feeding habits of adult blue runner near two platforms sampled during the summers of 1996 and 1999. This includes preliminary examination of diel feeding periodicity and prey size selection for decapod and amphipod prey. Limited zooplankton abundance data were collected from a passively fished, 60 cm diameter plankton net (335 μm) deployed in surface waters (2 m) directly beneath the platform structure. Chapter 3 further examines the diets of blue runner near platforms and

also contrasts the feeding habits of blue runner near platforms with fish captured from open waters away from platforms. Blue runner and zooplankton samples were collected during a series of cruises to two platforms east of the Mississippi Delta. Zooplankton were collected by a 0.865 m^2 rectangular plankton net (1000 μm) towed obliquely from 15 m to the surface. Evidence of prey type selectivity and prey size selectivity are presented as well as prey switching during the diel cycle. Chapter 4 evaluates zooplankton prey distribution near platforms through use of the plankton net collections. I also attempted to provide evidence that volume scattering strength measured by an acoustic Doppler current profiler (ADCP) is related to the abundance of zooplankton in the ensonified water. Finally, I present evidence demonstrating the ability of an ADCP to map the distribution of sound scattering particles (i.e., zooplankton) in the surface waters around platforms. Chapter 5 contains a final summary section. The chapters in this thesis were written as manuscripts for publication in peer-reviewed journals. Therefore, each chapter contains separate Introduction, Methods, Results and Discussion sections. As a result of duplication of references between chapters, a single literature cited section has been placed after Chapter 5.

Chapter II
Zooplanktivory by Blue Runner (*Caranx crysos*) I:
A Potential Energetic Subsidy to Gulf of Mexico Fish Populations at Petroleum Platforms[1]

Introduction

The majority of the substrate off the coast of Louisiana and Texas consists of sand and silt (Parker et al. 1983; Stanley 1994) with approximately 293 km^2 of known reef and hard bottom habitat (Stanley and Wilson 2000a). There are over 4000 offshore petroleum platforms in the northern Gulf of Mexico, which increase available reef-like habitat by an additional 12 km^2 (Kasprzak 1998). Unlike natural reefs in the same area, which are largely low relief features, platforms are three-dimensional structures extending throughout the water column. Platforms provide substrate for encrusting organisms and this fouling community in turn, provides habitat for a variety of demersal and pelagic fish species. The platforms in the northern Gulf have been described as the largest unplanned artificial reef complex in the world (Stanley and Wilson 1998). High concentrations of fishes around platforms have stimulated attempts to quantify the distribution and abundance of associated fish assemblages. Stanley and Wilson (1996; 1998; 2000b) utilized hydroacoustics and video surveys to estimate densities and distributions of fishes associated with platforms. Their findings suggested that 10,000 to 30,000 fishes were associated with each of the manned platforms they examined.

Artificial reef design and management is centered on the often controversial "attraction versus production" issue (e.g., Grossman et al. 1997; Lindberg 1997; Bohnsack et al. 1997). Our research utilized platforms to address the question: do platforms serve as functional, productive habitat capable of supporting high fish biomass? This is an important question in evaluating the relationship between platforms and fishes. While data exist on densities and distributions of platform-associated adult fishes, relatively little is known about how such assemblages are sustained. Understanding the trophic ecology of platform-associated fishes may help evaluate the degree to which platform production is transferred to fish, and assist in developing strategies for converting decommissioned platforms into productive artificial reefs.

One of the most common pelagic fish species in the Gulf is the blue runner *Caranx crysos*. This coastal pelagic carangid is found in the western Atlantic from Nova Scotia to Brazil (McKenney et al. 1958), throughout the eastern Atlantic and Mediterranean and has been recorded in waters of the United Kingdom (Swaby et al. 1996). This medium sized fish, commonly attaining 400 mm fork length, (Cervigón et al. 1993) is generally found in large schools in the open waters of the Gulf of Mexico. Blue runner are frequently the most abundant species in the surface waters around offshore platforms (Sonnier et al. 1976, Stanley and Wilson 2000a&b). For example, at a mid-shelf platform off Louisiana (Grand Isle 94B), Stanley and Wilson (2000b) found that blue runner numerically constituted up to 94% of the fish assemblage present.

Blue runner are likely major components of the diets of larger predatory fish that are associated with platforms (e.g., barracudas, groupers, cobia and other large jacks) as well as

---

[1] Reprinted by permission of the Transactions of the American Fisheries Society

predators that frequently visit platforms (e.g., king mackerel, billfish and tunas). Blue runner are potentially important trophic links in platform food webs, however, relatively little is known about their diet. Some data exist on feeding habits of larval and juvenile blue runner, while accounts of adult feeding habits are anecdotal. McKenney et al. (1958) and Schekter (1972) stated that blue runner less than 160 mm standard length (SL) were carnivorous planktivores that primarily consumed calanoid and cyclopoid copepods. The size range of prey in the diets of larger juveniles increases to include zooplankton such as hyperiid amphipods, decapod and stomatopod larvae, and ichthyoplankton (McKenney et al. 1958). Randall (1967) quantified the stomach contents of 17 mature (190–520 mm FL) blue runner from reef habitats in the West Indies. All but two of these had "small silvery schooling" fish in their stomachs, while two fish (222 and 250 mm FL) contained 40% planktonic organisms with the remaining contents being fish. The stomachs of two adult male blue runner (365 and 370 mm SL), collected in Mississippi coastal waters, contained anchovies and two mantis shrimp (*Squilla empusa*) of unstated developmental stage (Christmas et al. 1974).

Observations of adult blue runner that appeared to be feeding on zooplankton at night beneath a mid-shelf petroleum platform motivated the present study. My research was designed to quantify the diet of blue runner at mid-shelf petroleum platforms off the coast of Louisiana. The objectives of my study were to: (1) describe the food habits of, and monthly variability in the diet of blue runner over summer months; and (2) evaluate the diel periodicity in feeding. In addition, I analyzed a limited dataset to evaluate evidence for size selection of prey items by blue runner.

Methods

Study Sites

The diets of blue runner were investigated at two offshore platforms, one located west and one east of the Mississippi delta. Grand Isle 94B (GI94B) is a mid-shelf platform located west of the Mississippi River (28.5267°N, 90.0983°W) in 63 m of water (Fig. 1). Samples were collected from GI94B during 28-30 June, 28 July - 1 August, and 12-15 August 1996. Main Pass 259A (MP259A) is a outer-shelf platform located east of the Mississippi River (29.2833°N, 88.0333°W) in approximately 130 m of water. Sampling trips were made to MP259A during 11-14 June, 9-12 July and 24-27 September 1999.

Fish Sampling

Each sampling trip lasted approximately three days during which time fish were collected opportunistically using hook and line angling with artificial lures. The weight of each blue runner was measured with a digital balance to the nearest 0.1 lb (± 45 g). Fork length and total length were measured to the nearest millimeter. Sex and time of capture were also recorded for each fish. Blue runner were anesthetized in an ice bath, which also served to arrest digestion and then sacrificed by severing the spinal cord behind the head. Stomachs were then removed by severing the esophagus and the duodenum below the pyloric sphincter. Stomachs were injected with 95% ethanol, stored in 70% ethanol preservative, and transported to the laboratory.
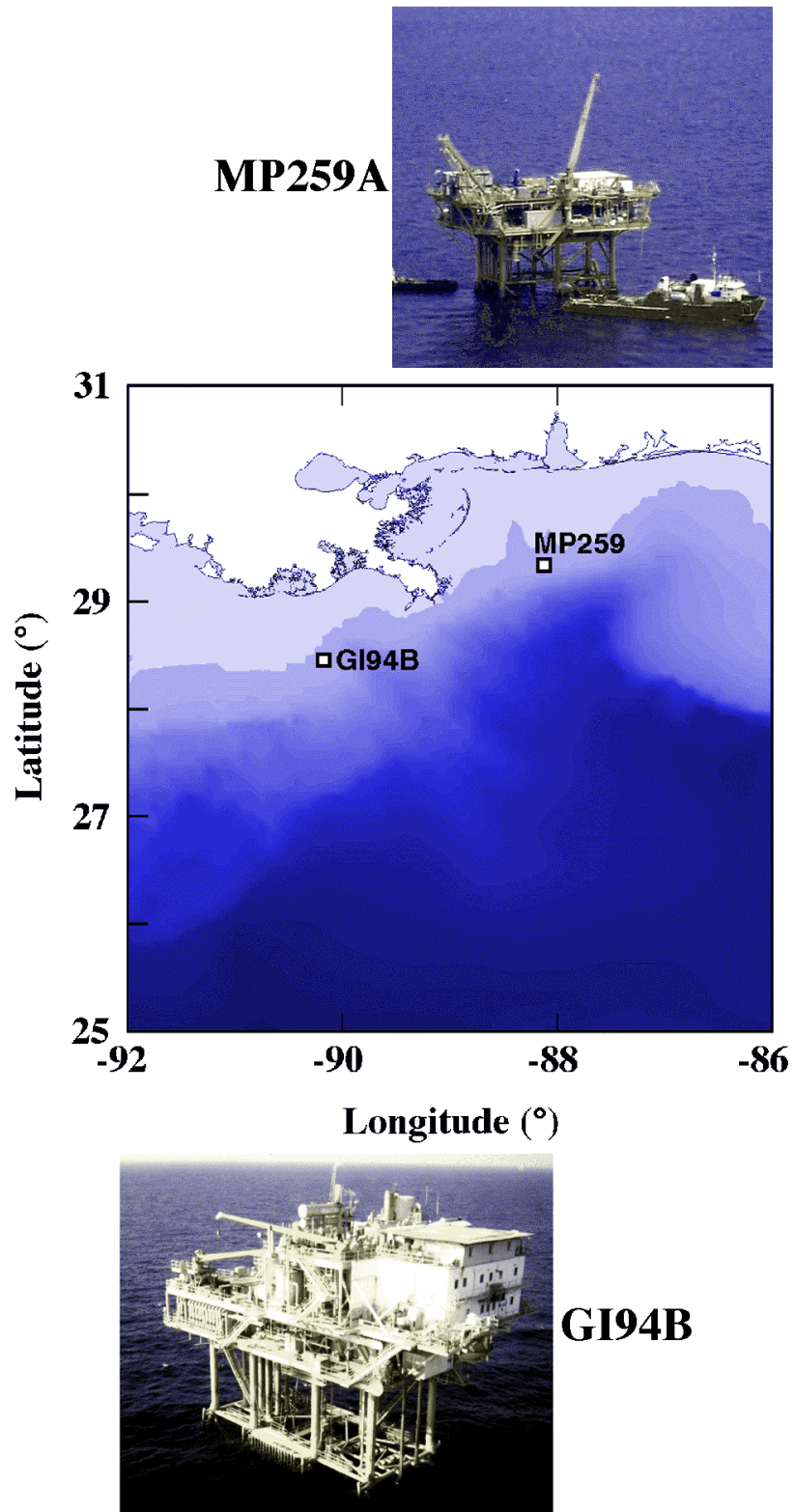
MP259A

GI94B

Figure 1. Locations and images of platforms sampled in 1996 (GI94B) and 1999 (MP259A).

Enumeration of Stomach Contents

Stomach contents were examined with a dissecting stereoscope (7X) and placed in the following taxonomic categories: fish, adult and larval decapods and stomatopod larvae, hyperiid amphipods, chaetognaths, other invertebrates (e.g., cephalopods, pteropods, copepods, ostracods) and unidentified material. The number of prey in each category was counted and wet weights recorded to the nearest milligram. Wet weights were obtained by gently blotting surface fluid from the prey items before weighing (Bowen 1996). Numbers consumed and prey weights provided numerical and wet-weight based estimations of the contributions of each prey category to the diet.

Plankton Sampling

A surface zooplankton sample was collected beneath MP259A using a passively-fished, 60 cm diameter ring net equipped with a 333 μm mesh net and a General Oceanics Model 2030 flow meter. The net was attached to a vertical monorail and mounted within a gimbaled frame fitted with a current vane so that the mouth of the net faced the prevailing current. The net was fished for 30 min from 17:45-18:15 h on June 12, 1999. Plankton were preserved in 5% formalin for 24 h before being transferred to 95% ethanol. The sample was sorted and classified into the same groups as for the dietary analysis.

Data Analysis

For this study, the term zooplankton includes decapods and larval stomatopods, hyperiid amphipods, chaetognaths, and other invertebrates excluding cephalopods. The weight of zooplankton in the diet was used to evaluate zooplanktivory over the size range of blue runner sampled. Blue runner were grouped into 20 millimeter size classes (range of 150–450 mm) for analysis. For each fish, percent zooplankton was computed by dividing the total zooplankton weight by the total weight of all stomach contents.

An index of relative importance (IRI; Bowen 1996; Cortes 1997) was used to evaluate monthly variation in blue runner feeding. The IRI values were estimated for each prey category (i) using:

$$IRI_i = (\%N_i + \%M_i) \times \%FO_i \tag{1}$$

Where N_i is the numerical proportion (%) of the ith prey category in the stomach, M_i is the gravimetric proportion not including unidentified (%) of the ith prey item, and FO_i is the frequency of occurrence expressed as the number of stomachs containing prey category (i) divided by the number of stomachs containing at least one prey item of any category (Hyslop 1980). The IRIs for each prey item were then converted to %IRI using:

$$\%IRI_i = \frac{IRI_i}{\sum IRI} \times 100 \tag{2}$$

Feeding Periodicity

Diel feeding periodicity was estimated using a stomach fullness index modified from Juanes and Conover (1994). Stomach fullness was computed for each fish by:

$$\text{Stomach Fullness} = \frac{\text{Total prey wet weight}}{\text{Wet weight of empty stomach}} \tag{3}$$

A stomach fullness index was estimated by dividing the fullness value for each fish by the maximum fullness value observed from all fish collected at the particular platform sampled. Blue runner were grouped over each platform, since it was not possible to capture blue runner from all hours of the day on any single trip. Fish were grouped into eight sequential three-hour time blocks. Differences in daily feeding periodicity were statistically evaluated for fish collected at the MP259A platform; however, the total number of fish collected at GI94B (n=38) was too low to permit a statistical evaluation of differences in stomach fullness over time. I evaluated the null hypothesis that stomach fullness indices among the three-hour time blocks within each composite day were not different using a Kruskal-Wallis test. A non-parametric test was used because stomach fullness values were not normally distributed and their distribution could not be rendered normal via transformation. A posteriori statistical differences among mean stomach fullness indices within each of the three-hour time blocks were evaluated using a nonparametric Tukey-Kramer test (Sokal and Rohlf 1981).

Prey Size Selection

A preliminary examination of prey size selection was evaluated from the MP259A platform during the June 1999 trip. Size selection was estimated by comparing the size distributions of some of the zooplankton taxa in the plankton net with the pooled contents of the stomachs of all fish (n=4) collected within ± 1 h of the plankton tow. After identification and enumeration, photographs were taken of prey items and samples from the net using a digital camera/microscopy system. These were analyzed with image processing software (NIH Image 1.62) to determine zooplankton body lengths. Fragmentation of zooplankton in stomachs generally precluded direct measurement of length. Certain body sections were more resistant to digestion and the relationships between the lengths of body parts and total length were used to estimate their original dimensions (Table 1).

Table 1. Regressions fitted for three prey categories commonly consumed by blue runner. These relationships were used to reconstruct whole body length (B.L.) from characteristic body sections of organisms taken from stomachs.

Taxa/Organism	Body Section	Equation	r^2
Hyperiid amphipods	Eye depth (ED)	$B.L. = 2.353 \times ED + 0.481$	0.64
Lucifer spp.	Eye Length (EL[a])	$B.L. = e^{1.523} \times EL^{1.01}$	0.92
Small shrimp	Carapace Length (CL)	$B.L. = e^{1.31} \times CL^{0.63}$	0.75

[a] This measurement is defined as the distance from the distal tip of the eye to the base of the eyestalk.

Decapods and hyperiid amphipods from the net and from the stomachs of the blue runner were binned into size classes (0.5 mm for decapods and 0.25 mm for amphipods). Size selection was statistically evaluated for decapod prey using a chi-square analysis. Size selection for hyperiid amphipods was not evaluated statistically because of the limited number of size classes

common to both the net and stomach samples. For the decapods, I tested the null hypothesis that the frequency of individuals within each size class did not differ significantly between the plankton net and blue runner stomachs. In this test I must assume that the net collected a representative sample of all sized decapods encountered by the blue runner. Expected frequencies in each size class were computed as the product of the fraction of individuals in each size class from the plankton net and the total number of individuals from the pooled blue runner stomach sample. A chi-square statistic (1 degree of freedom) was computed for each size class i using:

$$\chi_i^2 = \frac{(\text{observed}_i - \text{expected}_i)^2}{\text{expected}_i} + \frac{(\text{observed}_j - \text{expected}_j)^2}{\text{expected}_j} \tag{4}$$

where i is the size class of interest and j is all remaining size classes. Organisms less than 2.5 mm and greater than 12.5 mm were pooled so that at least 5 observations occurred in each size frequency category.

Results

The stomachs of 37 fish collected from GI94B in 1996 contained prey items, while 81 blue runner from MP259A in 1999 contained prey items. Regurgitation of prey was considered absent since no stomachs were everted or found empty with distended lining and examination of the contents of the ice bath did not reveal the presence of regurgitated prey. Barotrauma commonly associated with deep-water fish caught with hook and line (DeMartini et al. 1996) was not considered a factor, since most of the fish were caught within the upper 10-20 m of the water column.

Dietary analysis indicated a high degree of zooplanktivory in blue runner collected from both platforms (Fig. 2). Numerically, zooplankton constituted approximately 62% of the identifiable diet contents at GI94B in 1996 and 78% at MP259A in 1999. Zooplankton prey items were dominated by decapod crustaceans and larval stomatopods, however, chaetognaths and hyperiid amphipods comprised 20-30% of the diet. When diets were evaluated on the basis of prey weight, zooplankton made up 28% of the diet at GI94B and 44% of the diet at MP259A. While pteropods made up most of the individuals within the other invertebrate category, cephalopods contributed the majority by weight. The stomachs of fish from both platforms contained unidentifiable amorphous tissue, which constituted 42% and 29% of the overall diets at GI94B and MP259A, respectively.

Blue runner ranged in size from 255 – 445 mm FL at the GI94B platform and 165–449 mm FL at the MP259A platform. This size range indicated that most were at or approaching sexual maturity (Goodwin and Finucane 1985). Further, many fish contained developing or mature gonads. The diets of nearly all blue runner contained a large proportion of zooplankton regardless of fish size. From GI94B, all the fish below 330mm FL contained approximately 50% zooplankton by weight (Fig. 3). Similar trends were observed from the MP259A platform, where a broader size range of fish was collected. Approximately 40-50% of the diet of blue runner up to 330 mm FL consisted of zooplankton (Fig. 3). A decrease in zooplankton was seen in fish greater than 330 mm except for one 440 mm fish from GI94B with many amphipods, decapods and thecosomate pteropods in the stomach. There were, however, only four fish caught over 370 mm from both platforms.

Numerical Proportion   **Gravimetric Proportion**

GI94B
(n = 37)

MP259A
(n = 81)

■ Fish	■ Decapods/Stomatopods	■ Other Invertebrates
■ Amphipods	■ Chaetognaths	■ Unidentified
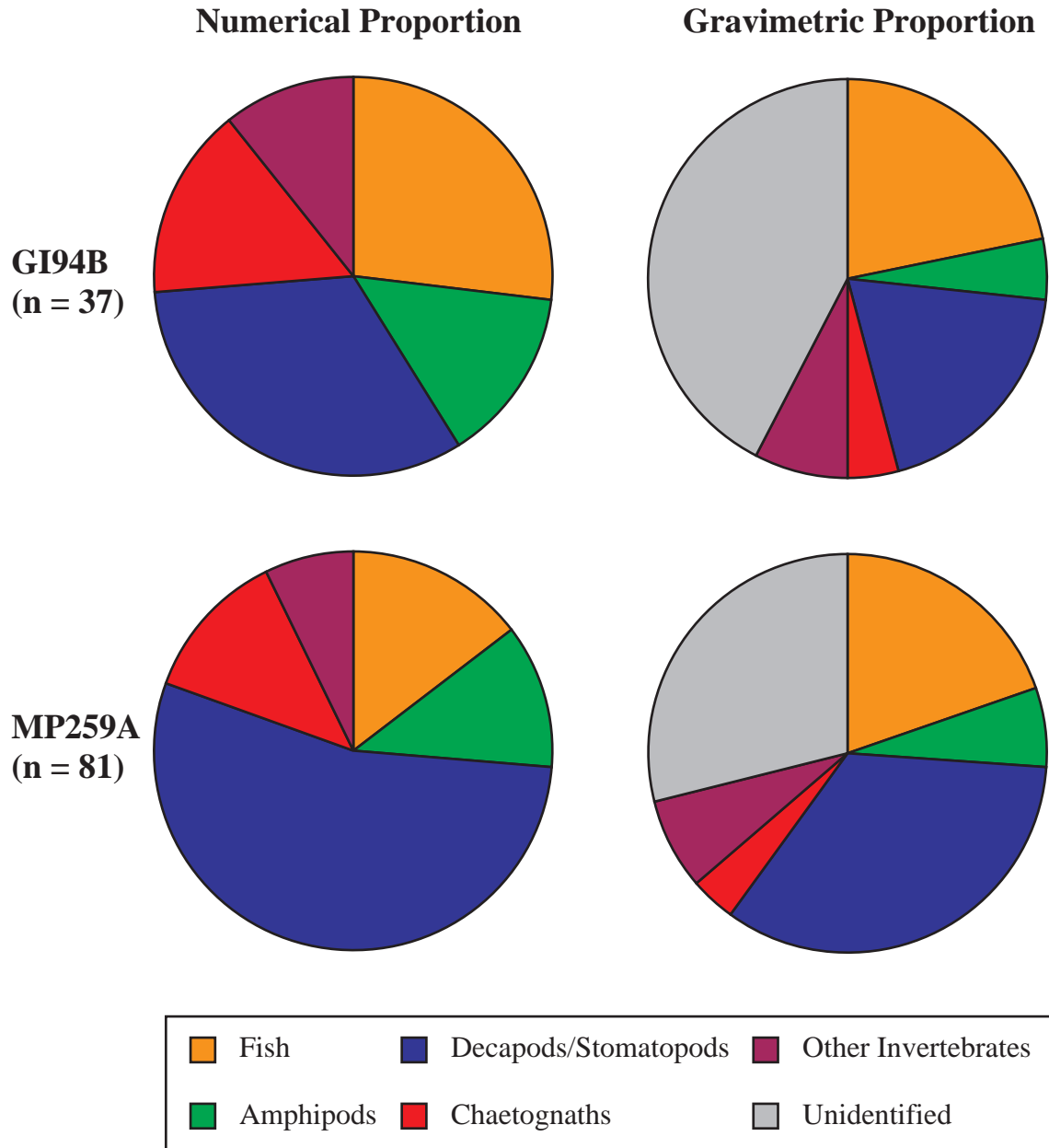
Figure 2. Numerical proportion (left column) and gravimetric proportion (right column) for the prey items in the diets of blue runner from the two platforms sampled. The proportions are pooled over the three trips to each of the platforms: June, July and August 1996 (GI94B) and June, July and September 1999 (MP259A).
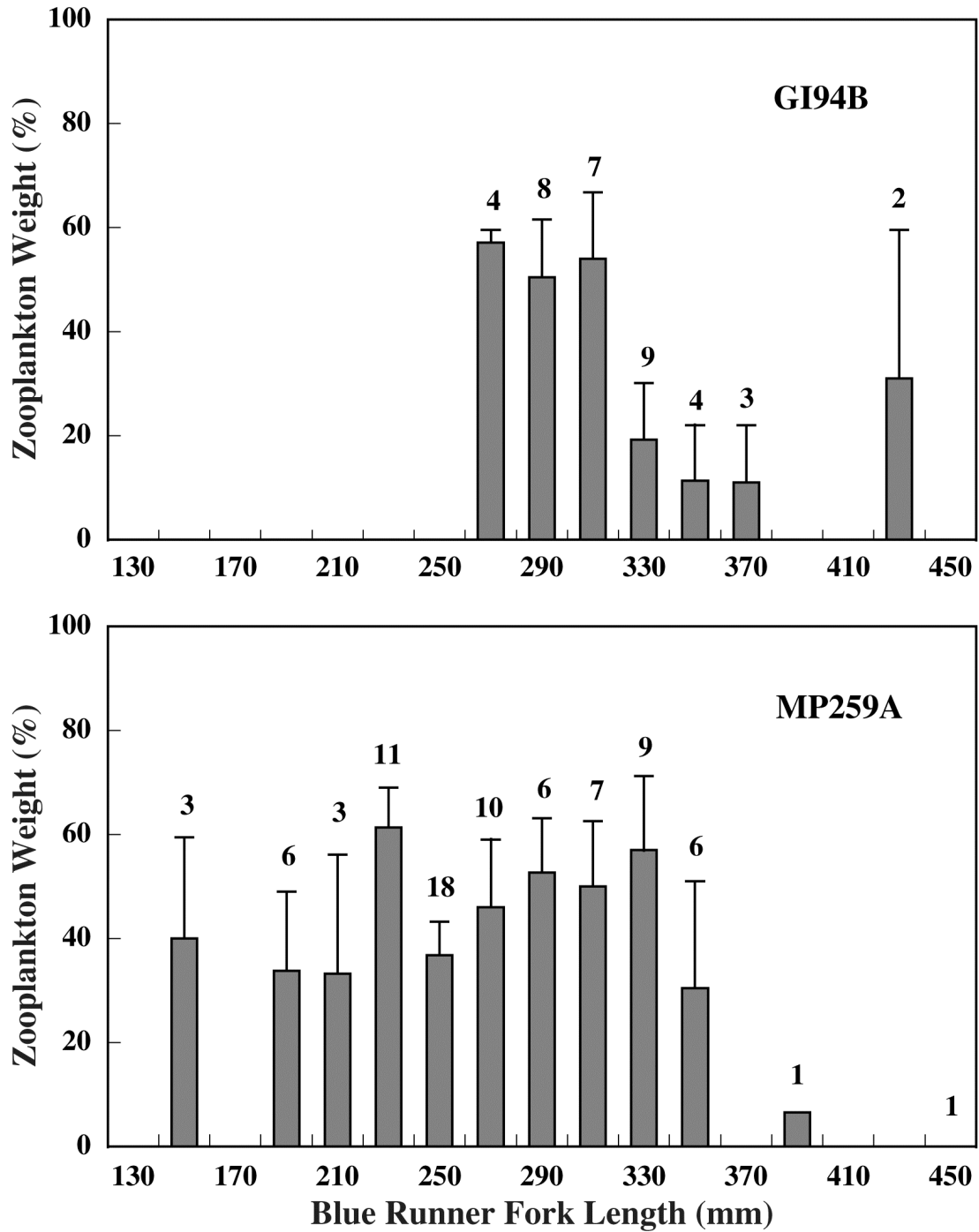
Figure 3. Gravimetric proportion of zooplankton (± SE) occurring in the diets of blue runner over all sizes collected from GI94B (top) and MP259A (bottom). Blue runner were placed into 20 mm size classes and fish were pooled over all months. The number above each bar indicates the number of blue runner per size class.

Table 2. Summary of the diets of blue runner taken during each sampling trip to GI94B (1996) and MP259A (1999). Expressed as numerical proportion (%N), gravimetric proportion (%W), and frequency of occurrence (%F.O.). Also included is an index of relative importance (I.R.I.), which is the sum of %N and %W multiplied by %F.O.

Month	Blue Runner caught	Prey category	% N	% W	% F.O.	I.R.I. value	% I.R.I.
		GI 94B (1996)					
June	23	Decapods/Stomatopods	40.1	27.1	87.0	7777.8	60.8
		Hyperiid Amphipods	19.5	7.3	82.6	2824.9	22.1
		Chaetognaths	24.5	6.5	52.2	1832.2	14.3
		Fish	2.2	1.4	17.4	123.5	1.0
		Other Invertebrates	13.7	10.6	6.8	232.6	1.8
		Unidentified	-	47.1	-	-	-
July	3	Decapods/Stomatopods	61.1	27.8	100	12770.0	72.6
		Hyperiid Amphipods	19.0	4.2	66.7	1880.9	10.7
		Chaetognaths	0	0	0	0	0
		Fish	0	0	0	0	0
		Other Invertebrates	19.9	12.6	66.7	2941.5	16.7
		Unidentified	-	55.4	-	-	-
August	11	Decapods/Stomatopods	5.5	0.3	27.3	163.8	1.0
		Hyperiid Amphipods	0	0	0	0	0
		Chaetognaths	0	0	0	0	0
		Fish	93.6	70.4	81.8	15795.6	98.9
		Other Invertebrates	0.9	0.1	11.0	9.9	0.1
		Unidentified	-	29.2	-	-	-
		MP 259A (1999)					
June	14	Decapods/Stomatopods	34.3	24.9	85.7	5296.3	34.7
		Hyperiid Amphipods	36.7	26.7	92.9	5917.7	38.7
		Chaetognaths	13.0	6.2	28.6	580.6	3.8
		Fish	9.1	35.2	64.3	2899.9	19.0
		Other Invertebrates	6.9	1.9	64.3	585.1	3.8
		Unidentified	-	5.1	-	-	-
July	50	Decapods/Stomatopods	58.2	37.6	84.3	9753.5	68.1
		Hyperiid Amphipods	7.1	2.7	51.0	581.4	4.1
		Chaetognaths	14.6	4.1	49.0	1009.4	7.0
		Fish	14.2	17.0	56.9	1951.7	13.6
		Other Invertebrates	5.9	10.2	56.9	1024.2	7.2
		Unidentified	-	28.4	-	-	-
September	17	Decapods/Stomatopods	60.0	30.5	81.3	10097.5	79.5
		Hyperiid Amphipods	3.5	0.6	31.3	153.4	1.2
		Chaetognaths	4.5	0.7	25.0	175.0	1.4
		Fish	20.9	14.7	31.3	1324.0	10.4
		Other Invertebrates	11.1	3.6	43.8	946.1	7.5
		Unidentified	-	49.9	-	-	-

The composition of blue runner diet changed over the course of both summers (Table 2). The IRI values indicate adult and larval forms of decapods and stomatopod larvae were a substantial component of the diet at GI94B during June and July. In August, the IRI indicated that fish, primarily a codlet, *Bregmaceros* spp., replaced decapods and stomatopods in the diet. Chaetognaths and a variety of hyperiid amphipods contributed to the diets of blue runner at GI94B in June and declined in importance over the summer. Cephalopods in the diets during July at GI94B raised the importance of other invertebrates during this month. Decapod/stomatopods and hyperiid amphipods were both important in the diets during June at MP259A, however, unlike the pattern observed at GI94B, decapods and stomatopods increased in importance during July and September. Fish prey from MP259A declined in importance over the summer, from 19% in June to 10% in September.

Gut fullness indicates that blue runner appeared to feed at low levels throughout the daylight hours and exhibited a peak in feeding activity in the pre-dawn and early morning hours (Fig. 4). They were capable of feeding after dark, however, at levels comparable to those observed during the day. The number of fish collected at GI94B was insufficient to construct a complete picture of the feeding periodicity of blue runner. The pattern at GI94B, however, was similar to that observed at MP259A where a larger number of fish produced a less ambiguous picture of feeding periodicity. Evidence for early morning feeding at GI94B was based on a single fish; however, the existence of a feeding pulse beginning sometime after midnight and extending past dawn was supported by the data from MP259A (Fig. 4). The Kruskal-Wallis test indicated time of day had significant effect ($p < 0.01$) on stomach fullness values at the MP259A platform. Multiple comparisons showed that fullness values from 02:00–05:00h and 05:00–08:00 h were significantly greater ($p < 0.05$) than 14:00–17:00 h, while gut fullness from 02:00–05:00 h was also significantly greater than during 23:00–01:00 h. This indicates nocturnal and early morning feeding.

Blue runner appear to preferentially avoid small zooplankton and in some cases, the length of prey exceeded the size ranges that were present in our net sample. The size distributions of decapod prey in the stomach overlapped the upper end of the size distribution for this group in the net (Fig. 5). Small zooplankton such as crab megalopae and crab zoea were absent from or rare in the stomachs. Chi-square analysis indicated significant (see Fig. 5 for p-values) size selection for decapod prey with organisms greater than 11.5 mm being positively selected for and decapod prey less than 9.5 mm being avoided. Similarly, figure 6 indicates that blue runner appeared to forage on hyperiid amphipods larger than those collected in the net (prey median length = 3.2 mm; net median length = 2.3 mm).

14
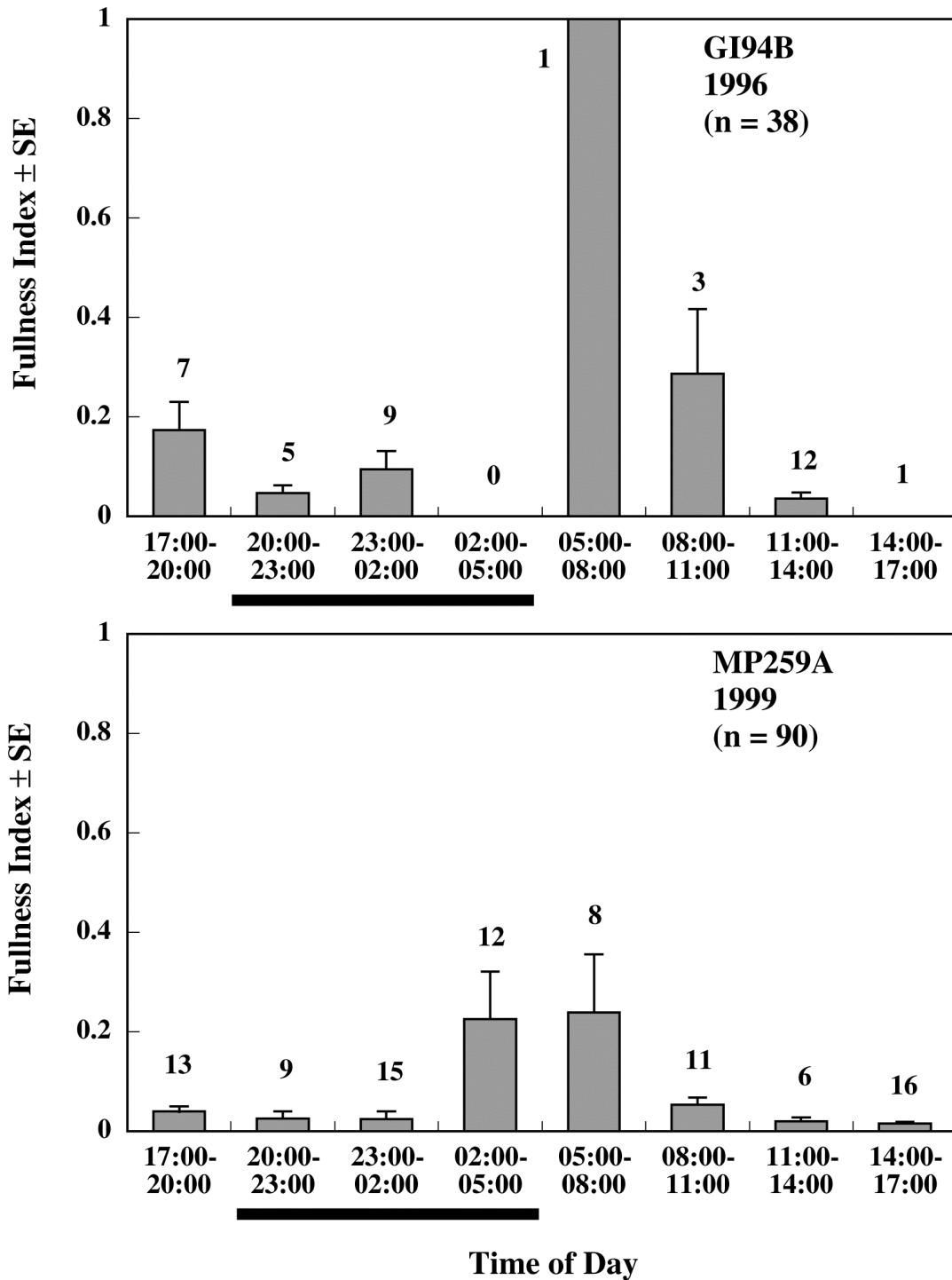
Figure 4. Stomach fullness values for blue runner collected over the summer at GI94B (top) and MP259A (bottom). Fish were pooled over all months and binned into three-hour time blocks. Nighttime hours are indicated by a black bar below the time block legends. The number of fish caught in each block appears above the bars. Error bars indicate ± 1 SE on the mean.
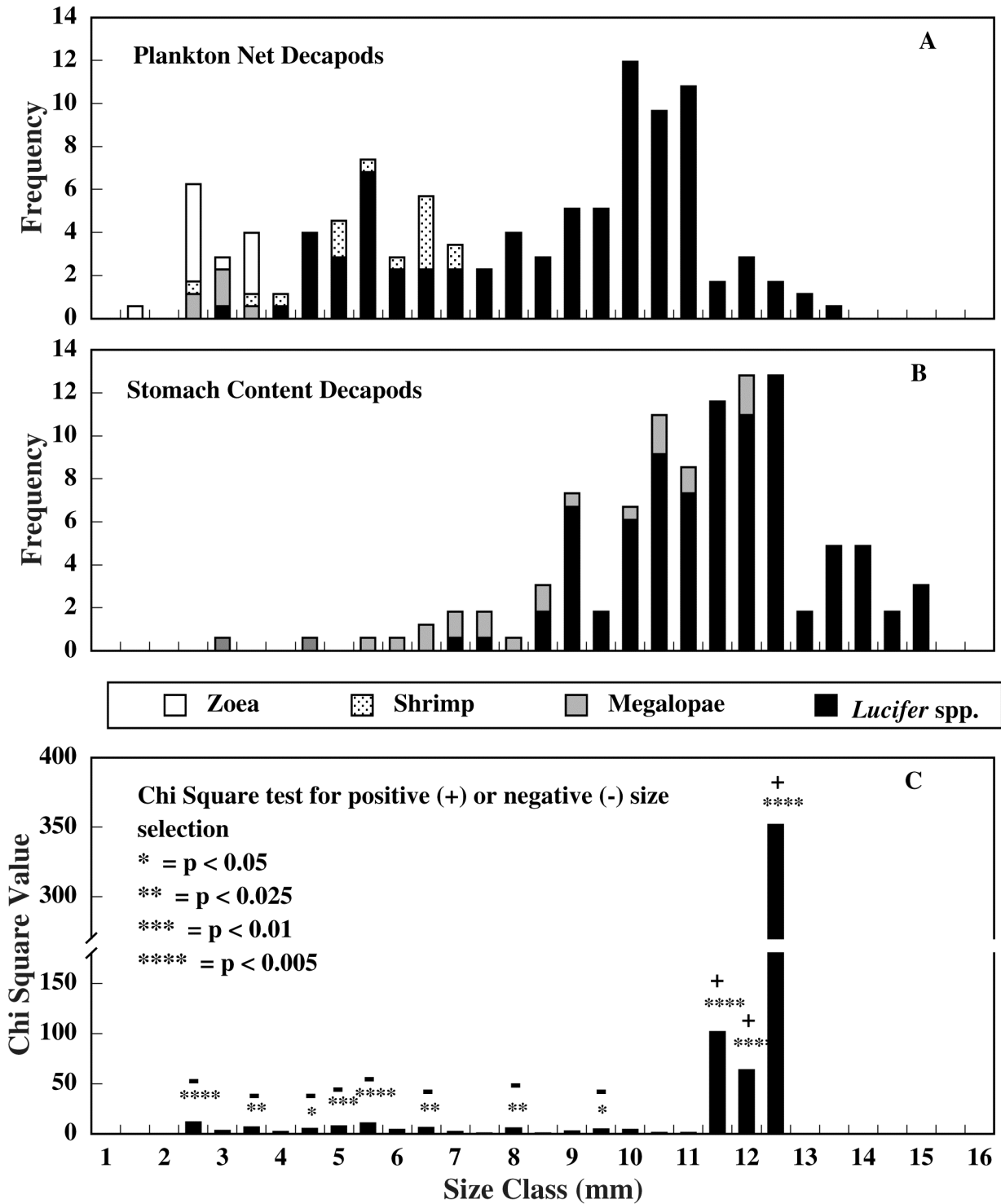
Figure 5. Length frequency distributions for decapods taken from A) surface plankton net, B) stomachs of concurrently captured blue runner (n=4), and C) chi-square analysis for biased size selection during June 1999 at the MP259A platform. Positive (+) selection and negative selection or avoidance (-) is indicated above each size class.
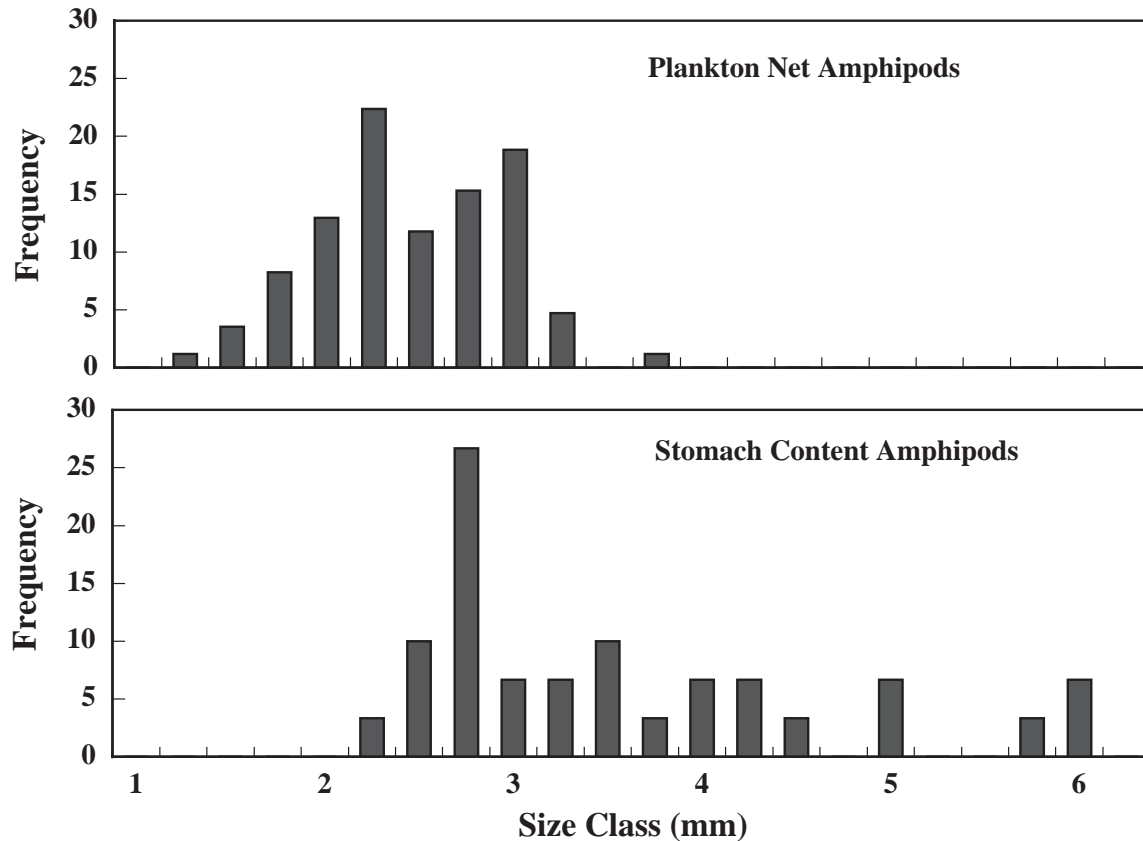
Figure 6. Length distributions of hyperiid amphipods collected from a surface plankton net (top) and from blue runner stomachs (below) in June 1999 at MP259A.

Discussion

Zooplankton comprised an important part of the diets of mature blue runner in proximity to petroleum platforms during summer months. Blue runner up to 350 millimeters FL appeared to consume large numbers (50% by weight) of holoplanktonic and meroplanktonic, meso- and macro-zooplankton. This is contrary to existing literature that characterized mature individuals of this species (> 270 mm) as primarily piscivorous (Randall 1967; Goodwin and Finucane 1985). There appeared to be a monthly shift in diet over the course of the study at both platforms that may reflect changes in the abundance of prey, shifts in preference by blue runner, or some combination of these two effects. While the dietary patterns displayed by blue runner differed between the two sites, the presence of relatively large zooplankton in the form of hyperiid amphipods, chaetognaths, decapods and stomatopod larvae was a consistent feature. Blue runner are likely opportunistic feeders and the shift towards the fish *Bregmaceros* spp. at GI94B in August may have been a response to a local increase in the abundance of this prey type.

The relative contribution to the diets of different prey types (e.g., fish versus zooplankton) is complicated by variable evacuation rates (Andersen 1999). Studies of the evacuation rates of whiting (*Merlangius merlangus*) showed that small shrimp (*Crangon vulgaris*) were digested at rates that were approximately three times slower than those of small sized Atlantic herring prey, *Clupea harengus*, (Singh-Renton and Bromley 1996). Andersen

17

(1999), also working with whiting, found that brown shrimp (*Crangon crangon*) were evacuated more slowly than fish prey, however, softer-bodied euphausiids (*Meganyctiphanes norvegica*) were evacuated at similar rates to fish prey. In contrast, Temming and Herrmann (2001) reported similar evacuation rates for brown shrimp (*C. crangon*), smelt (*Osmerus eperlanus*) and herring in the diet of horse mackerel (*Trachurus trachurus*). The same study demonstrated that evacuation rates of euphausiids and mysids (*Neomysis integer*) by horse mackerel were slightly greater than the above three prey. This result was explained primarily by differences in prey size and energy density (i.e., evacuation rates were negatively correlated with energetic value of prey items). The observations that horse mackerel digest crustacean and fish prey at different rates have relevance to my study on blue runner. In general, the diet of horse mackerel consists primarily of crustacean zooplankton and ichthyoplankton (Macer 1977). Thus, blue runner and horse mackerel, both comparably sized carangids, have similar life histories and feeding habits. Many of the zooplankton taken from my blue runner stomachs possessed relatively soft bodies (*Lucifer* spp., chaetognaths) and were smaller than fish or cephalopod prey. If such prey were digested at greater rates than fish, this could have led to underestimation of zooplankton weight contribution. Further information on the digestion rates of different prey types by blue runner will be required to evaluate this hypothesis.

Gut evacuation rates are also positively correlated with temperature in temperate (Popova and Sierra 1985; Buckel and Conover 1996) and cold water fish (Singh-Renton and Bromley 1996). Increased digestion rates by blue runner in the warm surface waters of the Gulf may have rapidly rendered many of the zooplankton prey unidentifiable. Haywood (1995) examined the digestion rates of penaeid postlarvae by a carnivorous fish *Monocanthus chinensis* held in warm water (25.3–28.5°C). Haywood estimated that after 3 h, rapid digestion could lead to a 33% underestimate in the number of postlarval prey in the stomach and a 75% underestimate in their dry weight. Rapid digestion may also lead to underestimation of the nutritional value of zooplankton prey in fish diets (Cortes 1997). Some fraction of the unidentifiable matter from blue runner stomachs that could not be associated with either zooplankton or fish prey likely came from zooplankton that were in advanced stages of digestion, however, correlation analysis would be required to evaluate this hypothesis.

At both platforms there was evidence that blue runner fed during the night and increased their feeding activity into the early morning. The daily feeding periodicity of blue runner does not appear to have been previously described. Other comparably sized, zooplanktivorous visual predators such as Atlantic mackerel (*Scomber scombrus*) reduce feeding rates with diminishing light intensity (Macy et al 1998). A reduction in light intensity decreased the reactive distance of *Lepomis macrochirus*, a zooplanktivorous particulate feeder, over a range of prey sizes (Vinyard and O'Brien 1976). All manned, and larger unmanned satellite platforms in the Gulf are equipped with large floodlights that illuminate the surrounding waters. This artificial light field may be sufficient to permit blue runner to extend their feeding into the night, since gut fullness values at night were comparable with those observed during the day.

Based on my statistical evaluation of the size selection for decapods, blue runner appear to consume more of the larger individuals present. These findings are limited, however, to the sizes of decapods and hyperiid amphipods collected by the surface plankton net. My examination of size selection was restricted to decapods because this was the only group of prey for which

there was a broad overlap in the size distributions in both the plankton net and in blue runner stomachs. Preferential selection of larger individuals of other prey types also appeared to take place, however, it could not be evaluated statistically. For example, larger hyperiid amphipods commonly found in blue runner stomachs are relatively strong swimmers and were absent from the net, presumably due to avoidance. Large chaetognaths were common in both the stomachs and the net, however, they were usually fragmented in the gut and I was not able to develop a reliable allometric regression to reconstruct intact lengths from fragments. Small zooplankton such as ostracods and copepods were present in the net samples but absent from stomachs further suggesting that blue runner actively select for large prey. Positive size selection for larger individuals follows precepts of optimal foraging theory, since larger prey items generally provide greater energetic value (Gerking 1994).

The appearance of zooplankton in the diets of blue runner does not directly establish a trophic linkage between the platform and their prey. Most of the plankton taxa consumed by blue runner were from holoplanktonic or meroplanktonic groups that likely were carried beneath the platform from pelagic waters rather than originating from the platform fouling community. Hyperiid amphipods are known for their association with gelatinous zooplankton (Bowman and Gruner 1973), but have not been reported to be associated with fouling communities. Little is known about the responses of amphipods and other zooplankton to the structure of a platform when encountered in the pelagic zone although, as discussed subsequently, many of these taxa are attracted to light.

While the predominant taxa in the diets of blue runner are not direct associates of platforms, there may still be a connection between the platforms and the prevalence of zooplankton in the diets of blue runner. Evidence for passive entrainment has been observed via flotsam, *Sargassum* and foam, which frequently accumulate beneath platforms. This is probably due to reduction in the current velocity and an increase in flow complexity as the prevailing current interacts with platform structure. Forristall (1996) measured the degree of current blockage near the Bullwinkle (GC65) platform in the Gulf with acoustic Doppler current profilers arranged in an outward looking horizontal plane at 18 meters depth. His findings indicated that the mean current velocity inside the platform structure was approximately 80% of the unimpacted up-current velocity, and reductions were even greater directly behind dense conductor casings. Decreases in current velocities coupled with an increase in eddy formation and vertical shear could allow zooplankton to extend their residence time beneath a platform, which would lead to an increase in the local zooplankton prey field.

The lights of large platforms may further increase zooplankton concentrations at night and enhance the effect due to currents alone. Many zooplankton, such as amphipods, display positive phototaxis and actively swim towards light. Light traps have proven to be an effective collection gear for zooplankton and ichthyoplankton around platforms (Ditty et al. 2000, Hernandez 2001) and the same organisms that predominate in blue runner stomachs (decapods, hyperiid amphipods, chaetognaths and small fish) are the dominant constituents of light trap samples. Comparisons of the catch per unit effort of hyperiid amphipods in light traps placed beneath, and down current from a large platform suggest that this group can accumulate beneath the platform at night (Keenan et al. 2000). The combined influence of the artificial light field and reduced current may cause platforms to act as large, passive zooplankton accumulators. Thus the

platforms may provide blue runner with enhanced densities of prey and an opportunity to feed around the clock. Such conditions could explain how large densities of blue runner and their predators can be sustained in the waters around platforms.

Chapter III
Zooplanktivory by Blue Runner (*Caranx crysos*) II:
A Comparison Between Platform-Associated and Non-Platform-Associated Fish

Introduction

The pelagic and reef-associated fishes found near offshore oil and gas platforms in the northern Gulf of Mexico (Gulf) draw large numbers of recreational anglers and SCUBA divers (Stanley and Wilson 1990). Reggio (1987) estimated over 70% of all recreational angling trips in the Exclusive Economic Zone (over 3 miles from shore) off Louisiana were to petroleum platforms. A logbook survey indicated many reef and pelagic species were taken by recreational anglers, which included: snappers (Family Lutjanidae), red drum (*Sciaenops ocellatus*), greater amberjack (*Seriola dumerili*), mackerels (*Scomberomorus* spp.), cobia (*Rachycentron canadum*) and many species of sharks (Stanley and Wilson 1990). It remains unclear why large numbers of fishes aggregate near platforms, however, Hastings et al. (1976) hypothesized a trophic linkage. They proposed predation on smaller baitfish (e.g., *Decapterus punctatus*, *Harengula pensacolae*, and *Sardinella* spp.) caused part of the attraction of larger pelagic species.

Platforms functioning as artificial reefs are hypothesized to enhance secondary productivity by increasing growth and survival of new individuals in a habitat-limited environment (Bohnsack 1989; Stanley and Wilson 1991). An alternative hypothesis is that platforms (and other artificial structures such as fish aggregating devices, FADs) merely attract and aggregate fishes from surrounding waters potentially leading to overexploitation. The attraction-production issue remains a debated theme in artificial reef design and management (Grossman et al. 1997; Lindberg 1997; Bohnsack et al. 1997; Shipp 1999). Ongoing research into fish movement patterns, site fidelity (Patterson et al. 2001), growth and trophic dynamics are addressing this issue on a species-specific basis. Mechanisms hypothesized to increase productivity through trophic linkages around structures include that they: 1) provide additional food; and/or 2) increase feeding efficiency of associated fish (Bohnsack 1989). Understanding the trophic dynamics of fishes near platforms is essential in evaluating the function of these structures as productive artificial reefs. Few studies have evaluated the feeding habits of the highly abundant species of fish around offshore petroleum platforms in the Gulf and none have focused on pelagic species.

The blue runner (*Caranx crysos*) is a pelagic species commonly found in waters around offshore platforms as well as in open waters of the Gulf (Sonnier et al. 1976; Stanley and Wilson 2000a). This medium-sized carangid (common to 400 mm fork length (FL)) is often found in large schools and ranges from Nova Scotia to Brazil (McKenney et al. 1958). A limited fishery exists in the U.S. with approximately 300 metric tons collected commercially and 763 metric tons from recreational fisheries during 1999-2000 (National Marine Fisheries Service 2000). In addition, they are harvested by an artisanal fishery in South America and marketed as food (Cervigón et al. 1993). Recreational anglers near Louisiana platforms frequently use blue runner as baitfish because of their abundance, hardiness, and attractiveness to larger gamefish. Stanley and Wilson (2000a) found that blue runner numerically constituted up to 94% of the fish assemblage found near a mid-shelf platform (GI94B) off Louisiana and school sizes commonly reached over 10,000 individuals.

Blue runner appear to play an important role in the diets of larger fish, however, little is known about adult blue runner feeding habits. Studies of larval and juvenile blue runner (up to 160 mm standard length) report that they fed on zooplankton, primarily cyclopoid and calanoid copepods (McKenney et al. 1958; Sckhekter 1972). Adult blue runner (greater than 190 mm FL) were considered primarily piscivorous (Randall 1967; Christmas et al. 1974), however, both studies were limited to anecdotal observations. Two adult (365 and 370 mm standard length (SL)) blue runner collected off Mississippi coastal waters contained anchovies and two mantis shrimp (*Squilla empusa*) while the stomachs of 17 mature fish (190-520 mm) from West Indies reef habitats contained "small silvery schooling" fish. In a recent feeding study of adult blue runner collected near two Louisiana mid-shelf platforms during 1996 and 1999, I found that macro-zooplankton comprise a large portion of their diet (Chapter 2).

I hypothesize that platforms may provide blue runner with an enhanced feeding environment. Blue runner are likely visual particulate planktivores that forage during daylight hours in ambient light. Platforms are well illuminated at night and this artificial light field allows blue runner to forage around the clock. In addition, these large, lighted structures may attract different prey taxa at night and this may influence blue runner feeding intensity and/or prey selectivity over the course of the diurnal cycle. The following objectives were formed to address these related hypotheses. The objectives of this study were: 1) to describe the food habits of platform-associated and open water adult blue runner; 2) to evaluate diel feeding periodicity and daily variations in blue runner feeding habits; and, 3) to examine prey type and prey size selectivity of platform-associated and open water fish.

Methods

Sites

Blue runner were collected during a series of cruises in the northern central Gulf from June to August 2000. Two platforms served as primary sampling sites for blue runner (Fig. 7), while one cruise was devoted to collecting blue runner in open waters. The three to four day cruises were made aboard an 11.3 m charter-fishing vessel, the C/V Admiral Semmes. This vessel was equipped with a global positioning system (GPS). GPS position was logged by a laptop computer at approximately 1s intervals. Vertical water column temperature profiles were measured with a VEMCO temperature-depth recorder (model TDR-8) and a CTD (YSI Model 6920 sonde).

Viosca Knoll 203A (VK203A) is a mid-shelf platform located approximately 70 km south of Dauphin Island, Alabama (29.7816 °N, 88.3330 °W) in 37 m of water. This platform is a four-leg structure with a complex wellhead adjoining the platform (Fig 7). Cruises were made to VK203A during 29 May – 1 June, 5–8 June, 17–20 July 2000. Main Pass 140A (MP140A) is an eight-leg structure in 45 m depth and is located approximately 30 km east of Venice, Louisiana (29.2947 °N, 88.8612 °W). Cruises were made to MP140A during 12–16 June and 26–29 June 2000. Another cruise was made to VK203A during 1–3 August 2000 to evaluate the diel feeding periodicity of blue runner by collecting replicate fish for 24 h at two-hourly intervals. An additional cruise from 6–9 August 2000 was designed to locate and catch blue runner from waters away from platforms. This cruise covered a large expanse of mid-shelf water

east of the Mississippi delta. In addition to collecting blue runner, during two trips to each of the platforms as well as in open waters, zooplankton samples were collected to evaluate prey availability. A summary of each trip is provided in Table 3.

Fish Collection

Blue runner were collected opportunistically using hook-and-line angling with artificial lures. The date and time of capture were recorded for each fish. Immediately following capture blue runner were anesthetized in a seawater ice bath for 15 minutes, which also served to slow digestion. Fish then were sacrificed by severing the spinal cord immediately posterior of the opercle. Fish weight was measured with a digital balance to the nearest 0.1 lb ($\pm$ 45g) and fork length (FL) and total length (TL) were measured to the nearest millimeter. The abdominal cavity was opened to determine sex of the fish (based on gonadal morphology and color) and to remove the stomach. Stomachs were removed by cutting at the posterior end of the esophagus and the pyloric sphincter. The stomach was injected with 10% buffered formalin and placed in a labeled jar containing formalin. All stomachs were transported to the laboratory, where they were rinsed and transferred to 70% ethanol preservative within two days after completion of each cruise.

Diet Evaluation

The contents of each stomach were flushed into a petri dish and examined under a dissecting stereomicroscope (70X). Prey items were categorized as hyperiid amphipods, larval and adult decapods and larval stomatopods, chaetognaths, cephalopods, fish, other invertebrates (e.g., thecosomate pteropods, copepods, ostracods, and polychaetes), and unidentified material. Taxa were assigned into the other invertebrate category when their contribution to the diets of all fish sampled was less than 1% by weight of the pooled weight of all prey items. Therefore, taxa in the other invertebrate category remained the same over the course of the study. The number of individuals for each prey taxa was recorded to estimate numerical contribution to the diet for each non-empty blue runner stomach. Wet weights were obtained by blotting surface fluids from the prey before weighing (Bowen 1996) and weight were recorded to the nearest milligram ($\pm$0.1mg). This provided estimates of weight contribution to the diet (Hyslop 1980) for all non-empty stomachs. Percent frequency of occurrence was also recorded for each category and is defined as the number of stomachs in which one or more items of a given food type was present expressed as a percentage of all non-empty stomachs examined (Bowen 1996). Unidentified material was defined as any amorphous tissue that could not be identified into any particular category above. The weight from this tissue was included in weight contribution to the diet, but was not included in numerical contribution or frequency of occurrence. An index of relative importance (IRI) for each prey taxa was computed for each blue runner by equation 1 (Chapter 2). A mean IRI for each prey taxa was computed by averaging the IRI values from blue runner caught during each cruise. The IRI for each prey item were then converted to %IRI using equation 2 (Chapter 2).

Open Water Blue Runner Diet

In addition to being found in large numbers around platforms, Cervigón et al. (1993) noted that blue runner travel in open water schools throughout the Gulf, an observation that I confirmed during research cruises. To evaluate whether there was a platform affect on prey selection, blue runner were caught in waters away from the influence of platforms. Blue runner were considered to be collected in open water if they were over 2.40 km from the nearest
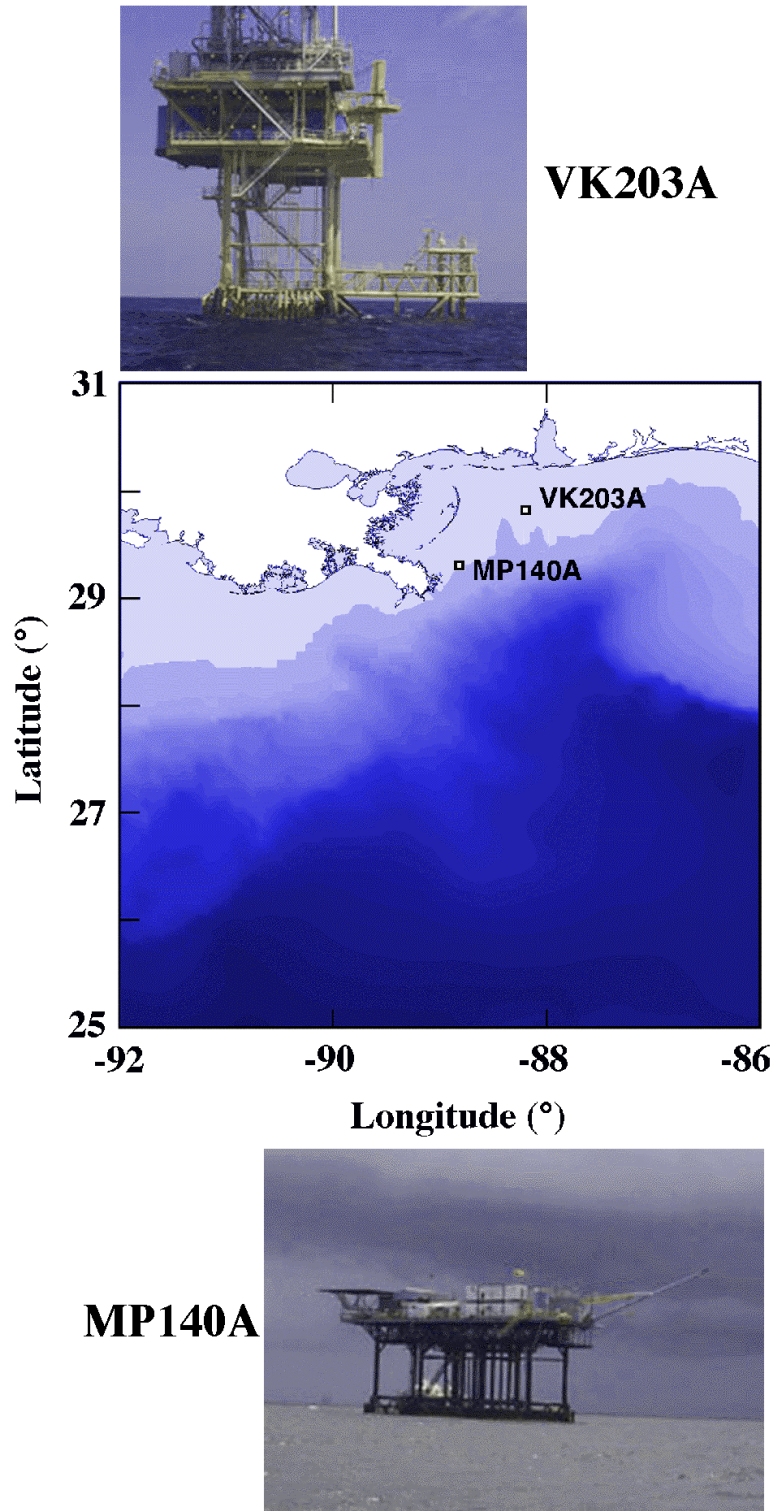
Figure 7. Geographical location and images of platforms for summer 2000 sampling trips. Sampling occurred near VK203A on 5–8 June, 17–20 July, 1–3 August, and trips to MP140A were during 12–16 June and 26–29 June 2000.

Table 3. Summary of sampling activities associated with quantification of blue runner diets for each cruise during summer 2000 research trips in the northern Gulf of Mexico.

Date	Destination	Objective (n = no. of blue runner collected)
30 May – 1 June	VK203A	Preliminary cruise, test equipment, identify suitable platforms
5–8 June	VK203A	Plankton net tows (1 day set, 1 night set), blue runner collection (n=20)
12–16 June	MP140A	Plankton net tows (2 day sets, 2 night sets), blue runner collection (n=21)
26–29 June	MP140A	Plankton net tows (2 day sets, 2 night sets), blue runner collection (n=25)
17–20 July	VK203A	Plankton net tows (2 day sets, 2 night sets), blue runner collection (n=22)
1–3 August	VK203A	Diel feeding study (n=117), open water blue runner collection (n=1)
6–9 August	Open water	Open water blue runner trip (n=13)

platform. This distance criterion was based on an estimate of the product of an estimated optimal cruising speed of 2*body lengths sec^{-1} (Videler 1993) for a 30 cm blue runner and an estimate of the time for prey breakdown (60 min). The latter value was based on measurements of the digestion time for postlarval penaeid shrimp by another planktivorous species held between 25°C and 28.5°C (Haywood 1995). The product of these swimming velocities and prey digestion time (2.16 km) were increased by 10% to provide a more conservative estimate of digestion time and space. This was to ensure that blue runner that may have fed near a platform and were subsequently captured, would have digested any prey items that were consumed at the platform. Fishing for open water blue runner occurred during transit to and from the platform. Blue runner were detected by observing bird activity or visually observing a school at the surface. The final cruise (6–9 August) was devoted to searching for open water schools. The fish were processed following the standard protocol and stomach contents were evaluated in the same manner as fish collected near platforms.

Zooplankton Sampling at Platforms

Zooplankton and micronekton were collected with a rectangular frame 92 cm X 94 cm (0.865 m^2) net (3 m length), equipped with 1 mm mesh and a flow meter (General Oceanics Model 2030). The net was lowered vertically over the stern of the boat to 15 m with the vessel pointed into the current and then the boat steamed up-current at approximately one knot while the net was retrieved using an electric winch. Each oblique tow lasted approximately three minutes and approximately 70–80 m^3 of water was filtered. A Vemco temperature-pressure datalogger (Model TDR-8) was fixed to the vertical midpoint of the net frame to record net trajectory. A set of net tows consisted of three replicate tows into the prevailing surface current on the up-current side of the platform. The tows were conducted during the first and second day and the first and second night of each platform trip. Two plankton samples also were collected near an open-water school by making tows on the up-current side of a surface drogue deployed near the center of the school. Plankton samples were preserved in 5% buffered formalin. After being transported to the laboratory, samples were transferred to 70% ethanol before being sorted and classified into the following taxonomic categories: hyperiid amphipods, larval and adult decapods and larval stomatopods, chaetognaths, fish and other invertebrates (e.g., thecosomate

pteropods, copepods, ostracods, polychaetes and cephalopods). Cephalopods were rarely seen in plankton net tows and were therefore placed into the other invertebrate category.

Feeding Periodicity

Diel feeding periodicity was evaluated in the same manner as that described in Chapter 2, however, during one cruise to VK203A from 1–3 August, continuous sampling of blue runner permitted an evaluation of feeding periodicity over a complete 24 hour cycle. During this cruise, approximately ten fish were caught every two hours and the stomachs were removed following the standard protocol. A modified stomach fullness index was computed from a gut fullness model adapted from Juanes and Conover (1994). Stomach fullness was computed by dividing the wet weight of all the prey taken from each stomach by the corresponding weight of the empty stomach. A stomach fullness index was then computed by dividing the fullness value of each fish by the maximum fullness value observed during the sampling. Therefore, a completely full stomach received a value of 1.0 and empty stomachs were assigned 0. The null hypothesis that stomach fullness indices did not vary during the diel sampling was tested using a Kruskal-Wallis test (proc npar1way, SAS v. 6.12). This non-parametric test was required because the residuals from the fullness values within two-hour blocks could not be normalized via transformation. Stomach fullness was evaluated for the open water fish caught during the 6–9 August cruise in the same manner as the fish collected during the diel feeding study. The maximum fullness value observed from the diel feeding study was used to compute the stomach fullness index for open water fish, since these two trips occurred within 5 days of one another. Fullness values from the open water fish were compared with those of platform blue runner caught during the same two-hour block.

In addition, the gravimetric percentage contribution of two predominant prey categories (fish and decapods/stomatopods) was computed for each blue runner within every two-hour time block during the diel feeding study. The difference between weight contribution was calculated for each blue runner by subtracting the weight contribution of decapods/stomatopods from the weight contribution of fish prey. If the prey were fed upon in equal quantities, the differences in weight contribution were expected to be zero and deviations from zero would indicate preferential selection for either prey. The differences within each two-hour block were tested against zero by using a t-test in the SAS proc means statement (SAS v. 6.12). The difference in gravimetric percentage contribution of fish and decapods/stomatopods were also computed for open water blue runner.

Prey Type Selectivity

Prey selectivity in blue runner was evaluated by comparing the numerical proportion of each prey item in the stomachs to the numerical proportion of the same prey items from the plankton nets. Numerical proportion in the plankton samples was determined from the mean proportions of the three replicate collections within a sample set. Selectivity was computed for five prey categories: hyperiid amphipods, decapods/stomatopods, chaetognaths, fish, and other invertebrates (e.g., pteropods, copepods, ostracods, polychaetes and cephalopods). These prey items were selected because they occurred frequently in both the plankton net (with the exception of cephalopods) and in blue runner stomachs. Feeding selectivity was evaluated for any time where at least five blue runner were caught within ± 1 h of corresponding plankton samples. Chesson's index (Chesson 1983) was used to examine prey type selectivity:

$$\alpha_i = \frac{\left(\dfrac{r_i}{p_i}\right)}{\sum \dfrac{r_j}{p_j}} \text{ for } j = 1 \text{ to } m \tag{5}$$

where α_i is the selectivity for the ith prey type for an individual blue runner; r_i is the numerical proportion of the ith prey type in an individual blue runner stomach; p_i is the numerical proportion of the ith prey type in the environment; and m is the number of prey types (categories).

Mean alpha values for each prey category were calculated by averaging individual alpha values for all blue runner caught during corresponding plankton net sets. Non-selective feeding occurs when $\alpha_i = 1/m = 0.2$, positive selection when $\alpha_i > 1/m$, and negative selection (avoidance) when $\alpha_i < 1/m$. Significance was evaluated using a t-test comparing mean α_i with $1/m$ for each prey category within each blue runner/zooplankton collection (Chesson 1983). In addition to analyzing selectivity for blue runner groups of 5 or more, all platform-associated blue runner caught during daytime plankton sampling and during the nighttime plankton sampling were pooled, respectively, to estimate the influence of time of day on feeding selectivity. This analysis included blue runner that were not analyzed as a group because fewer than five were collected during corresponding plankton net tows. Further, open water blue runner caught during the 6–9 August cruise were compared to the net tows conducted in the vicinity of the fish school and selectivity was evaluated and compared to that of platform associated fish.

Prey Size Selection
Size-selective feeding on zooplankton and fish prey was evaluated by comparing the size distributions of fish and decapod/stomatopod prey items taken from blue runner stomachs to the size frequency of decapod/stomatopod and fish taken from plankton net sets. Only blue runner collected within ± 1 h of plankton net tows were used in this analysis. The number of blue runner used for this analysis varied because not every blue runner that was collected during plankton net tows contained fishes, decapods, or a combination of both prey types. For the 12–16 June trip, decapod prey lengths were taken from 14 blue runner caught during the daytime and four during the nighttime, while decapods from six daytime and five nighttime blue runner were measured from the 26–29 June trip. Measurements of fish prey were recorded for three daytime and two nighttime blue runner from 12–16 June, and from one daytime and two nighttime blue runner during the 26–29 June trip. From the open water trip, decapod prey was measured from six blue runner and fish prey were measured from four blue runner.

Decapods/stomatopods and fishes collected from plankton nets and blue runner stomachs were measured using a digital camera/microscopy system (Pixera VCS 1.2.3) and image processing software (NIH Image 6.12, see Chapter 2 for further detail). Organisms were placed into 0.5 mm size classes, with the exception of decapods smaller than 2.5 mm and larger than 14 mm, and fish smaller than 4 mm and larger than 14 mm, which were pooled to assure adequate sample sizes in all prey size categories. Measurements were recorded for over 400 decapods and 100 fish that were collected from each of the daytime and nighttime plankton net sets from each trip.

Size selection for decapod and fish prey were examined using: Chi-square test and Chesson's alpha test. These analyses provided two methods for testing the null hypothesis that the proportion of prey items within each size class did not differ significantly between the plankton net and blue runner stomachs. The chi-square test is a traditional approach to evaluating goodness of fit between two frequency distributions (Sokal and Rohlf 1981), whereas the Chesson's alpha test evaluates the "preference" for particular food types for each individual predator and allows an estimate of variability. The chi-square test was the same as that explained in Chapter 2. The expected frequency of prey in each size class was computed as the product of the fraction of individuals in the size class from the plankton net and the total number of individuals from pooled blue runner stomach samples within a particular sampling period (i.e., daytime or nighttime). A Chi-square statistic (df=1) was computed for the ith size class using equation 3. There were instances where organisms within a particular size class were not observed in plankton nets and consequently, a Chi-square value could not be calculated for these size classes even if organisms within the size class were observed in blue runner stomachs.

Chesson's index of selectivity also was used to examine prey size selectivity for decapods and fish prey (Chesson 1983; Buckel et al. 1999). The use of this index was similar to its use in the prey type selectivity calculations; however, size class was substituted for prey type.

$$\alpha_i = \frac{\left(\dfrac{r_i}{p_i}\right)}{\sum \dfrac{r_j}{p_j}} \text{ for } j = 1 \text{ to } m \tag{6}$$

Where α_i is the selectivity for the ith size class for an individual blue runner, r_i is the numerical proportion of the ith size class in an individual blue runner stomach, p_i is the numerical proportion of the ith size class in the environment, and m is the number of size classes.

Alpha values for each size class were averaged among all blue runner caught during corresponding plankton sets. The same α_i criteria used for prey type selection (non-selective, positive and negative selection) were used to evaluate prey size selectivity. Prey size selectivities were statistically evaluated using a t-test, comparing mean α_i with 1/m for each size class (1/m = 0.040 for decapods/stomatopods and 1/m = 0.048 for fishes) within each blue runner/zooplankton collection (Chesson 1983). Size selectivity was evaluated for blue runner caught from each platform trip and from the open water trip. To further examine the influence of time of day on size selection, blue runner collected during the daytime and nighttime hours were each pooled.

Results

Fish Collection

A total of 205 blue runner were caught near platforms, while 14 were taken from open water environments. Relatively few open water blue runner were collected because high sea states made it difficult to locate surface schools during most trips and fish in surface schools that were located were generally difficult to catch, possibly because of avoidance reactions to the vessel. Mean blue runner lengths were 282.0 mm FL (±2.8 mm SE) from platform waters and 301.8 mm FL (±7.4 mm SE) from open waters. These mean lengths were not significantly

different (t-test p > 0.05, proc glm SAS). Catches of blue runner at platforms varied among trips. At least 20 blue runner were collected during each platform trip, however, the majority of fish (n=117) were collected during the diel sampling study during 1–3 August.

Hydrography
        During every trip except one, the upper 15 m of the water column appeared thermally well mixed (Fig. 8). The 17–20 July trip to VK203A showed evidence of thermal stratification above 9–10 m and a thermocline below this zone with temperature decreasing from 28 °C at 9 m to 22 °C at 15 m. From other platform trips temperature did not vary more than three degrees from 1 m to 15 m during day or night. The average daytime surface temperature increased approximately four degrees over the course of the summer from 26°C in early June to 30°C in early August. The open water trip showed slightly higher surface temperatures than three out of the four platform trips, but comparison of the surface temperature of the open water trip to the mean of the platform trips showed no significant difference (t-test p > 0.05, df=3; Sokal and Rohlf 1981).

Diet Evaluation
        The majority of blue runner diets consisted of zooplankton. Based on the stomach contents of blue runner collected during all 6 trips, zooplankton made up 81%, 90% and 97% of the numerical composition of blue runner diets at VK203A, MP140A and open waters, respectively (Fig. 9). Percent composition by prey weight also indicated that zooplankton constituted a large portion of the diet. Excluding unidentified prey, zooplankton formed 43% of the weight of blue runner diets at VK203A and MP140A, respectively, and 56% of the weight of the diets of the open water fish. The majority of zooplankton prey weight consisted of decapods and larval stomatopods for both platform and open water fish. Open water blue runner, however, had greater amounts of chaetognaths in their stomachs (20% by weight) than platform blue runner. Unidentified tissue, which could not be placed into a specific prey category, remained relatively consistent between platforms and open water fish (approximately 30–40% of total prey weight).

        The IRI values indicate that the diet of blue runner remained relatively consistent between platforms and did not vary greatly among trips (Table 4). Larval and adult decapods and larval stomatopods were the most important prey category over all platform sampling trips, although during the 1–3 August trip to VK203, there was an increase in the importance of fish and cephalopods (Table 4). Decapods/stomatopods and chaetognaths dominated the diet of blue runner at open water sites, while fish were less prevalent on both a numerical and a gravimetric basis (Table 4). Chaetognaths increased in importance in the diet of open water fish, compared to platform associated blue runner, because 11 out of 13 fish stomachs contained numerous individuals of this prey category. The percent IRI value for chaetognaths during the open water trip (33.8%) was much greater than was observed for platform-associated fish (~1% over all trips).
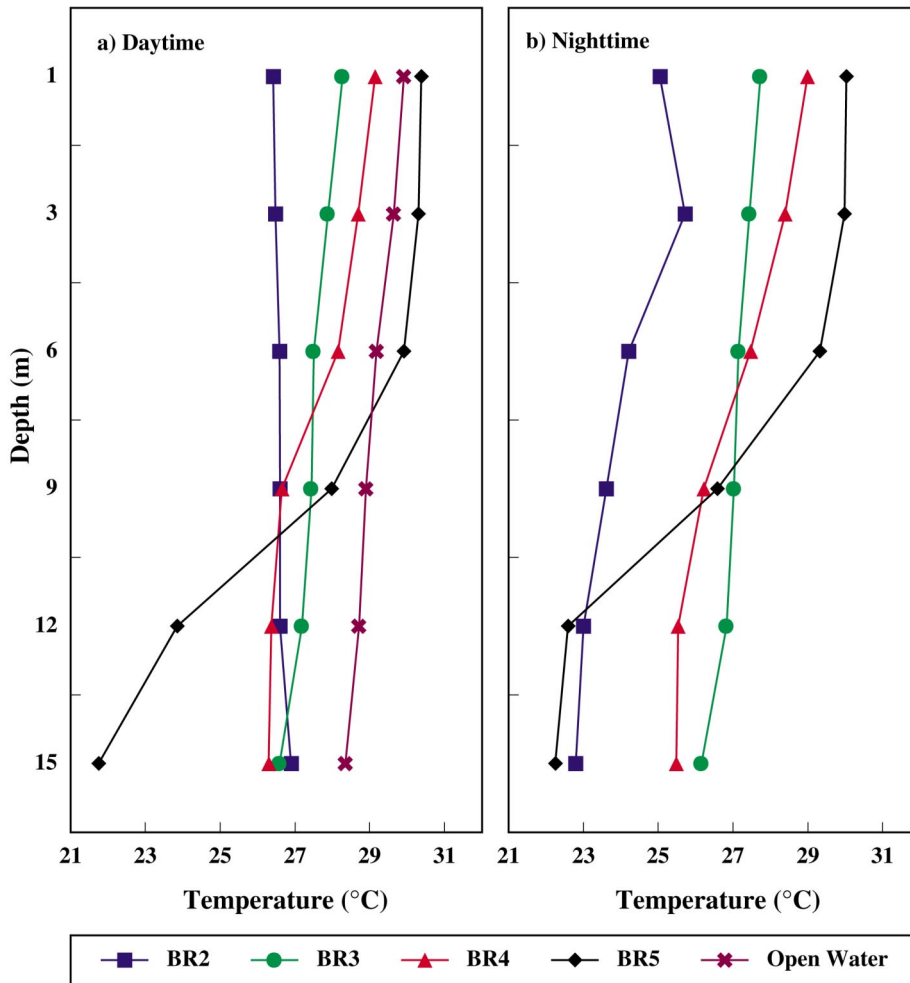
Figure 8. Temperature depth diagrams for each trip during a) day and b) night. BR2: 5–8 June (VK203A); BR3: 12–16 June (MP140A); BR4: 26–29 June (MP140A); BR5: 17–20 July (VK203A) and Open Water corresponds to the 6–9 August trip near an open water school. All trips show upper 15m well mixed, with the exception of BR5, which showed temperature stratification at approximately 9–10m.
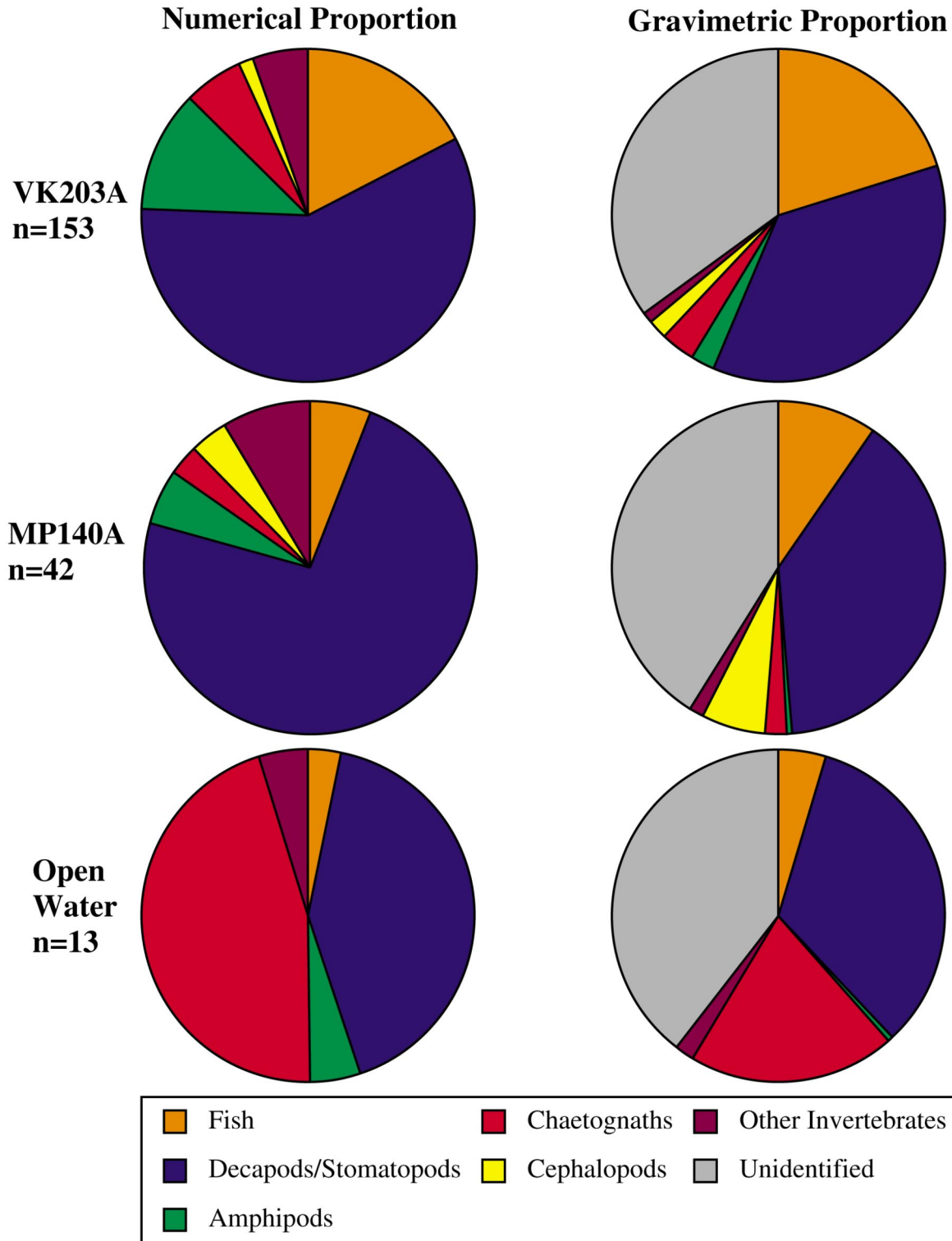
Figure 9. Numerical proportion (left column) and gravimetric proportion (right column) for the prey items in the diets of blue runner from the summer 2000 sampling trips. The proportions are pooled over all blue runner from the two trips each to VK203A and to MP140A.

Table 4. Summary of blue runner diet for all sampling trips to VK203A and MP140A. Numerical proportion (%N), Weight proportion (%W), Frequency of Occurrence (%F.O.) and Index of Relative Importance (I.R.I.) values are indicated for each prey category.

Trip	Blue Runner (empty stomachs)	Prey category	% N	% W	% F.O.	I.R.I. value	% I.R.I.
		Summer 2000					
5–8 June (VK203)	20 (0)	Decapods/Stomatopods	66.8	41.4	100.0	14003.0	78.1
		Hyperiid Amphipods	13.1	2.1	90.0	1573.3	8.8
		Chaetognaths	2.9	1.0	25.0	122.7	0.7
		Fish	5.7	4.2	60.0	833.7	4.7
		Other Invertebrates	10.0	3.4	75.0	1287.0	7.2
		Cephalopods	1.5	4.7	15.0	97.9	0.5
		Unidentified		43.2			
12–16 June (MP140A)	20 (1)	Decapods/Stomatopods	66.2	36.2	95.0	13264.9	83.8
		Hyperiid Amphipods	10.5	0.9	55.0	668.4	4.2
		Chaetognaths	0.6	0.2	10.0	8.8	0.1
		Fish	5.3	10.8	30.0	491.3	3.1
		Other Invertebrates	17.4	2.9	45.0	1393.1	8.8
		Cephalopods	0.0	0.0	0.0	0.0	0.0
		Unidentified		49.0			
26–30 June (MP140A)	22 (3)	Decapods/Stomatopods	80.0	41.7	95.5	14586.9	91.2
		Hyperiid Amphipods	0.7	0.2	31.8	32.5	0.2
		Chaetognaths	5.3	3.9	36.4	382.3	2.4
		Fish	6.4	8.5	45.5	704.0	4.4
		Other Invertebrates	0.5	0.1	22.7	25.1	0.2
		Cephalopods	7.1	11.9	13.6	259.9	1.6
		Unidentified		33.7			
17–20 July (VK203A)	20 (2)	Decapods/Stomatopods	79.1	52.7	95.0	15670.3	89.2
		Hyperiid Amphipods	4.3	0.4	60.0	327.3	1.9
		Chaetognaths	0.5	0.1	20.0	12.5	0.1
		Fish	9.3	8.2	55.0	1128.8	6.4
		Other Invertebrates	6.8	1.0	50.0	422.3	2.4
		Cephalopods	0.0	0.0	0.0	0.0	0.0
		Unidentified		37.6			
1–3 August (VK203A) (Diel feeding periodicity)	113 (4)	Decapods/Stomatopods	53.0	32.3	82.3	8942.5	67.1
		Hyperiid Amphipods	12.9	2.6	54.0	941.8	7.1
		Chaetognaths	7.3	4.3	31.9	433.4	3.3
		Fish	21.0	25.2	54.9	2819.9	21.2
		Other Invertebrates	4.3	0.7	30.1	165.9	1.2
		Cephalopods	1.5	1.8	5.3	18.0	13.5
		Unidentified		33.1			
6–9 Aug Openwater	13 (1)	Decapods/Stomatopods	41.7	33.4	100.0	9979.1	53.6
		Hyperiid Amphipods	4.9	0.5	84.6	480.5	2.6
		Chaetognaths	45.4	20.1	84.6	6286.2	33.8
		Fish	3.2	4.6	92.3	1066.4	5.7
		Other Invertebrates	4.8	1.9	92.3	797.4	4.3
		Cephalopods	< 0.1	< 0.1	7.7	0.4	< 0.1
		Unidentified		39.5			

Diel Feeding Periodicity

Blue runner did not exhibit a statistically significant peak in feeding during the diel sampling trip (Fig. 10), however, the pattern of gut fullness values indicated elevated feeding intensity during early evening and pre-dawn hours. Gut fullness values during the 02:00–03:00 h (0.186 ± 0.096) and 04:00–05:00 h (0.139 ± 0.039) suggested that blue runner are capable of feeding during nighttime at levels that can exceed daytime levels. The gut fullness value during 18:00–19:00 h (0.142 ± 0.084) also indicated that blue runner feed at dusk. Time of day had a significant effect on gut fullness values (proc npar1way, $p < 0.002$, df=11), however, multiple comparison tests were unable to determine which times of day (2 h blocks) were significantly different. Stomach fullness from the 14 fish caught during the open water trip had comparable fullness values (0.105 ± 0.018) to blue runner caught during 18:00–19:00 h on the diel trip (Fig. 10).

Fish and decapod/stomatopod prey predominated the diets of blue runner caught during the diel sampling study (Table 4, %W), however, the gravimetric contribution of these two prey groups shifted over the course of 24 hours (Fig. 11). Decapods and stomatopod larvae were more prevalent as prey in the diet during daytime hours with a shift towards fish prey during the night (Fig. 10). Fish prey comprised a significantly greater weight component of the diet than decapods/stomatopods from 22:00 to 01:00 h. Blue runner from the open water trip ($n = 11$) contained similar gravimetric proportions of fish and decapod/stomatopod prey as blue runner collected during the same time of day from the diel sampling study at VK203A.

Prey Type Selectivity

There was no clear evidence of a platform-specific pattern in prey selectivity. Daytime prey selectivity indicated that blue runner near platforms frequently selected prey disproportionately to their relative abundance in the environment; however, these selection patterns were often non-significant (Table 5). For example, during daytime samples from the platforms, decapods/stomatopods were positively selected for, however, in only one instance was this selection significant (12–16 June, $\alpha = 0.414$, t-test vs. 0.2, $p < 0.05$). Amphipods were positively selected for during all daytime collections, however, alpha values did not indicate significant selection (Table 5). Fish were significantly avoided in three out of the five trips where daytime blue runner were collected near platforms. Chaetognaths and other invertebrates were significantly avoided during three of the five daytime samples. These prey type selectivity patterns were generally consistent during similar times of the day among sampling trips to each platform.
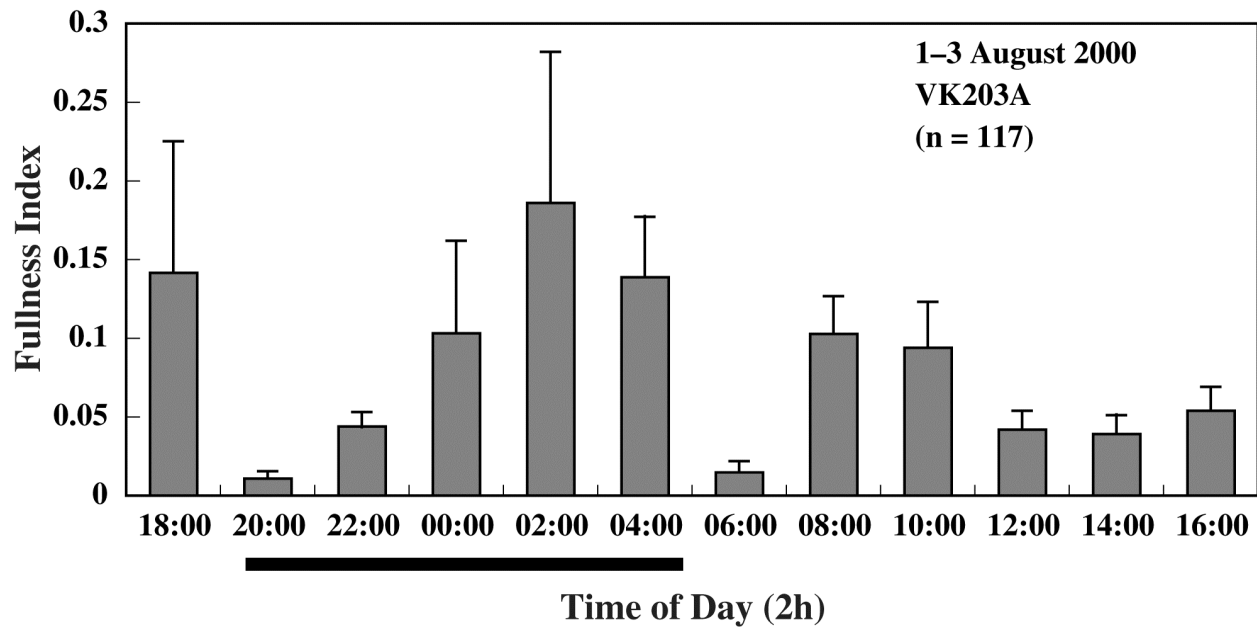
Figure 10. Fullness index for blue runner (n=117) collected during the diel sampling trip (1–3 August 2000) to VK203A. The horizontal black bar indicates nighttime and error bars are SE.
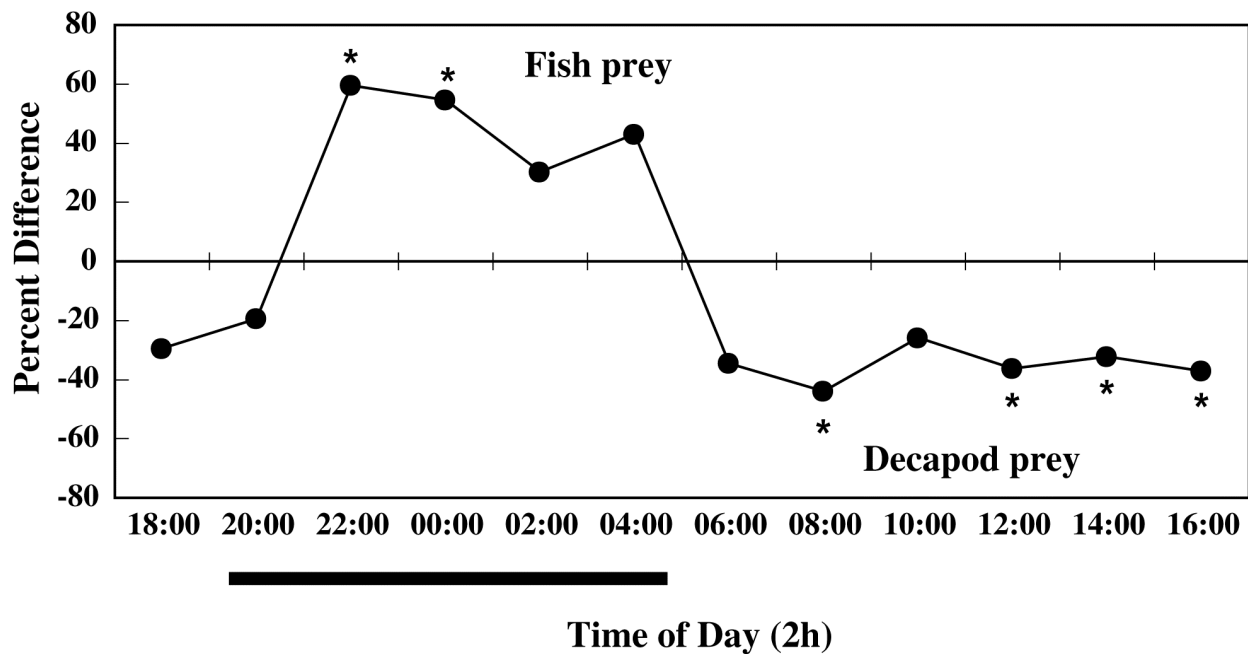
Figure 11. Difference in weight contribution to the diet during the diel sampling trip for fish and decapod/stomatopod prey. Positive difference signifies diet dominated by fish prey and negative differences indicate decapod/stomatopod prey. Significant differences ($p < 0.05$) in weight contribution to the diet by hour are indicated by asterisks (*).

Table 5. Daytime prey type selectivity showing average alpha values for each prey category during samples with n≥ 5 blue runner. Significance of feeding selectivity was evaluated with a t-test to determine whether selection was positive (+, $\alpha > 1/m$) or negative (−, $\alpha < 1/m$). The 12–16 June and 26–29 June samples were from MP140A and 17–20 July was from VK203A.

Prey Type	12–16 June Day (n=14)	26–29 June Day 1 (n=6)	26–29 June Day 2 (n=9)	17–20 July Day 1 (n=5)	17–20 July Day 2 (n=5)
Fish	0.058 ± 0.038 (−)	0.029 ± 0.029(−)	0.308 ± 0.091	0.017 ± 0.017 (−)	0.158 ± 0.058
Decapods/ Stomatopods	0.414 ± 0.091 (+)	0.524 ± 0.154	0.352 ± 0.126	0.510 ± 0.201	0.354 ± 0.078
Amphipods	0.260 ± 0.091	0.131 ± 0.131	0.248 ± 0.103	0.472 ± 0.194	0.393 ± 0.162
Chaetognaths	0.019 ± 0.018 (−)	0.210 ± 0.127	0.064 ± 0.040 (−)	0.000 ± 0.000 (−)	0.057 ± 0.031 (−)
Other Inverts	0.248 ± 0.099	0.105 ± 0.105	0.029 ± 0.015 (−)	0.002 ± 0.002 (−)	0.039 ± 0.025 (−)

Selectivity for prey was affected by time of day and presence of a platform. Prey type selectivity was evaluated for 39 pooled blue runner during the day and 18 at night near platforms while 11 blue runner were evaluated from open waters (Table 6). During daytime, platform-associated blue runner significantly selected for decapods/stomatopods ($\alpha = 0.421$, t-test vs. 0.2, $p < 0.001$). These fish also significantly avoided fish, chaetognaths, and other invertebrates and were non-selective of hyperiid amphipods. During the night around platforms, this pattern changed when blue runner significantly avoided decapods/stomatopods ($\alpha = 0.077$, $p < 0.05$) and begun to show positive selection for fish prey ($\alpha = 0.353$, $0.10 > p > 0.05$) and other invertebrates ($\alpha = 0.277$, $p > 0.10$), although variability among fish rendered the latter two trends non-significant. Open water blue runner significantly selected only for amphipods ($\alpha = 0.534$, $p < 0.01$), while showing avoidance of decapods/stomatopods ($\alpha = 0.094$, $p < 0.01$) and other invertebrates ($\alpha = 0.012$, $p < 0.01$). Open water blue runner were non-selective in feeding on fish prey ($\alpha = 0.152$, $0.10 > p > 0.05$) and chaetognaths ($\alpha = 0.208$, $p > 0.10$).

Table 6. Combined prey type selectivity data for time of day from platform and open water blue runner. Alpha values are averaged over all blue runner collected during noted times of day. Selective feeding was examined with a t-test to determine if selection was positive (+, $\alpha > 1/m$), negative (−, $\alpha < 1/m$) or neutral (no sign).

Prey Type	Day (n = 39)	Night (n = 18)	Open water (n = 11)
Fish	0.119 ± 0.031 (−)	0.353 ± 0.101	0.152 ± 0.030
Decapods/ Stomatopods	0.421 ± 0.055 (+)	0.077 ± 0.055 (−)	0.094 ± 0.018 (−)
Amphipods	0.282 ± 0.055	0.293 ± 0.094	0.534 ± 0.053 (+)
Chaetognaths	0.061 ± 0.024 (−)	0.000 ± 0.000 (−)	0.208 ± 0.043
Other Invertebrates	0.117 ± 0.041 (−)	0.277 ± 0.097	0.012 ± 0.002 (−)

<u>Prey Size Selection</u>

        Blue runner around platforms exhibited size selective feeding for intermediate sized decapods and smaller fish prey during the day. Blue runner selected for 9.5–12.5 mm decapods for both the 12–16 June and 26–29 June platform trips (Fig. 12, 13). The Chesson's alpha test indicated significantly positive selection ($\alpha = 0.13$ vs. $1/m$ (0.04), $t = 2.17$, $df = 24$, $p < 0.05$) only for the 9.0 mm (June 26–29) and 9.5 mm (June 12–16) size categories. Further, the Chi-square test showed significant negative selection for many of the smaller decapods (3.5–7.5 mm) collected by the plankton net. Evaluation of the selection for different sized fish prey was constrained because fewer blue runner stomachs contained fish prey during the day. Where it could be evaluated, selectivity was opposite to that observed for decapod prey with primarily smaller fish selected during the day. Daytime blue runner from both platforms fed on 4–8 mm ichthyoplankton (Fig. 14, 15), which represented the small to intermediate size range collected by the net. Chi-square and Chesson's alpha indicated significant positive selection from the June 26–29 cruise, although this result is based solely on the stomach contents of the only blue runner with fish prey (Fig. 15). When pooled over platforms (Fig. 16), Chesson's alpha showed that blue runner fed on the intermediate sized decapods (9–12.5 mm) and smaller sized fish prey (<9 mm) during the day.

        During night foraging around platforms, both Chi-square and Chesson's alpha test indicated decapods greater than 14 mm were highly selected (Fig. 17, 18). Decapod/stomatopod prey below 12 mm in length were generally not observed in blue runner stomachs at nighttime. Blue runner from each platform fed on larger sized fish and generally fish prey larger than that collected by the net (Fig. 19, 20). Pooled alpha values increased the sample size to nine blue runner with decapod prey and four with fish prey (Fig. 21). The results were similar for both decapod and fish prey with larger (>14 mm) prey consumed by blue runner.

        From open water fish, positive selection was shifted to smaller sized decapods (3.5–5.5 mm), although many of the larger size classes present in blue runner stomachs were not sampled by the plankton net (Fig. 22). Decapods/stomatopods between 6 and 10 mm were significantly avoided by open water blue runner. Open water blue runner did not display distinct size selectivity patterns for fish prey (Fig. 23) and feeding was observed for both larger (>14 mm) and smaller (<7 mm) fish. Significant selection for any particular size of fish prey was not detected by the Chesson's alpha test suggesting random or non-selective feeding. Thus, the size selectivity displayed by blue runner in open waters was similar to that observed at platforms during the day.

36

Figure 12. Daytime size selection for decapod/stomatopod prey from blue runner (n=14) during the 12–16 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection or avoidance is indicated with a (+) or (–), respectively.

Figure 13. Daytime size selection for decapod/stomatopod prey of blue runner (n=6) from 26–29 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection or avoidance is indicated with a (+) or (–), respectively. The zeros (0) indicate when this size class did not occur in a blue runner stomach and the N/A indicates this size class was not observed in the plankton net.
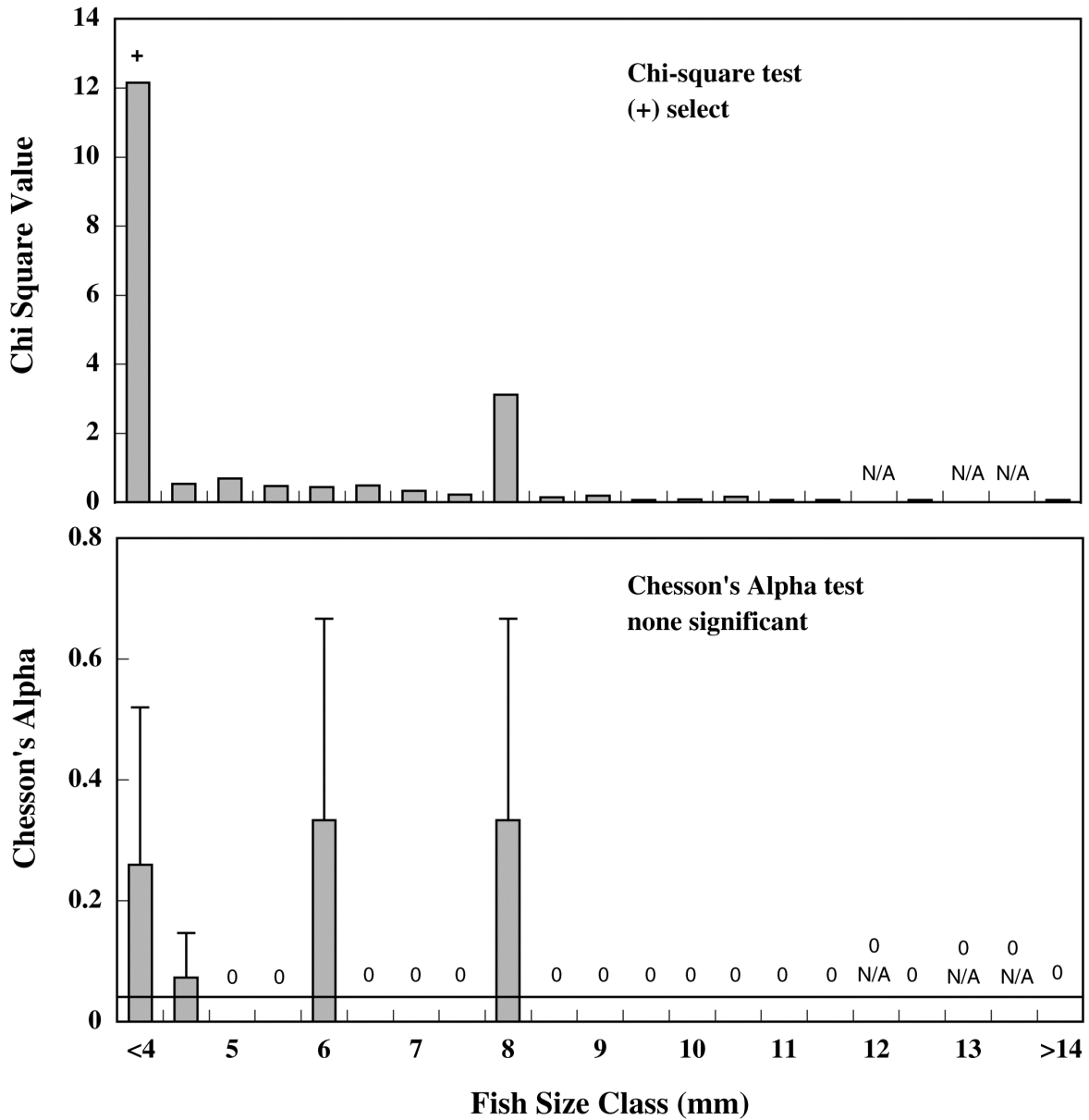
Figure 14. Daytime size selection for fish prey of blue runner (n=3) from the 12–16 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection is indicated with a (+). The zeros (0) indicate when this size class did not occur in the blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.
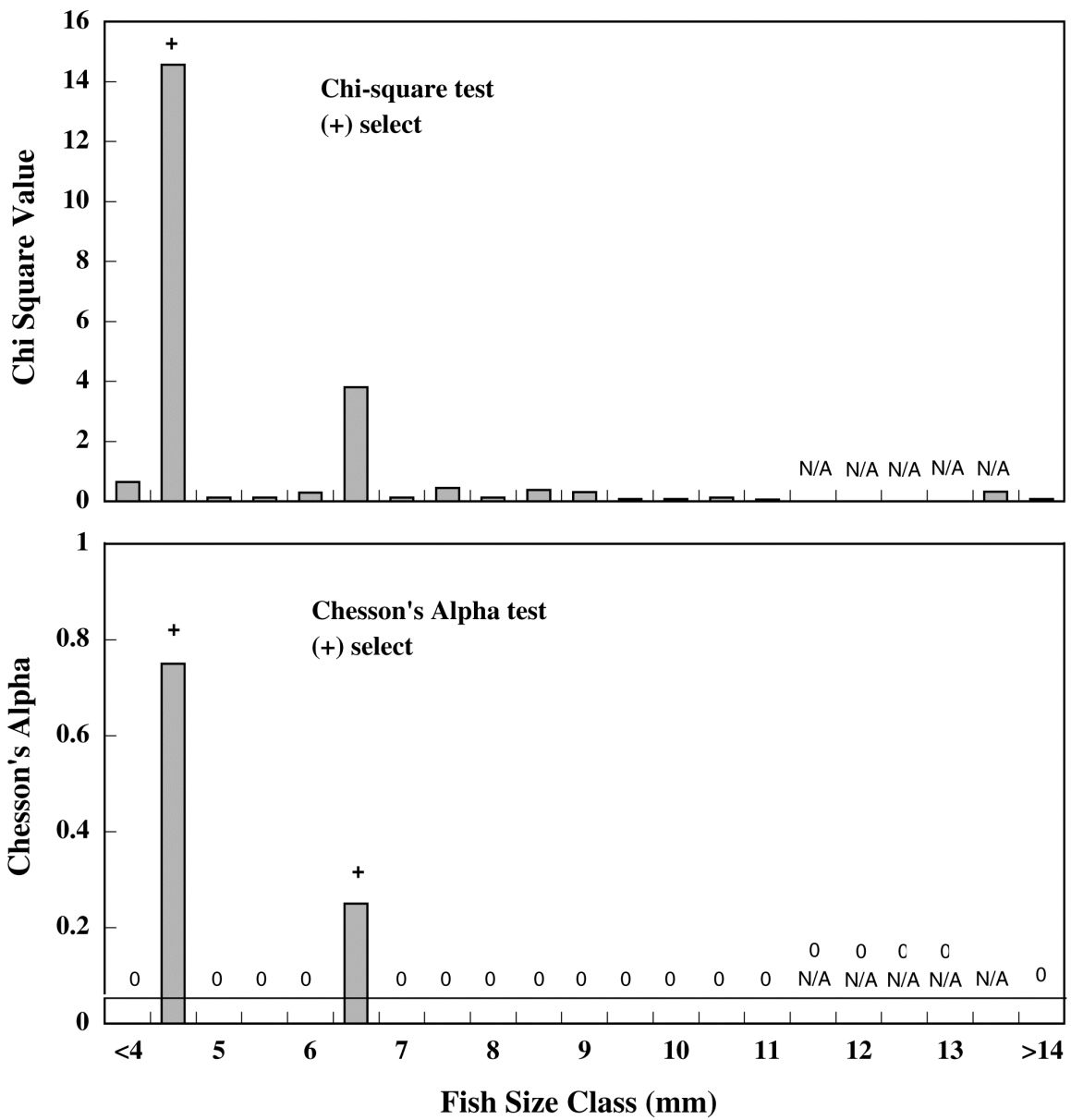
Figure 15. Daytime size selection for fish prey of blue runner (n=1) from the 26–29 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection is indicated with a (+). The zeros (0) indicate when this size class did not occur in the blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.
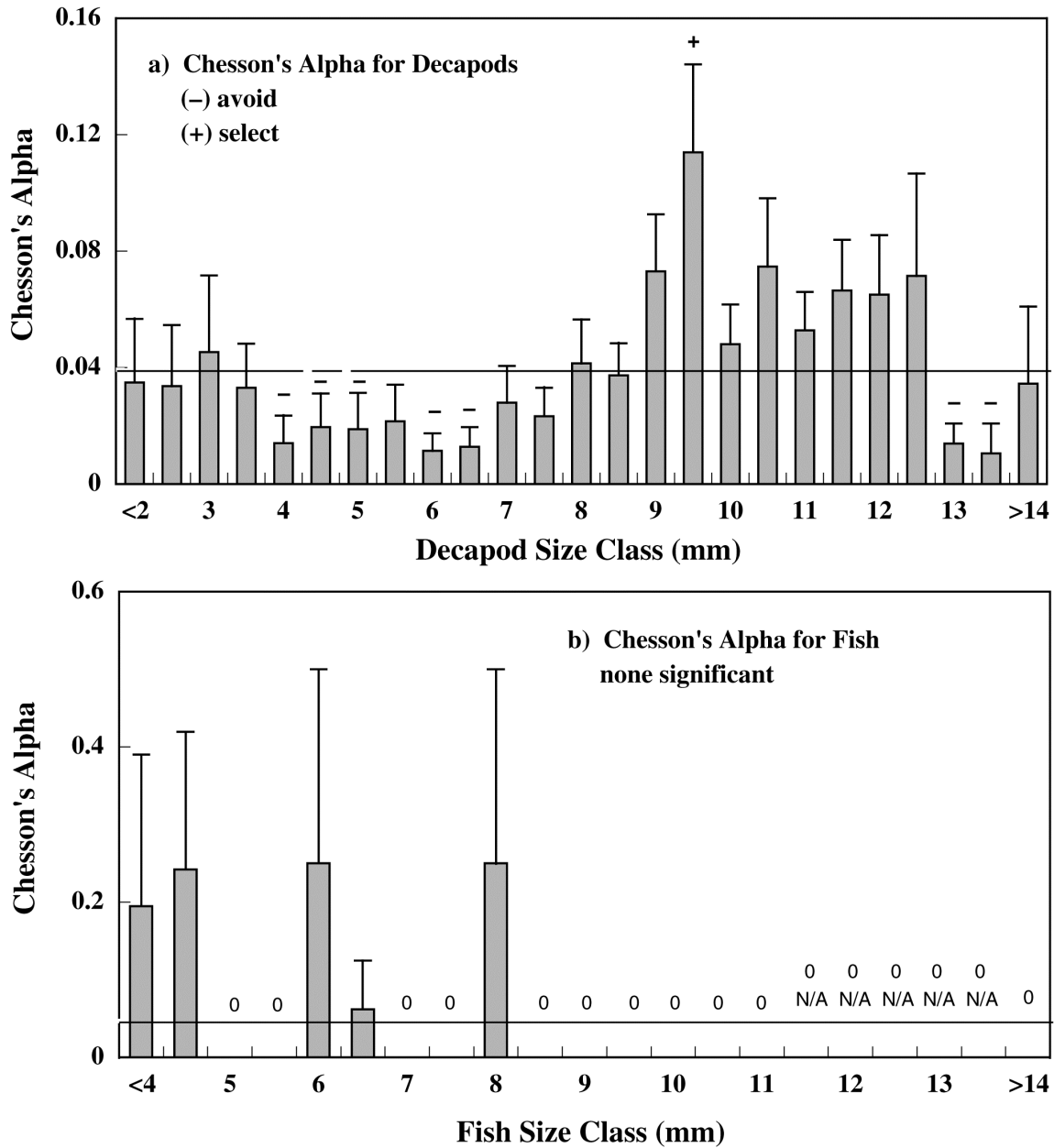
Figure 16. Daytime Chesson's alpha selectivity test for a) decapods (n=20 blue runner) and b) fish (n=4 blue runner) for blue runner pooled over 12–16 June and 26–29 June trips to MP140A. Significant selection or avoidance is indicated with a (+) or (−), respectively. The zeros (0) indicate when this size class did not occur in the blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.
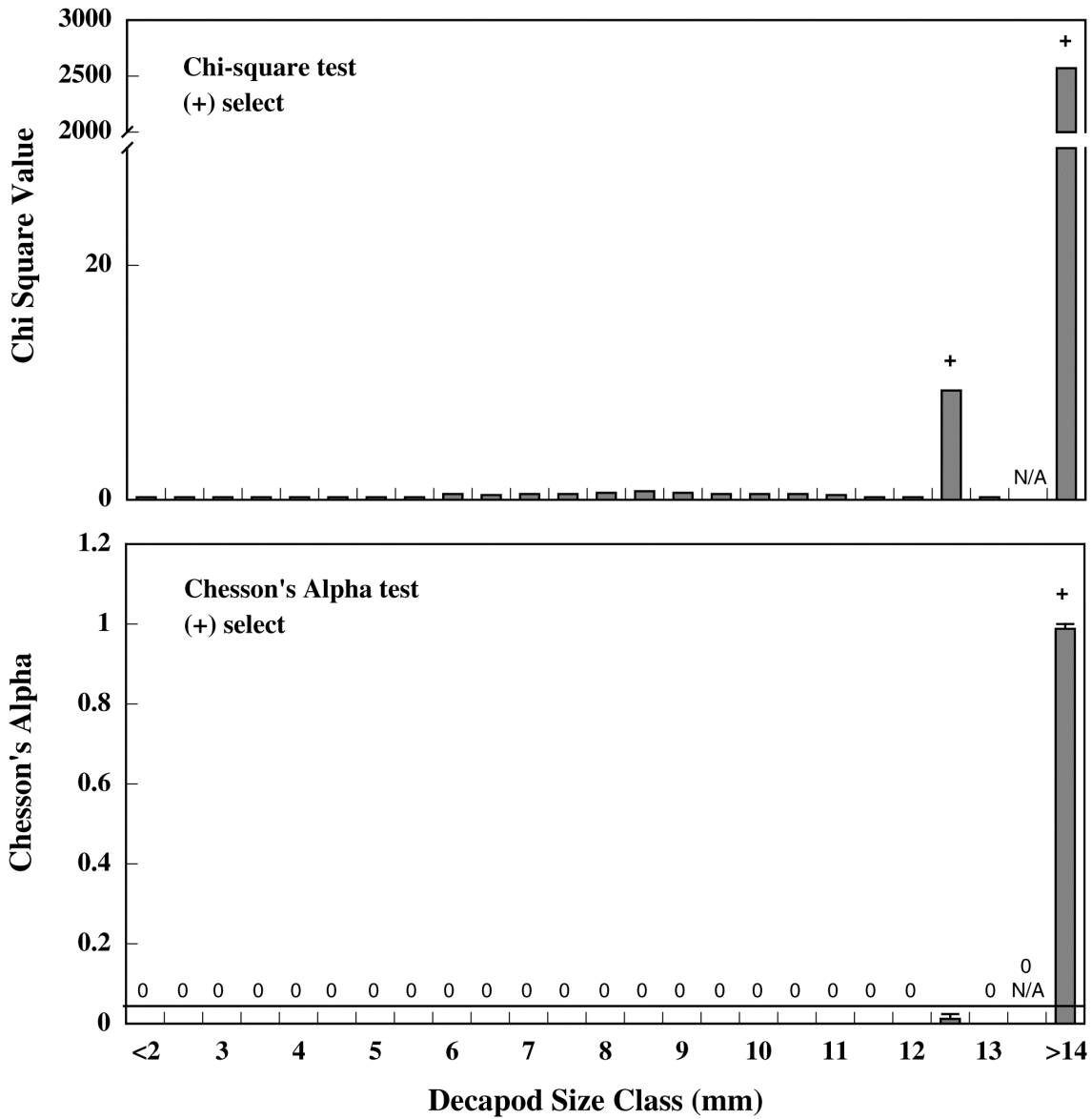
Figure 17. Nighttime size selection for decapod/stomatopod prey by blue runner (n=4) during the 12–16 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection is indicated with a (+). The zeros (0) indicate when this size class did not occur in a blue runner stomach and the N/A indicates this size class was not observed in the plankton net.
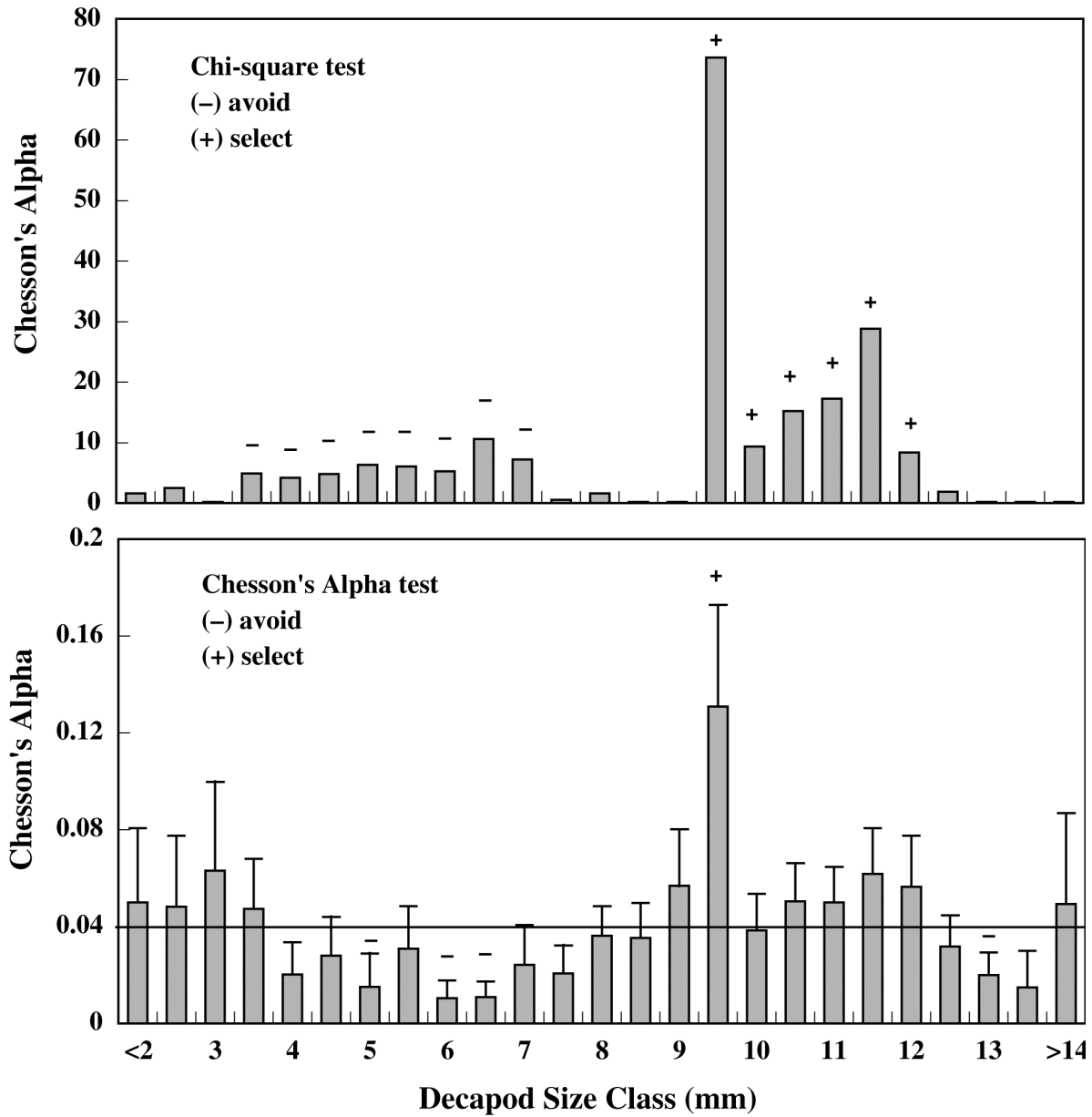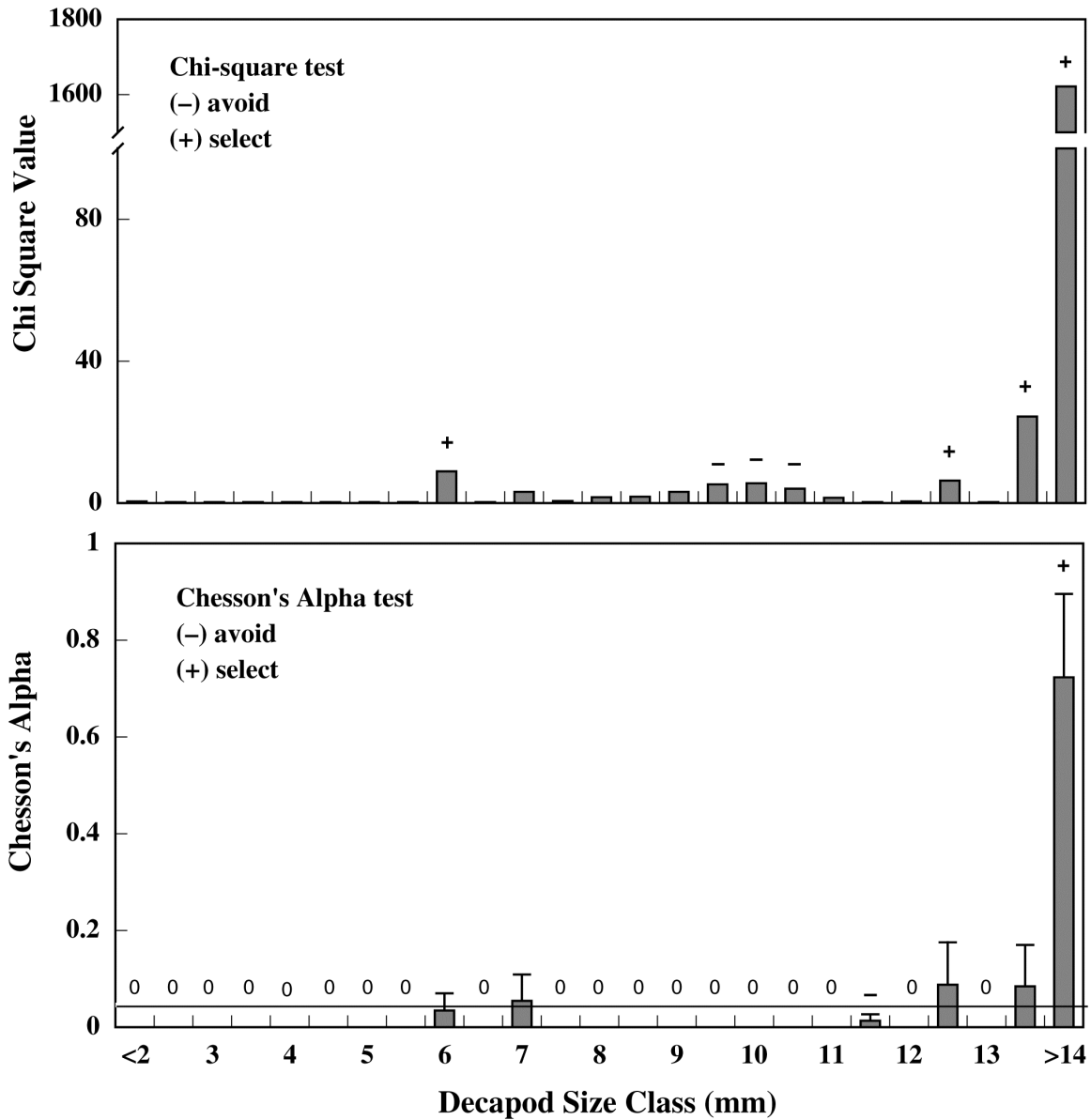
Figure 18. Nighttime size selection for decapod/stomatopod prey by blue runner (n=5) during the 26–29 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection or avoidance is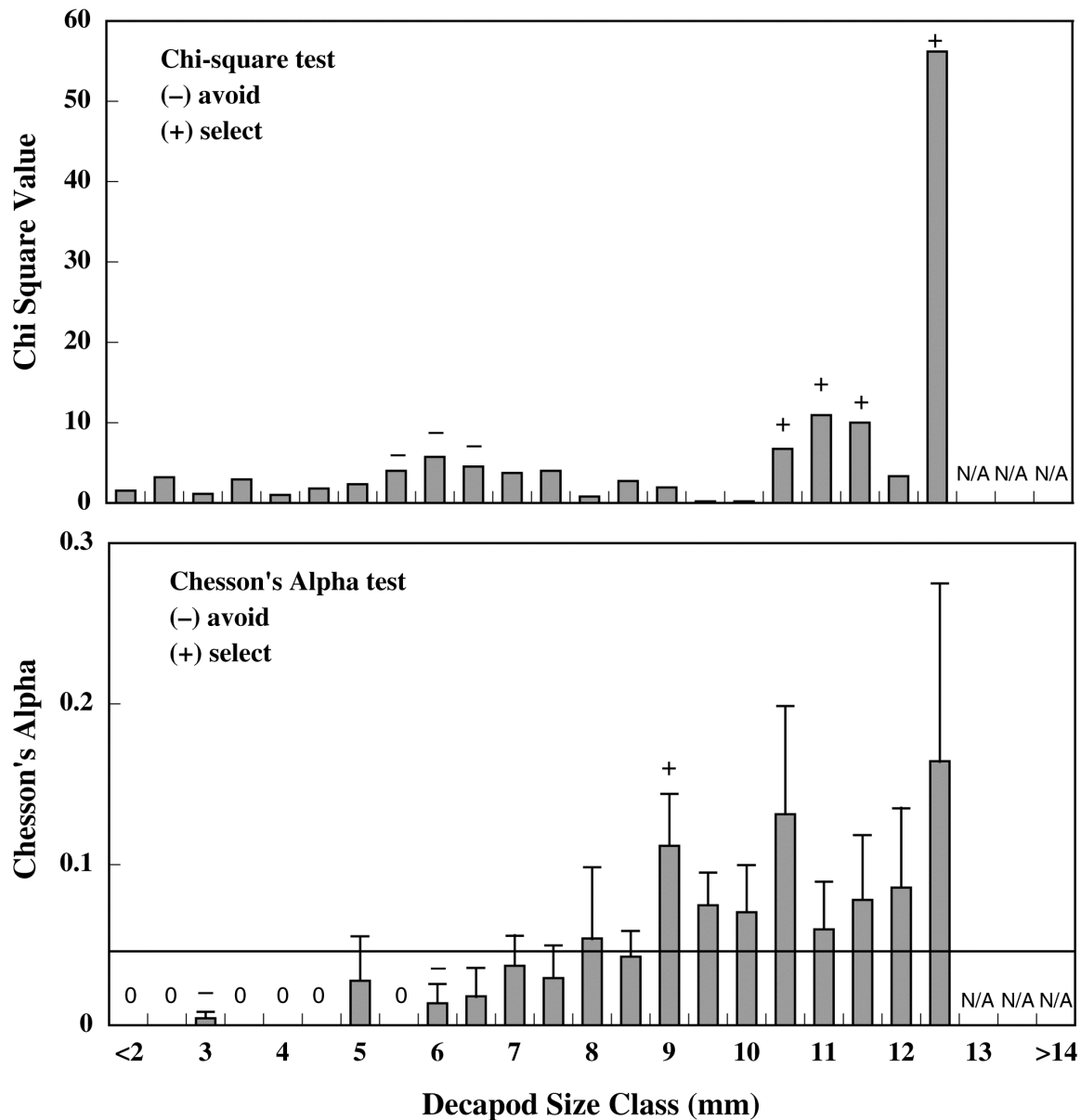 indicated with a (+) or (−), respectively. The zeros (0) indicate when this size class did not occur in a blue runner stomach.
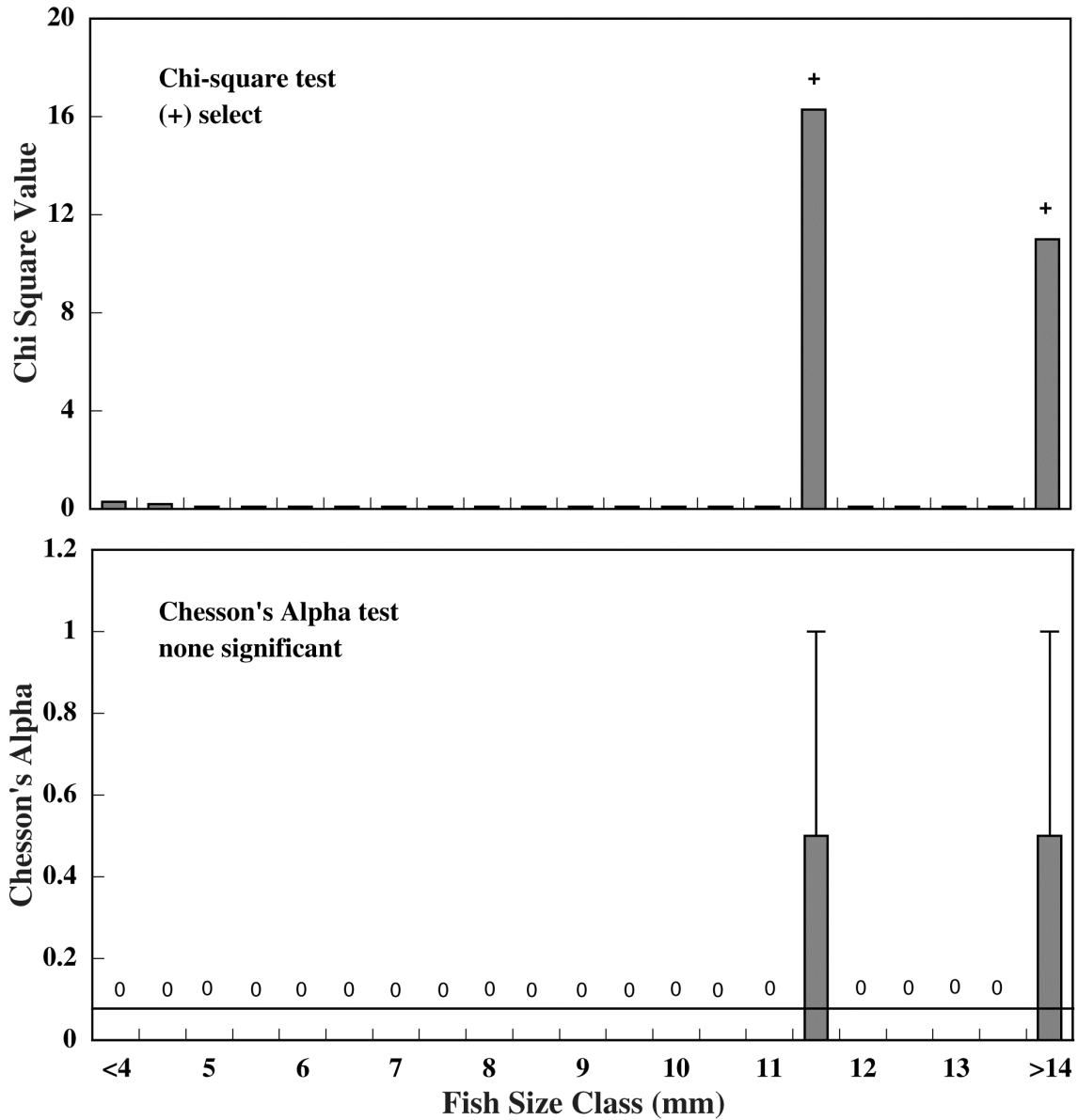
Figure 19. Nighttime size selection for fish prey by blue runner (n=2) during the 12–16 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection is indicated with a (+). The zeros (0) indicate when this size class did not occur in a blue runner stomach.
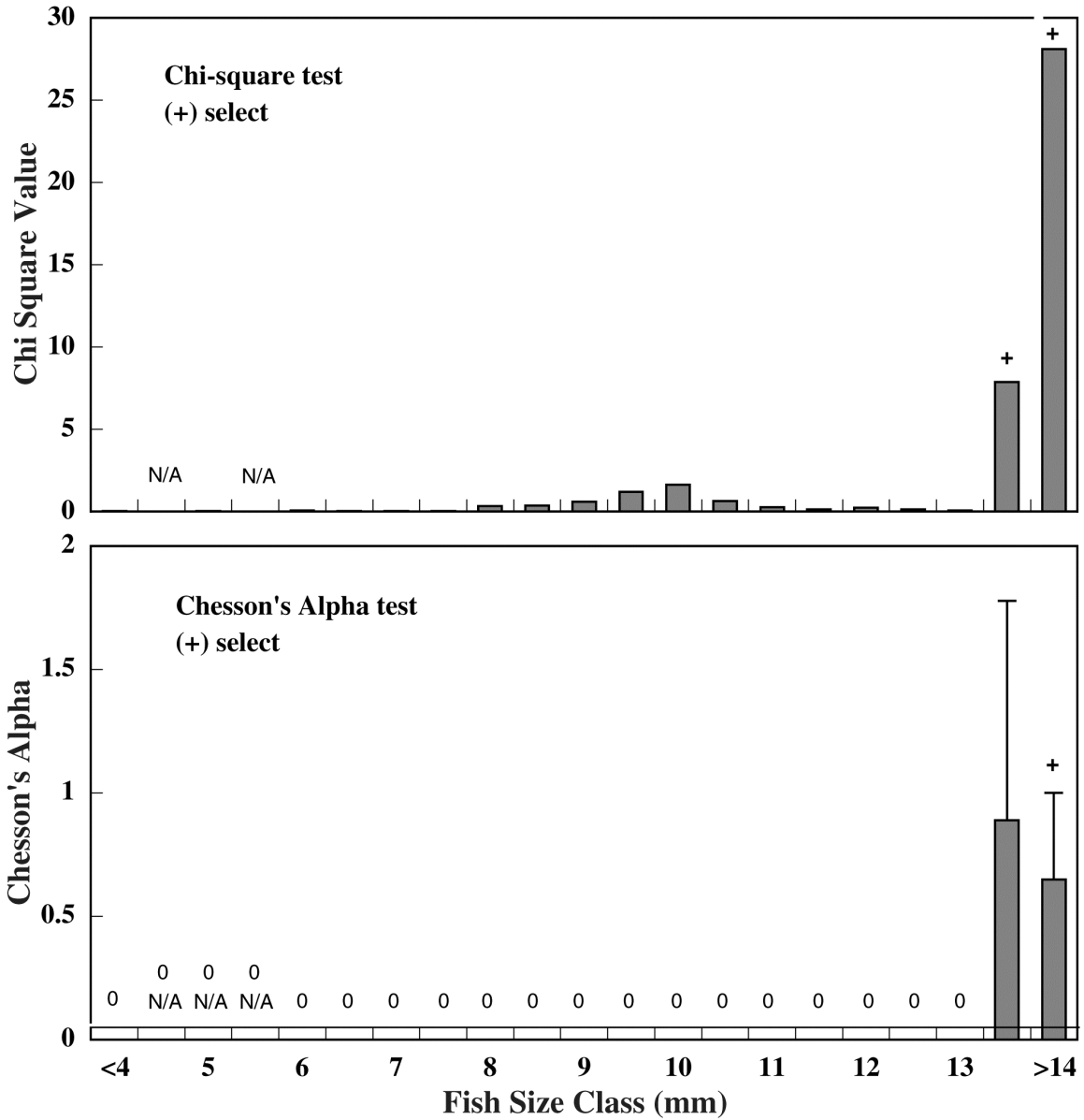
Figure 20. Nighttime size selection for fish prey by blue runner (n=2) during the 26–29 June trip (MP140A). The chi-square test is shown in upper panel and Chesson's alpha test is shown in the lower panel. Significant selection is indicated with a (+). The zeros (0) indicate when this size class did not occur in a blue runner stomach and the N/A indicates this size class was not observed in the plankton net.
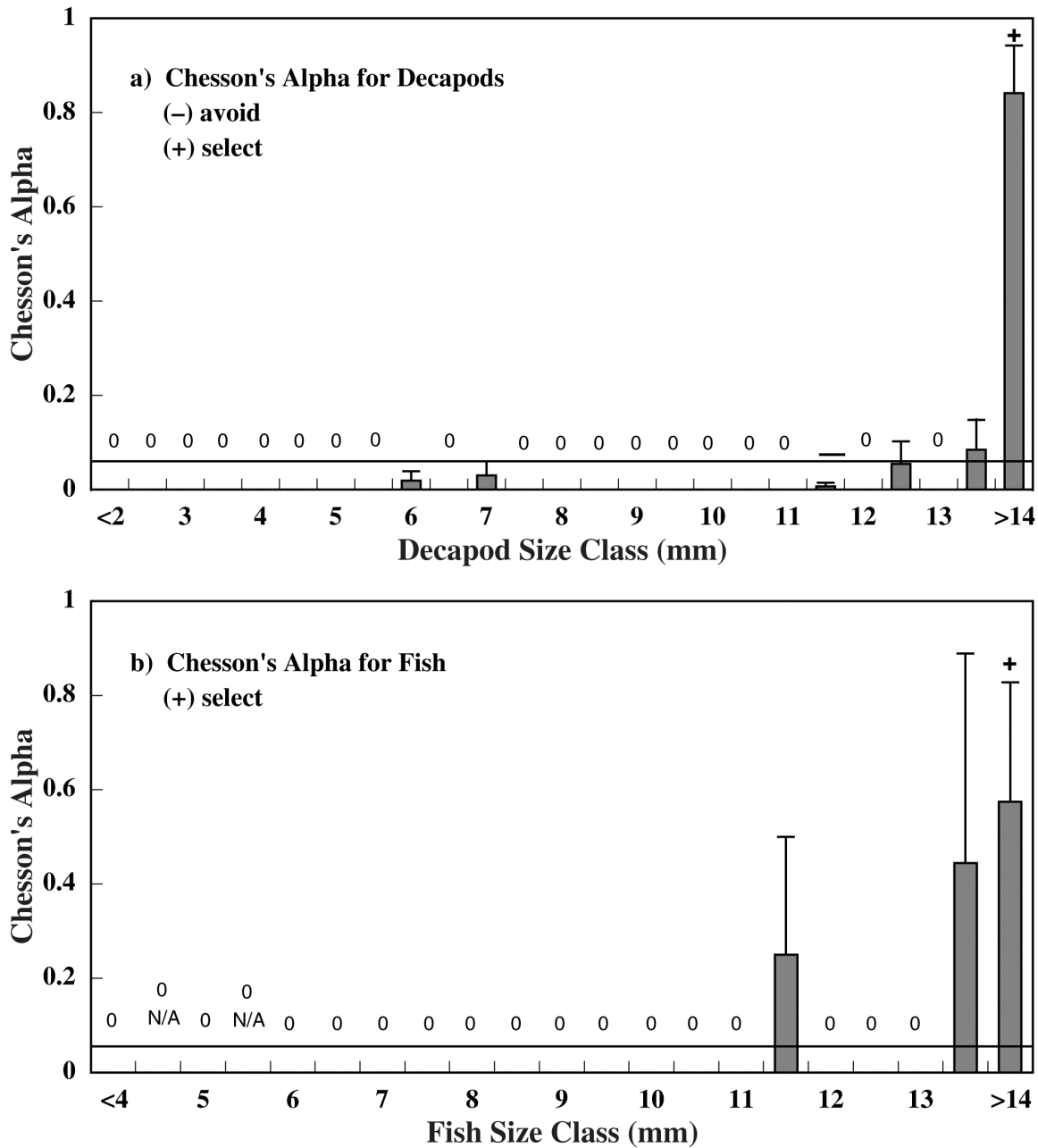
Figure 21. Nighttime Chesson's alpha selectivity test for a) decapods (n=9 blue runner) and b) fish (n=4 blue runner) for blue runner pooled over 12–16 and 26–29 June trips to MP140A. Significant selection or avoidance is indicated with a (+) or (–), respectively. The zeros (0) indicate when this size class did not occur in the blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.
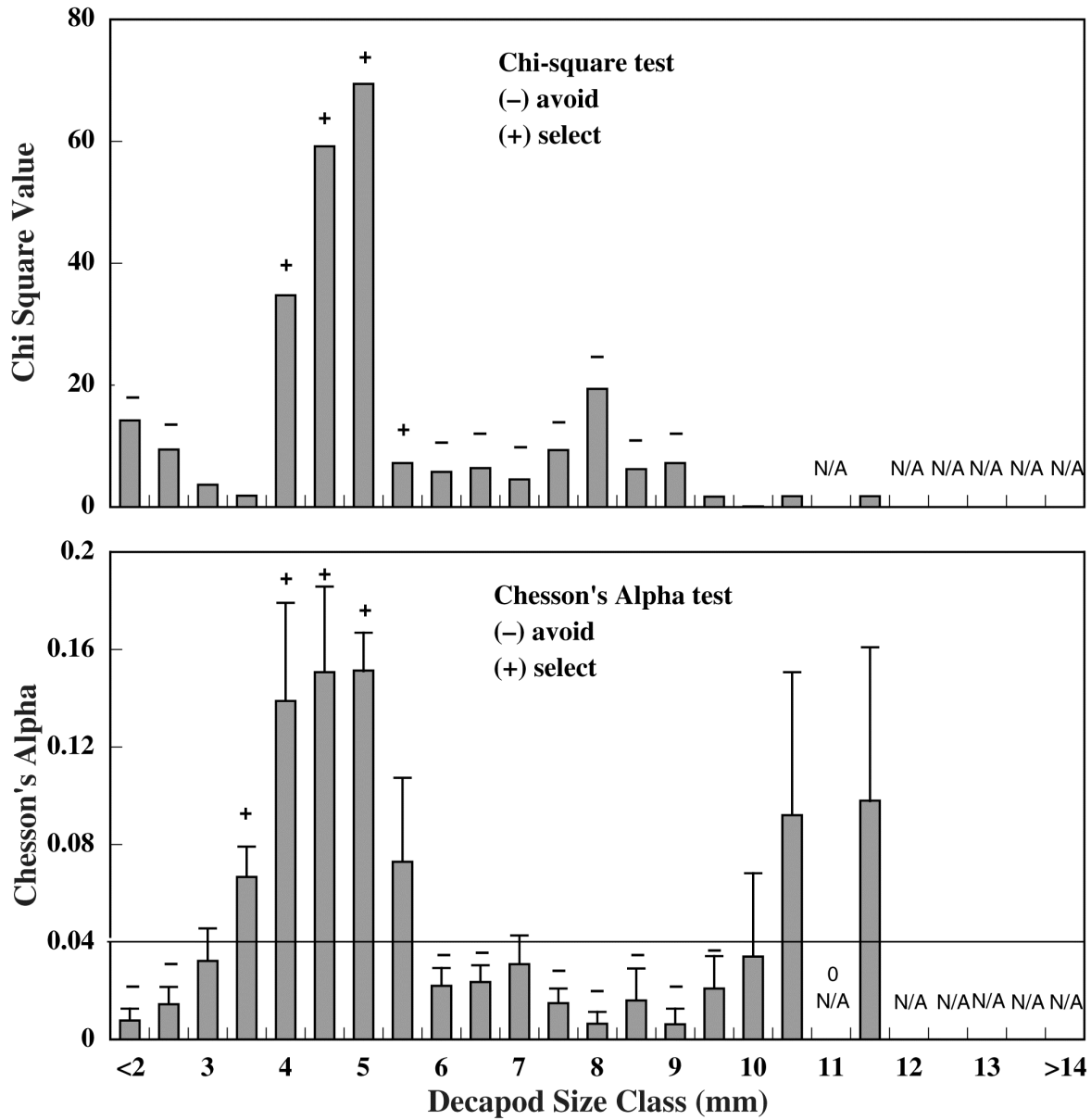
Figure 22. Size selection for decapod/stomatopod prey by blue runner (n=6) caught from open waters during 6–9 August 2000. The chi-square test is shown in the upper panel and the Chesson's alpha test is in the lower panel. Significant selection or avoidance is indicated with a (+) or (–), respectively. The zero (0) indicates when this size class did not occur in blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.

Figure 23. Size selection for fish prey by blue runner (n=4) caught from open waters during 6–9 August 2000. The chi-square test is shown in the upper panel and the Chesson's alpha test is in the lower panel. The zeros (0) indicate when this size class did not occur in blue runner stomachs and the N/A indicates this size class was not observed in the plankton net.
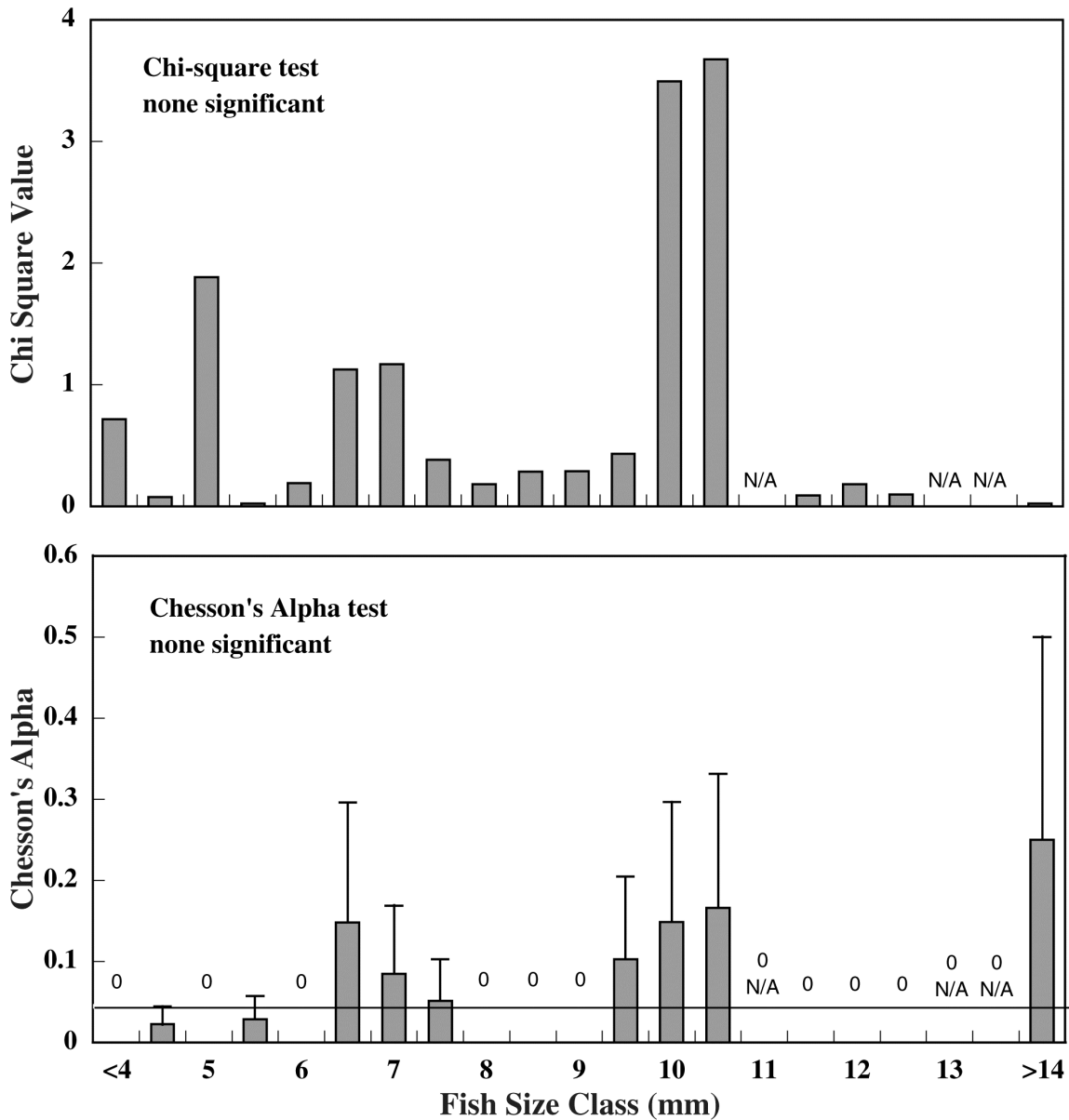
Discussion

<u>Diet Evaluation</u>

       Zooplankton comprise a large proportion of the diets of adult and sub-adult blue runner near offshore petroleum platforms as well as in open waters of the Gulf during summer months. Dietary analyses supported previous observations of zooplanktivory by blue runner at other platforms in the northern Gulf (Keenan et al. in press, and Chapter 2). Although fish are components of the diet, the present study suggests that earlier reports that adult blue runner (>270 mm) are primarily piscivorous (Randall 1967; Smith-Vaniz 1986) may be incorrect. Blue runner collected from open waters also appeared to forage mostly on zooplankton, however, the proportions of zooplankton taxa in the diet differed (e.g., dominance of chaetognaths) from platform-associated fish. The limited number of blue runner collected from open waters precluded definitive conclusions about the diets of these fish. It should be noted that the majority of open water fish were taken from one school, and therefore may not be representative of the feeding habits of other open-water schools. Preliminary examination of plankton samples indicated that chaetognaths were greater in abundance near this open water school compared to the daytime concentrations measured near the two platforms. In addition, the relative abundances of decapods and fish prey were lower in the vicinity of the open-water school than were observed in the vicinity of platforms suggesting a diet shift to more available chaetognath prey.

       My observations of blue runner foraging on holoplanktonic zooplankton are supported by records for other pelagic carangids commonly found around artificial structures. Donaldson and Clavijo (1994) examined the diets of round scad (*Decapterus punctatus*) on artificial versus natural reefs off North Carolina and determined that this carangid fed primarily on calanoid and cyclopoid copepods at both sites. They concluded that *Decapterus* were likely using the reefs as protection from predation pressure instead of a food source. Ibrahim et al. (1996) collected fishes (including *D. maruadsi* and *Atule mate*) from around FADs near Malaysia as well as their associated sessile organisms, and concluded that fishes were primarily feeding on pelagic crustaceans in surrounding waters rather than on encrusting organisms. Deudero (2001) examined the diets and interspecific trophic relationships of fishes, including five species of carangids near FADs in the Mediterranean. Three of the carangids were small-sized (40–100 mm) pelagic planktivores (*Trachurus mediterraneus*, *T. picturatus*, and *T. trachurus*), which fed primarily on copepods. Larger carangids (50–300 mm) such as pilotfish (*Naucrates ductor*) and greater amberjack (*Seriola dumerili*) each had similar diets comprised of larger organisms such as hyperiid amphipods and fishes. Greater amberjack, studied near artificial reefs in the Gulf, were defined as "reef-associated open water feeders" foraging primarily on schooling fishes and squid (Manooch and Haimovici 1983; Nelson and Bortone 1996). However, Gallaway (1980) noted that greater amberjack and almaco jack (*S. rivoliana*) near platforms off the Texas coast often consumed blennies, which are associated with the biofouling community.

<u>Food Enrichment in the Vicinity of Platforms</u>

       Enrichment of food resources has been proposed as one hypothesis for increased numbers of fishes near structures like FADs, artificial reefs and offshore petroleum platforms (Gooding and Magnuson 1967; Gallaway et al. 1981, Deudero 2001). Following a diet study on FAD associated fishes, Deudero and Morales-Nin (2001) sampled meso-zooplankton near

Mediterranean Sea FADs; however, they failed to show plankton densities were greater around FADs compared to ambient concentrations. In a study of the feeding habits of yellowfin tuna (*Thunnus albacares*) near FADs off Hawaii, Brock (1985) found that these fish exhibited a dietary shift to oplophorid shrimps when compared to non-FAD-associated tuna, which fed primarily on fish. Brock stated, however, that sonar surveys did not indicate that oplophorid shrimps aggregated beneath the FAD. In my study, the feeding habits of blue runner in open waters were generally consistent with those associated with platforms, although my sample size and temporal scope for open water fish was limited. Differences in diets between open water and platform-associated blue runner will be discussed later. Blue runner from both open waters and near platforms foraged primarily on larval and adult decapods and larval stomatopods although chaetognaths, hyperiid amphipods and fish prey were also important in the diet. Greater amberjack from open waters of the Mediterranean Sea (Andaloro and Pipitone 1997) and south Atlantic Ocean (Mannoch and Haimovici 1983) possessed similar diets compared to amberjack associated with artificial reefs in the northern Gulf (Nelson and Bortone 1996). In contrast to artificial reefs and FADs, however, offshore petroleum platforms possess a complex sub-surface architecture and powerful lights, which illuminate surrounding waters at night. These factors may influence prey distributions and facilitate blue runner foraging around these structures, especially at night. This topic will be explored further in Chapter 4.

Diel Periodicity

Blue runner are likely visual predators, however, my results indicate that they are capable of feeding throughout the night near platforms. Although a statistically significant nocturnal peak in feeding was not observed during the 24h-sampling trip, gut fullness levels were greatest during dawn and pre-dawn hours suggesting nocturnal feeding. This was consistent with previous feeding intensity studies for platform associated blue runner (Keenan et al. in press and Chapter 2). Another peak in feeding during the diel sampling occurred near dusk, which was not observed in my previous research. Other carangids display great variations in daily feeding periodicity. Hobson (1968) observed sub-adult *Caranx marginatus* (200–300 mm) feeding at night on crustaceans and "herring-like fishes" off of California, whereas larger *C. hippos* (>400 mm) were more crepuscular predators feeding primarily on fishes. Young black jack (*C. ruber*) in Cuban waters were reported to have morning and evening peaks in their daily feeding rhythm (Popova and Sierra 1985). Platform associated blue runner do not appear to be constrained to forage at any one time during the day. There was a new moon during the 24h-sampling trip, which may have influenced the feeding intensity pattern; because the large floodlights on platforms could have locally enhanced blue runner feeding intensity. Two other cruises occurred near full moon events and fullness values of blue runner caught at night were lower than blue runner taken at night during the diel feeding study. Open water blue runner, collected during the late afternoon and early evening (18:00 to 19:00 h) had gut fullness values similar to fish collected at the same time of day but 5 days earlier near VK203A. Although my study was undertaken with the objective of contrasting the diets of blue runner at platforms and in open waters, it proved extremely difficult to locate and collect fish away from platforms.

Blue runner collected during the diel study shifted their diet from large proportions (by weight) of decapods during the daytime to primarily fish at night. The decapods consumed during the daytime were mostly crab zoea, *Lucifer* spp., and larval shrimp. The forage fishes that blue runner consumed at night included but are not limited to the following families: Clupeidae

(herrings), Bregmacerotidae (codlets), Stromateidae (butterfish), Carangidae (jacks), Scombridae (mackerels), Synodontidae (lizardfishes), Bothidae (flatfishes), and Balistidae (filefishes). While these fishes are not identified as platform-dependent (Hernandez 2001) the lights from platforms may attract these fish making them more susceptible to predation. Blennies (family Blenniidae), commonly associated with the platform community, were also observed in the diets of blue runner.

Other carangid species showed diel variations in their diets. Starck and Davis (1966) reported a shift in the diet of a jack (species not named) from daytime feeding on fishes to zooplankton at night. Blue-spotted trevally (*C. bucculentus*) caught in Albatross Bay, Australia did not show diel variations in fish, crab or molluscan prey, however large trevally (276-335 mm) consumed more penaeid shrimp during the night than during the day (Brewer et al. 1989). This shift was reported as a response to an increase in availability of nocturnal penaeid species. In my study, net tows were not conducted during the diel sampling trip, although preliminary evidence from other trips indicates that fish are more abundant in net collections at night than during the daytime (Chapter 4). Due to difficulty locating open water blue runner, the diets of these fish at night remain uncertain.

Prey Type Selection

Blue runner around platforms selected for decapods/stomatopods and hyperiid amphipods consistently during the daytime, although levels of selection varied between days and among trips. The greater amount of ambient light during the day may allow blue runner to detect decapod and amphipod prey more easily, and at longer ranges than at night. In addition, hyperiid amphipods possess a robust body and are often pigmented (Vinogradov et al. 1996) which may make them more conspicuous to visual predators. It's unclear why blue runner demonstrated avoidance of fish during daytime hours, although net tows indicated that they are much less abundant than decapods (Chapter 4). At nighttime, blue runner around platforms altered their diet by selecting for fish, amphipods and other invertebrates (primarily thecosomate pteropods and cephalopods) and significantly avoided decapods and chaetognaths. Lower light levels likely favor predation on larger or more conspicuous targets (Hunter 1968; Vinyard and O'Brien 1976). My net tow data show that both fish and amphipods were more abundant at night than during the day. The open water blue runner significantly selected for hyperiid amphipods and showed positive selection for chaetognaths. Decapods were less abundant in the net samples from open waters than from tows near platforms, which may suggest a switch to a more available prey, since chaetognaths were more abundant in the vicinity of the open water school than near platforms. Hyperiid amphipods, however, generally were less abundant in the open water plankton samples than those taken near platforms, which indicate that open water blue runner may have actively selected for this less common prey type.

Prey Size Selection

During the daytime, platform blue runner fed on decapods and fish within the size range collected by the 0.865 m^2 plankton net. Selectivity tests from daytime feeding indicated that decapods below 8 mm are generally consumed in proportion to their availability in the water column and those between 8 mm and 12.5 mm may experience positive selection. Decapods fed upon by blue runner included crab and shrimp larvae, however, holoplanktonic shrimp (*Lucifer* spp.) predominated this category, which is consistent to findings reported in Chapter 2. Daytime

blue runner foraged on all sizes of fish encountered, although only one fish above 8 mm was observed in a blue runner stomach. This indicated that during the daytime, platform-associated blue runner positively selected small to intermediate sized fish prey. Blue runner may have avoided the larger sized fish due to greater availability of decapod/stomatopod prey.

The size selectivity pattern changed for nighttime blue runner, which fed upon larger sized decapod and fish prey. Platform associated blue runner fed actively on larger decapods (>14 mm) such as adult shrimp and larger larval stomatopods. Larger fish prey such as herrings and codlets were common prey items observed in blue runner collected at night. The larger prey organisms were likely able to avoid the plankton net and preliminary observation of net size-frequency histograms showed that decapods and fish over 15 mm were less abundant. Under low light, larger prey may be more visible to blue runner. In addition, prey species may be attracted to the platform lights at nighttime making them more available to blue runner. This will be explored further in Chapter 4.

Open water blue runner selected for smaller decapods and selected for all sized fish that were collected during the open water plankton net tows. Since the time of capture for the open water blue runner was during early evening, only a qualitative size-selection comparison of open water to platform feeding based on time of day was possible. Open water blue runner selected for smaller sized decapods (3.5–5 mm) compared to both daytime and nighttime platform blue runner. Decapod prey from open water blue runner consisted primarily of zoea and megalopae crab and shrimp larvae and larval stomatopods. All sizes of fish prey that were collected by the plankton nets were fed upon by open water blue runner, however, the greatest positive selection was for the largest-sized fish prey. This range of selection falls in between the daytime and nighttime platform selectivity patterns. The time these fish were caught (18:00–19:00h) may indicate a transition phase from feeding on smaller organisms during the daytime to feeding on larger prey when light levels decrease. The nocturnal feeding habits of open water blue runner remains unknown.

Chapter IV
Spatial Variability of Meso- and Macro-Zooplankton in Surface Waters
Near Offshore Petroleum Platforms in the Northern Gulf of Mexico

Introduction

One hypothesis set forward to explain the attraction of fishes to artificial structures is an enrichment of food resources (Gooding and Magnuson 1967; Hastings et al. 1976; Deudero and Morales-Nin 2001). Many commercially-important predatory fishes (e.g., greater amberjack, king mackerel, cobia) found near offshore petroleum platforms in the Gulf of Mexico (Gulf) are believed to be attracted to large schools of baitfish such as herrings and sardines (Gallaway 1980), which find protection amongst the legs of the structure. Other common fishes, such as gray triggerfish, sheepshead and blennies forage on the encrusting organisms and epifauna living on the structure itself. The previous chapters have focused on the feeding habits of a pelagic fish species, *Caranx crysos*, commonly found around platforms. These fish, which are often found in large schools, forage extensively on zooplankton. This raises the question: are there linkages between the platforms and the availability of zooplankton?

Studies on prey distributions around artificial structures have primarily focused on flotsam and fish attraction devices (FADs). Gooding and Magnuson (1967) observed large numbers of planktivorous juvenile and adult fishes (including *Caranx* spp.) near an underwater observation chamber in the Pacific Ocean, however, they failed to see an increase in zooplankton prey near the chamber. They believed that protection from predation explained the attraction rather than increased prey resources. Similarly, Ibrahim et al. (1996) examined stomach contents of fish associated with fish attraction devices (FADs) off Malaysia and found only holoplanktonic organisms such as copepods, *Lucifer* spp. and shrimps instead of encrusting organisms or epifauna growing on the FAD. Deudero and Morales-Nin (2001) collected zooplankton near FADs in the Mediterranean Sea using vertically towed nets and did not detect differences in plankton densities near these structures compared with open water control stations.

The surface areas of large artificial reefs and petroleum platforms may influence zooplankton prey distributions to a greater extent than smaller structures such as FADs. Lindquist and Pietrafesa (1989) examined the currents and fish distributions around a tugboat wreck in Onslow Bay, North Carolina. They determined that currents were slower on the upstream side of the tugboat due to deflection; and that round scad (*Decapterus punctatus*) were more abundant in this area during periods of high current velocity in ambient water. Reasons explaining this pattern included: that fish may aggregate in areas of lower current speeds to conserve energy; or that prey encounter rates may be higher since plankton would be entrained in upstream current vortices; or a combination of the two factors. Petroleum platforms, which provide a large amount of sub-surface structure, also create current disturbances (Dicks 1982; Taylor 1991). Forristall (1996) measured the amount of current reduction on the Bullwinkle platform in the Gulf during strong current events. He reported that currents in the wake of the platform were 20% lower than freestream currents and that current speed in the wake of a dense group of well conductors was lowered by 83%. In addition, platforms are equipped with large floodlights that illuminate the surrounding waters at night. Many zooplankton species are positively phototaxic and may be affected by the light from the structure. These characteristics

could influence zooplankton distribution, providing a potential increase in feeding efficiency for pelagic planktivores such as blue runner.

Several techniques exist for measuring zooplankton abundance and distribution dependent on the spatial scale and purpose (Skjoldal et al. 2000). The use of high frequency acoustics in combination with net sampling allows for resolution of fine-scale (centimeters to hundreds of meters) patterns as well as a physical sample for verification (Holliday and Pieper 1995; Greene et al. 1998; Foote and Stanton 2000). For frequencies on the order of 10^3 kHz, the particles responsible for acoustic backscattering are assumed to be zooplankton and micronekton (Heywood et al. 1991; Holliday and Pieper 1995). Thus, relating backscattering from a volume of water to numbers or biomass of sound-scattering organisms in that volume is the simplest way to evaluate sound scatter distributions through field measurements (Ressler 2001). Acoustic Doppler current profilers (ADCPs) are commonly used by physical oceanographers to examine the velocity of near-surface currents. The ADCP also measures the intensity of the backscattered acoustic returns which is proportional to the number and backscattering cross sections of sound scattering particles such as zooplankton (Foote and Stanton 2000; Ressler 2001). Recent studies have demonstrated the application of ADCPs in examining patterns of zooplankton and micronekton structures in the Gulf in proximity to physical features such as warm- and cold core eddies (Zimmerman and Biggs 1999; Wormuth et al. 2000; Ressler 2001).

In this study, I used a vessel-mounted ADCP in conjunction with obliquely towed plankton nets to examine zooplankton distributions around offshore petroleum platforms in the Gulf. Refer to Benfield et al. (in prep) for information on the calibration procedure and technical properties of the particular ADCP used in this study. By evaluating the distribution of zooplankton near these massive structures, I have attempted to determine whether the platforms provide enhanced prey resources for platform-associated fishes, such as blue runner.

The objectives of this research were to use plankton net tows in conjunction with acoustic backscattering strength data from the ADCP. The objectives were to: 1) evaluate zooplankton composition and abundance near two petroleum platforms; 2) examine relationships between zooplankton density and wet mass from plankton nets and backscatter strength from the ADCP; and, 3) demonstrate the utility of acoustics to visualize the spatial patterns of sound scattering particles near platforms. My null hypotheses examined, included that: 1) zooplankton abundance does not vary from the up-current to the down-current sides of platforms and density does not vary with distance from the structure, 2) there is no relationship between density and wet mass of zooplankton and volume backscatterering strength, and 3) fine-scale spatial patterns of sound scattering particles do not exist around platforms.

Methods

Sampling Sites

Zooplankton collection and acoustic sampling was conducted during a series of cruises in the northern Gulf from early June to mid-July 2000. Cruises aboard the 11.3 m C/V Admiral Semmes lasted approximately three to four days. The vessel was equipped with a global positioning system (Magellan GPS NAV 5000DX), which logged to a laptop computer at

approximately 1 Hz. A conductivity/temperature/depth (CTD) recorder (YSI Model 9320) measured hydrographic parameters (temperature and salinity).

Sampling was conducted near two petroleum platforms east of the Mississippi River. Viosca Knoll 203A (VK203A) is a mid-shelf platform located approximately 64 km south of Dauphin Island, Alabama (29.7816^{o}N, 88.3330^{o}W) in 37 m of water. This platform is a four-leg structure with a complex wellhead adjoining the platform (Fig. 7). Cruises were made to VK203A during 5–8 June and 17–20 July 2000. Main Pass 140A (MP140A) is an eight-leg structure in 45 m depth located approximately 32 km east of Venice, Louisiana (29.2947^{o}N, 88.8612^{o}W). Cruises were made to MP140A during 12–16 June and 26–29 June 2000. The order of platform sampling was determined by a coin toss.

Zooplankton Sampling

Zooplankton and micronekton were collected with a rectangular frame plankton net (1000 μm) towed obliquely from 14 m to the surface. Further description of the net system and deployment can be found in Chapter 3. A set of net hauls (n=12) consisted of three replicate tows conducted at four locations: up-current and down-current of the platform and up-current and down-current of a fixed open-water point located within 1000 m of each study platform, referred to as the reference site (Fig. 24). During each cruise, two sample sets were collected at night and two during the day. Prior to determining sampling sites, current direction was evaluated by observing movement of a surface drogue placed in the water near the platform. Plankton net tows from the reference sites allowed for comparison of natural levels of zooplankton variability at two points separated by similar distance as tows from the up-current and down-current sides of the platform. The order of net tows was randomized among all four possible locations.

Zooplankton Enumeration

Zooplankton were fixed in 10% formalin and transported to the laboratory, where samples were transferred to 70% ethanol before being sorted and identified. A Folsom plankton splitter was used to sub-sample the total plankton sample. Organisms were sorted and identified using a dissecting stereo-microscope (70X). Zooplankton were classified into the following taxonomic categories: fish, larval and adult decapods and larval stomatopods, hyperiid amphipods, chaetognaths, thecosomate pteropods, copepods, gelatinous invertebrates (e.g., salps, doliolids, siphonophores) and fish eggs. An additional category, termed "other invertebrates," contained organisms such as ostracods, polychaetes, and insects, which were relatively rare and not represented here. Splitting was limited so that the most numerous group, decapods/stomatopods, produced over 100 individuals. For less abundant groups, samples were split fewer times, so that at least 100 individuals were counted. When the total number of individuals present in a sample was less than 100, all individuals were enumerated without splitting.
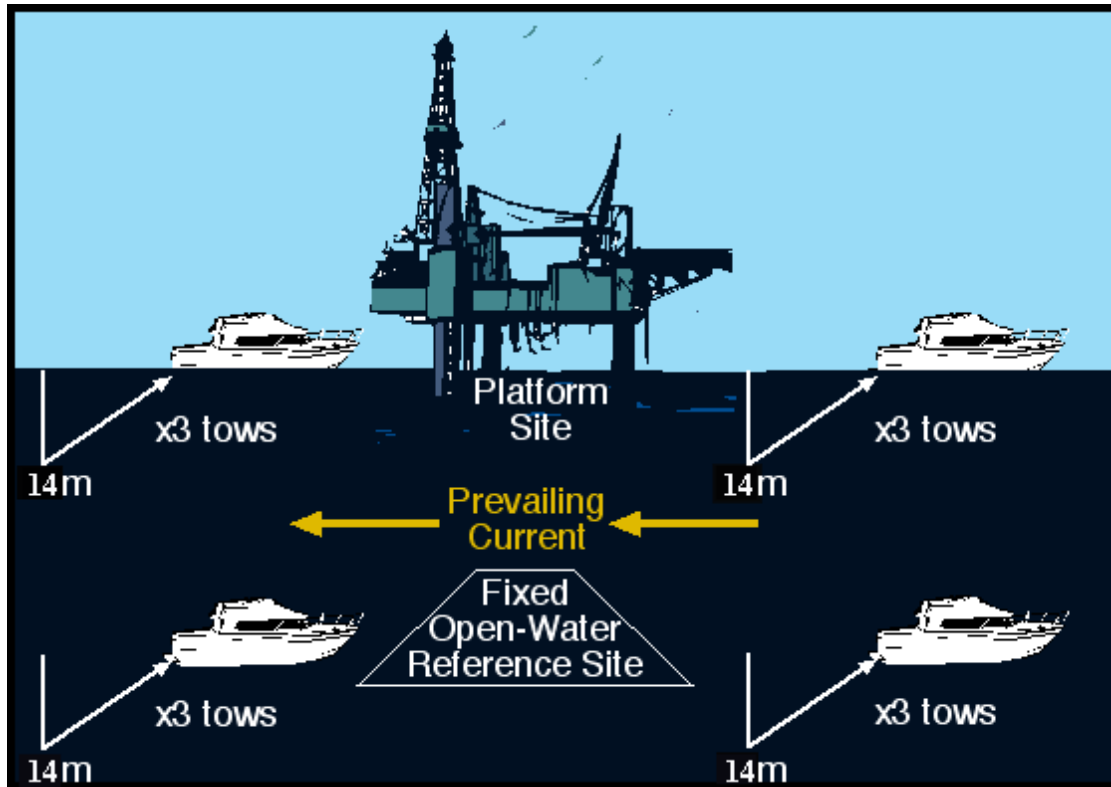
Figure 24. Example of one set of samples designed to evaluate the influence of a platform on the density of zooplankton up-current and down-current of a platform. A total of twelve net samples were collected: three replicate tows up-current of a platform, three tows up-current of a reference site located within 1000 m of the platform, three tows down-current of the platform and three tows down-current of the reference site. Each tow was an oblique haul from 14 m to the surface using a 0.865 m² net and the order of net hauls was randomized.

Zooplankton concentrations (individuals / m³) were computed by multiplying the number of individuals counted in each taxonomic category (corrected for the split factor) and then dividing by the volume filtered. A three-way analysis of variance (proc glm, SAS v. 6.12) was conducted to determine whether there was a statistically significant relationship between zooplankton abundance (total and by taxon) and: cruise date (5–8 June, 12–16 June, 26–29 June and 17–20 July), current direction (up-current vs. down-current), and site (platform vs. reference) for either day or night samples. The site-by-current-direction interaction (proc glm, lsmeans procedure, SAS v. 6.12) was used to examine density changes among the four sampling sites (i.e., platform up-current, platform down-current, reference up-current, reference down-current) during each cruise. The assumption of normality of the residuals was examined using a SAS procedure (proc univariate, SAS v. 6.12) and the data were transformed (log +1) if this assumption was violated. If the transformation did not correct the violation, a non-parametric Kruskal-Wallis test was conducted (Sokal and Rohlf 1986).

Owing to changes in current direction during sampling, and sea states that limited vessel maneuverability, the exact position of the net tow sites could not be replicated during the net tow

collections; therefore, I also tested distance from the platform as a factor influencing density. A Matlab (v. 5.2) program was written to calculate the distance of each net tow from the platform whenever sufficient GPS data were available. Regressions of plankton density versus distance to the platform were done for each replicated day and night set for each cruise to the two platforms (i.e., 7 net collections during the day and 7 at night) for each taxon identified. Again, transformations (log+1) of raw density values were performed when the error residuals of the data were not normally distributed.

Acoustics

The distributional patterns of sound scattering particles (e.g., zooplankton) were evaluated using a RD Instruments BroadBand 1200 kHz ADCP. The ADCP was mounted on the side rail of the boat and positioned at approximately 1.0 m below the waterline. The ADCP's four transducers were orientated downward with each beam 20° from vertical. An external cable provided power to the ADCP and was connected to an onboard laptop computer. The ADCP transmitted at 2 Hz and measurements of backscattering intensity were averaged into 10 s ensembles representing 20 pings. The effective range of the sound pulse for this frequency was approximately 14 m and data were recorded in 0.5 m depth cells. Volume backscattering strength (S_v) was calculated following procedures described in Benfield et al. (in prep). Although differential GPS was not available, selective availability had been disabled and positional data were recorded concurrently with acoustics. GPS data were edited to remove outliers and the trackline was smoothed using a five point running mean.

The ADCP recorded concurrently with plankton net tows near each platform, therefore it was possible to examine the relationship between ADCP volume scattering strength and net tow contents. During each cast, acoustic ensembles were selected that corresponded with the time period when the net was being retrieved. Volume backscatter was averaged from the lowest depth the net reached (determined from the net Temperature/Depth/Recorder, Chapter 3) to approximately 2 m below the surface. Acoustic data were not used for the upper 2 m of the water column because the ADCP data began at 1.5 m and the first 0.5 m cell was corrupted by side-lobe returns from the vessel's hull. Acoustic data beyond 14 m were not available because of attenuation and consequently the net was rarely deployed to this depth. For each net cast, the mean volume scattering strength was estimated as the average of all volume backscattering coefficients (s_v) from 2–14 m for the duration of the tow. Mean s_v was then converted to volume scattering strength (S_v) using the equation (Wiebe et al. 1996):

$$S_v = 10\log_{10}(s_v) \tag{7}$$

where S_v is volume scattering strength (dB re 1 m^{-1} $4\pi^{-1}$). Relationships between volume scattering strength and the logarithm of zooplankton density and wet weight were conducted following procedures adopted from Zimmerman and Biggs (1999) and Wormuth et al. (2000). Volume backscatter values were computed for 24 net tows from the 5–8 June cruise to VK203A and 46 net tows from the 12–16 June cruise to MP140A. Analyses were conducted separately for day and night net tows.

Backscatter and Density

Simple linear regressions of the logarithm of plankton density (individuals/m^3) as a function of volume scattering strength (S_v) were conducted using SAS (proc reg, v. 6.12).

Separate regressions were performed for complete day and night net tow sets from 5–8 June (VK203A) and 12–16 June (MP140A). Regressions were computed for each taxon sorted from the plankton net including total zooplankton.

Backscatter and Wet Weight

A preliminary examination of relationships between zooplankton wet mass and volume backscattering strength was also attempted. Linear regressions were conducted on the logarithm of wet weight per unit volume (mg / m^3) for each taxon collected from plankton samples on volume scattering strength. Wet weight was computed following methods in Postel et al. (2000), where all individuals from specific taxon were placed onto a pre-weighed paper filter disc and then vacuum filtered to remove excess fluid. Each taxonomic category was then weighed to the nearest milligram (AND, Inc., GR-120 microbalance). Wet weights were measured from 12 net tows from 12–16 June (day 2) and 11 net tows from 12–16 June (night 1).

Acoustic Surveys

Acoustic surveys were conducted around the platforms as a series of concentric boxes beginning at approximately 500 m away from the platform, getting nearly 200 m closer during each circuit (Fig. 25). Surveys lasted approximately 1 h and were conducted during both the day and night for each cruise. The surveys usually followed the series of net tows, however, this varied among cruises. The goals of these surveys were to examine the distributional patterns of S_v in relation to the platform. Surveys during the first day and night of the 5–8 June cruise (VK203A) and the first day and second night of the 12–16 June cruise (MP140A) were processed for this section. The complete analysis of these surveys will be the subject of a separate investigation. Consequently, this chapter contains a preliminary, and largely qualitative analysis of the acoustic survey data.

Outliers were identified and deleted from GPS data because a differential GPS receiver was not used when recording location. A smoothed survey trackline was produced using a 5 s running mean before positions were re-calculated at 10 s intervals to correspond with the frequency of the acoustic record. Local time, recorded by both the GPS and the ADCP, was used to merge volume scattering strength data with positional data and the resultant data were visualized in two (time and depth) and three dimensions (latitude, longitude, depth) using Matlab.

Results

Plankton Net Sampling

A total of 168 plankton net tows were conducted; 84 during the day and 84 at night (Table 7). Four complete sets of tows representing four days and four nights were completed at MP140A (n=48 day and 48 night) while only three sets representing three days and nights were done near VK203A (n=36 day and 36 night). The discrepancy in the collection resulted from inclement weather during the first trip to VK203A (5–8 June). All plankton samples were collected between 100–1000 m of the respective platform. All plankton samples were identified and enumerated into the taxonomic categories.
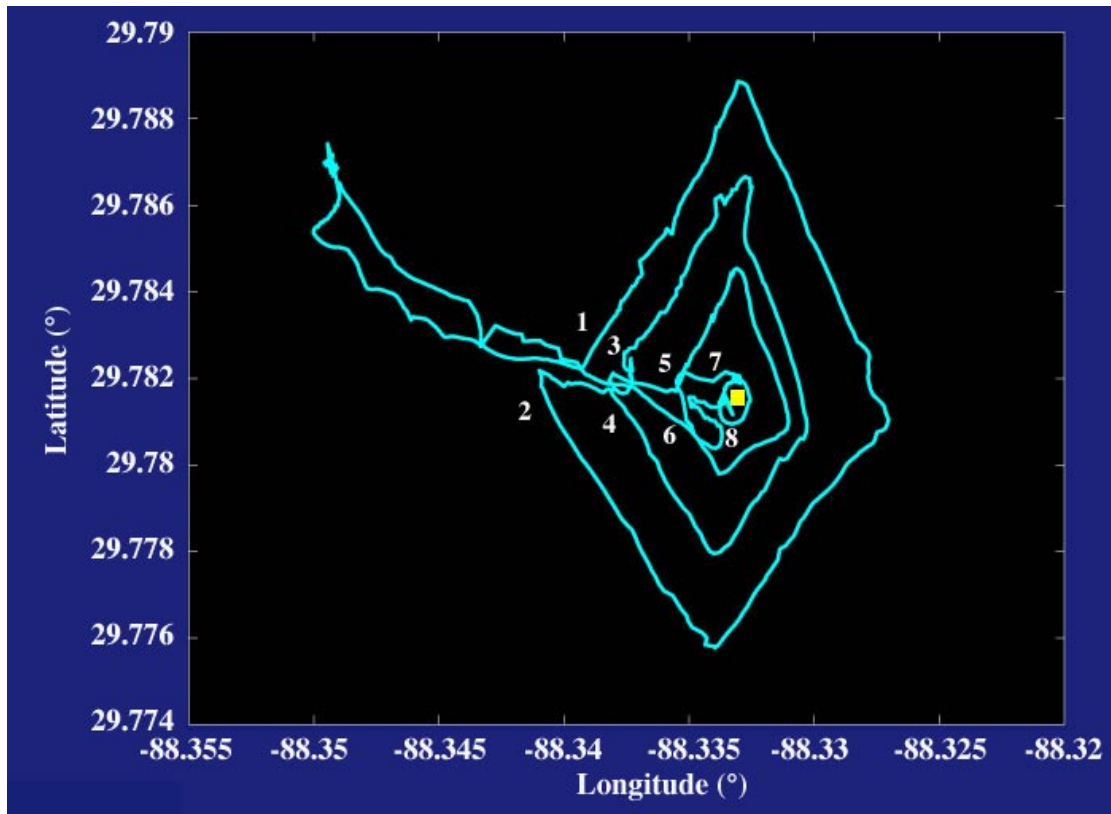
Figure 25. Two-dimensional GPS plot of a typical survey around a platform (indicated by the square in the middle of the graph). The successive loops depicted by the numbers: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (points 5 to 6), and near-platform pass (7 to 8).

Table 7. Summary of sampling activities associated with surface zooplankton collections and acoustic sampling for each cruise during summer 2000 research trips in the northern GOM.

Date	Destination	Objective
30 May – 1 June	VK203A	Preliminary cruise, test equipment, identify suitable platforms
5–8 June	VK203A	Plankton net tows: 1 day set (n = 12), 1 night set (n = 12), Acoustic survey (1 day and 1 night)
12–16 June	MP140A	Plankton net tows: 2 day sets (n = 24), 2 night sets (n = 24), Acoustic survey (2 day and 2 night)
26–29 June	MP140A	Plankton net tows: 2 day sets (n = 24), 2 night sets (n = 24), Acoustic survey (2 day and 2 night)
17–20 July	VK203A	Plankton net tows: 2 day sets (n = 24), 2 night sets (n = 24), Acoustic survey (2 day and 2 night)

Differences in zooplankton densities were dominated by among cruise variability (Fig. 26, 27) and the patterns did not appear to be related to specific platforms or time of day. During the day, the total zooplankton abundance category was greatest during the 12–16 June cruise to MP140A, however, there were no significant difference among the other three cruises (Fig. 26).

The high number of gelatinous organisms (e.g., salps, doliolids, and calycophore siphonophores) during the day sampling of the 12–16 June trip likely contributed to this result. Fish, amphipods, pteropods, copepods, and gelatinous organisms also were significantly greater ($p < 0.05$) during 12–16 June (MP140A) than the other three cruises (Fig. 26). The density of decapods/stomatopods and fish eggs were also greater during this cruise, but the differences were not statistically significant (Fig. 26).

Total zooplankton densities were generally elevated at night relative to daytime samples. There was no evidence of a platform effect when platform sites were compared to controls. Blue runner forage on small fish during the night and fish abundances from my net tows indicated lower fish densities on the down-current side of platform in relation to the up-current side on five of the seven nights sampled (Fig. 38). This difference was statistically significant ($p = 0.002$) on the second night of the 26–29 June trip. Results for decapods/stomatopods, which were abundant at night, did not indicate a platform effect (Fig. 39). The majority of decapods sampled were small (1-4 mm) holoplanktonic species such as *Lucifer*, with limited locomotion powers. The other taxa sampled showed high variability among the four sampling sites, which made it difficult to identify any platform effect. During the second night of sampling for the 12–16 June cruise there were large number of fish eggs collected in the platform down-current samples, which suggested a spawning event near, or at the platform (Fig. 45).

Figure 26. Daytime density of zooplankton categories (a–i) during summer 2000 cruises: BR2 (5–8 June, VK203A), BR3 (12–16 June, MP140A), BR4 (26–29 June, MP140A), BR5 (17–20 July, VK203A). Letters indicate significant difference ($p < 0.05$) from Tukey's mean test. Asterisks (*) indicate significance tested with Kruskal-Wallis non-parametric test ($p < 0.01$).
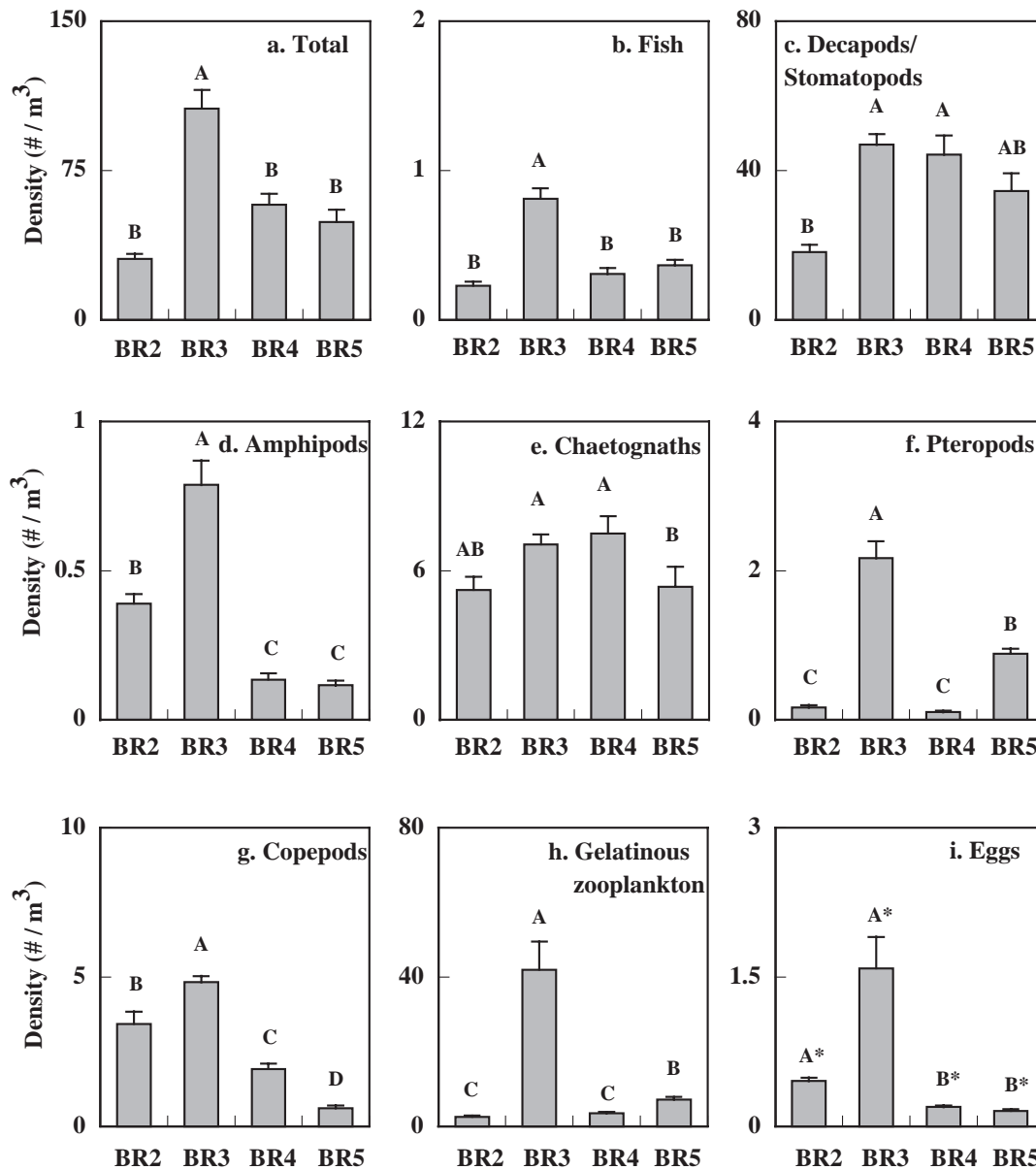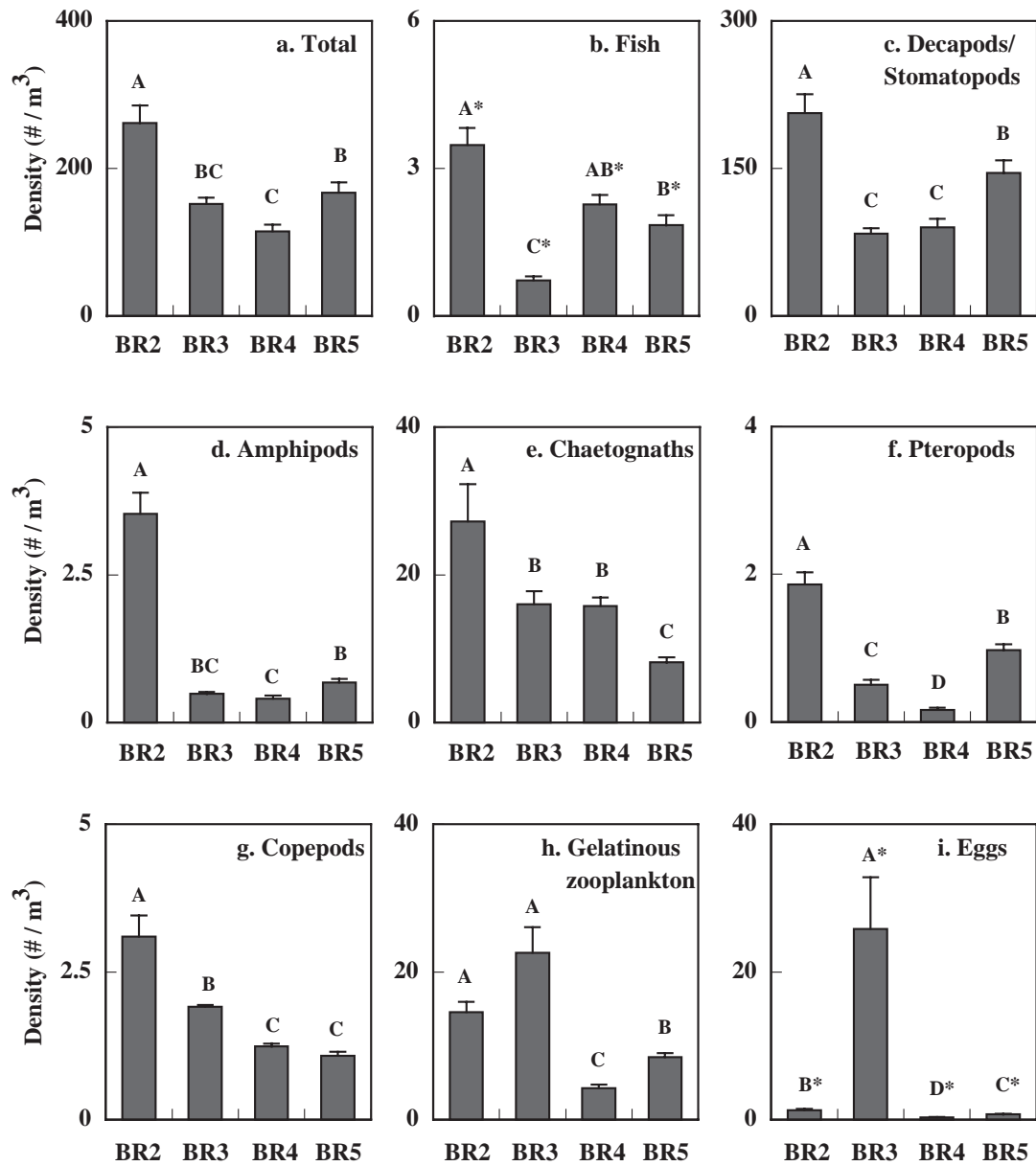
Figure 27. Nighttime density of zooplankton categories (a–i) during summer 2000 cruises: BR2 (5–8 June, VK203A), BR3 (12–16 June, MP140A), BR4 (26–29 June, MP140A), BR5 (17–20 July, VK203A). Letters indicate significant difference ($p < 0.05$) from Tukey's mean test. Asterisks (*) indicate significance tested with a Kruskal-Wallis non-parametric test ($p < 0.01$).

Figure 28. Total zooplankton density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

Figure 29. Fish density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
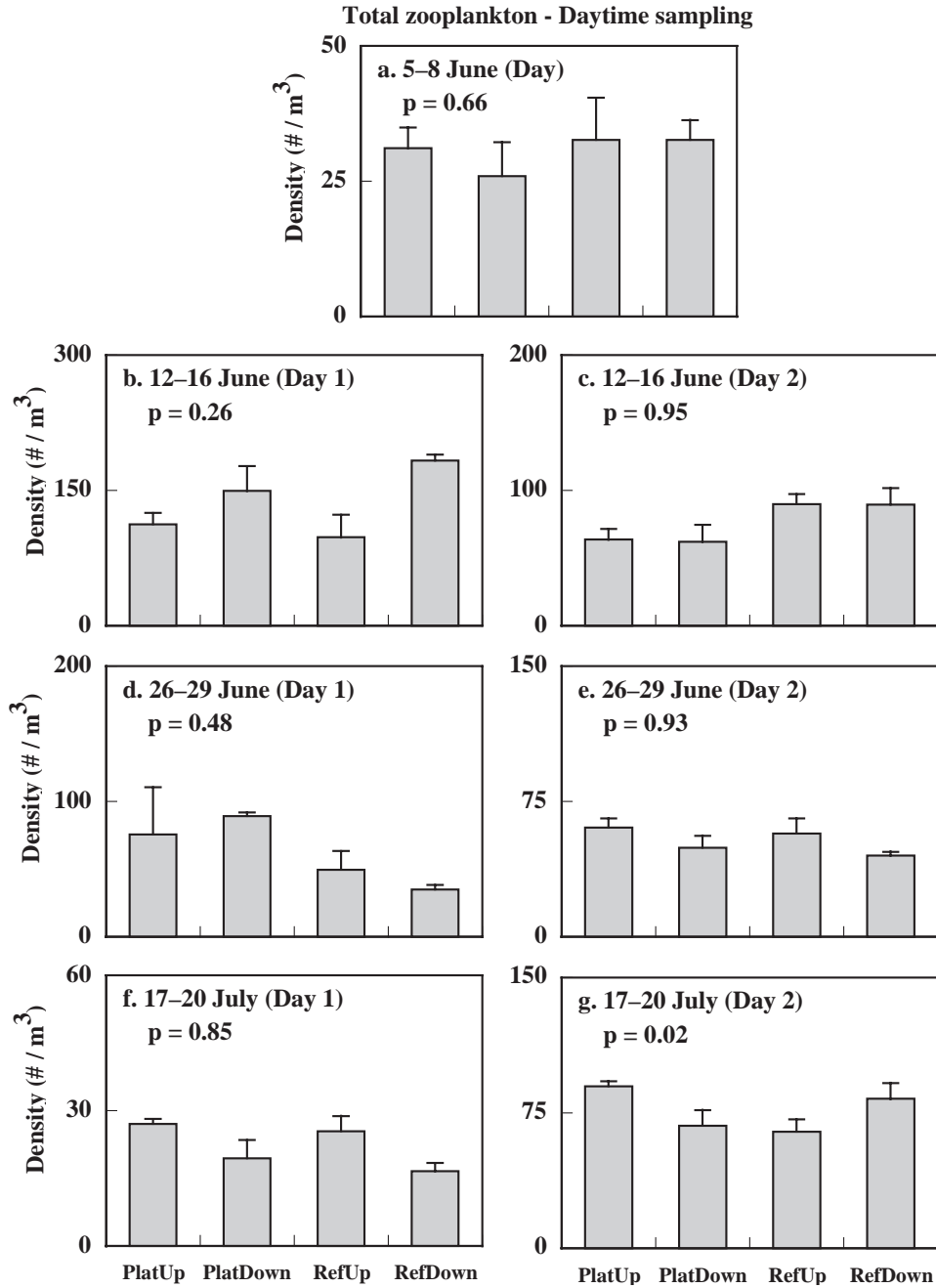
Figure 30. Decapod/Stomatopod density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

Amphipod - Daytime sampling

Figure 31. Amphipod density (# / m³) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
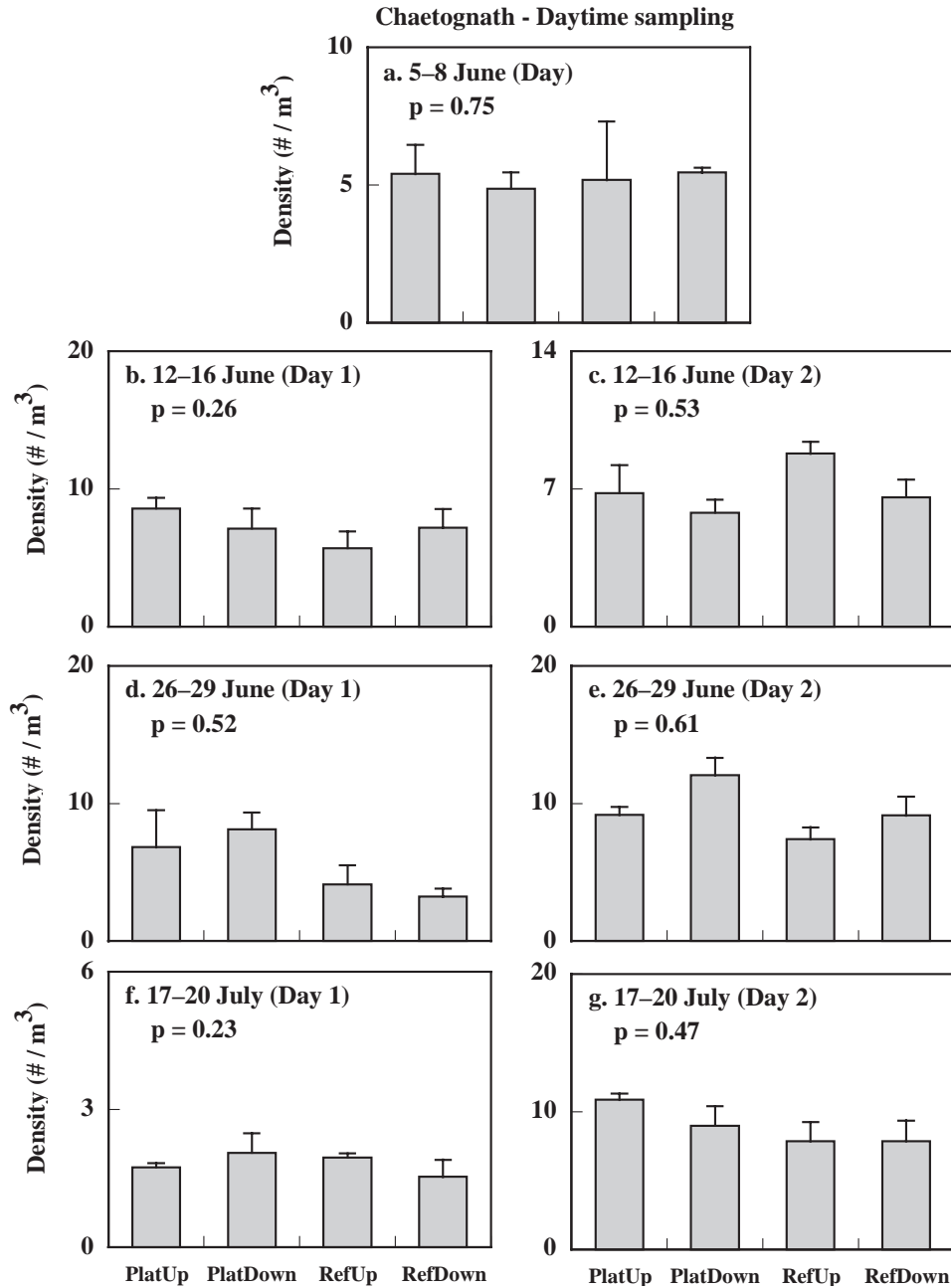
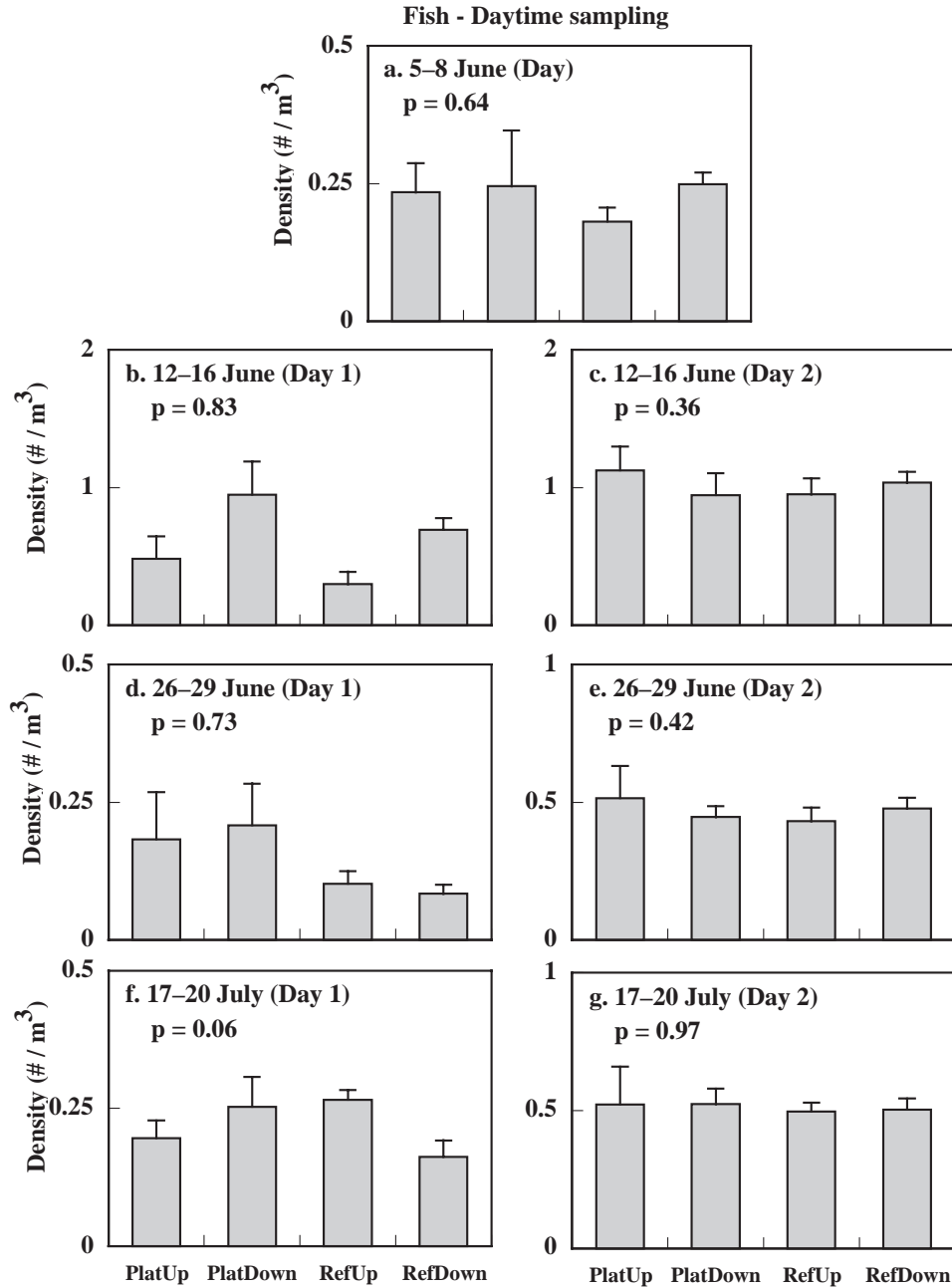Figure 32. Chaetognath density (# / m³) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

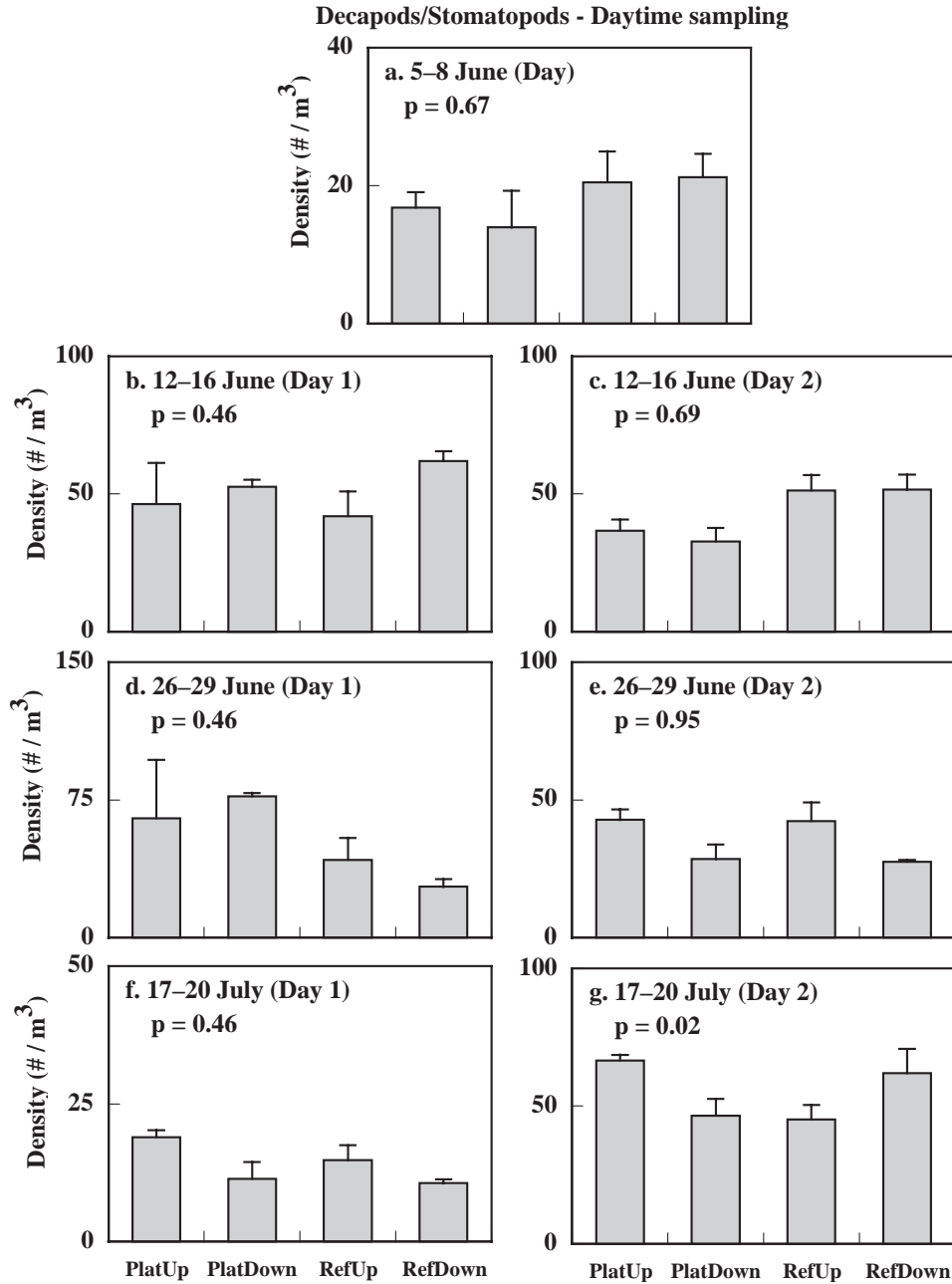**Pteropod - Daytime sampling**

Figure 33. Pteropod density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

Figure 34. Copepod density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

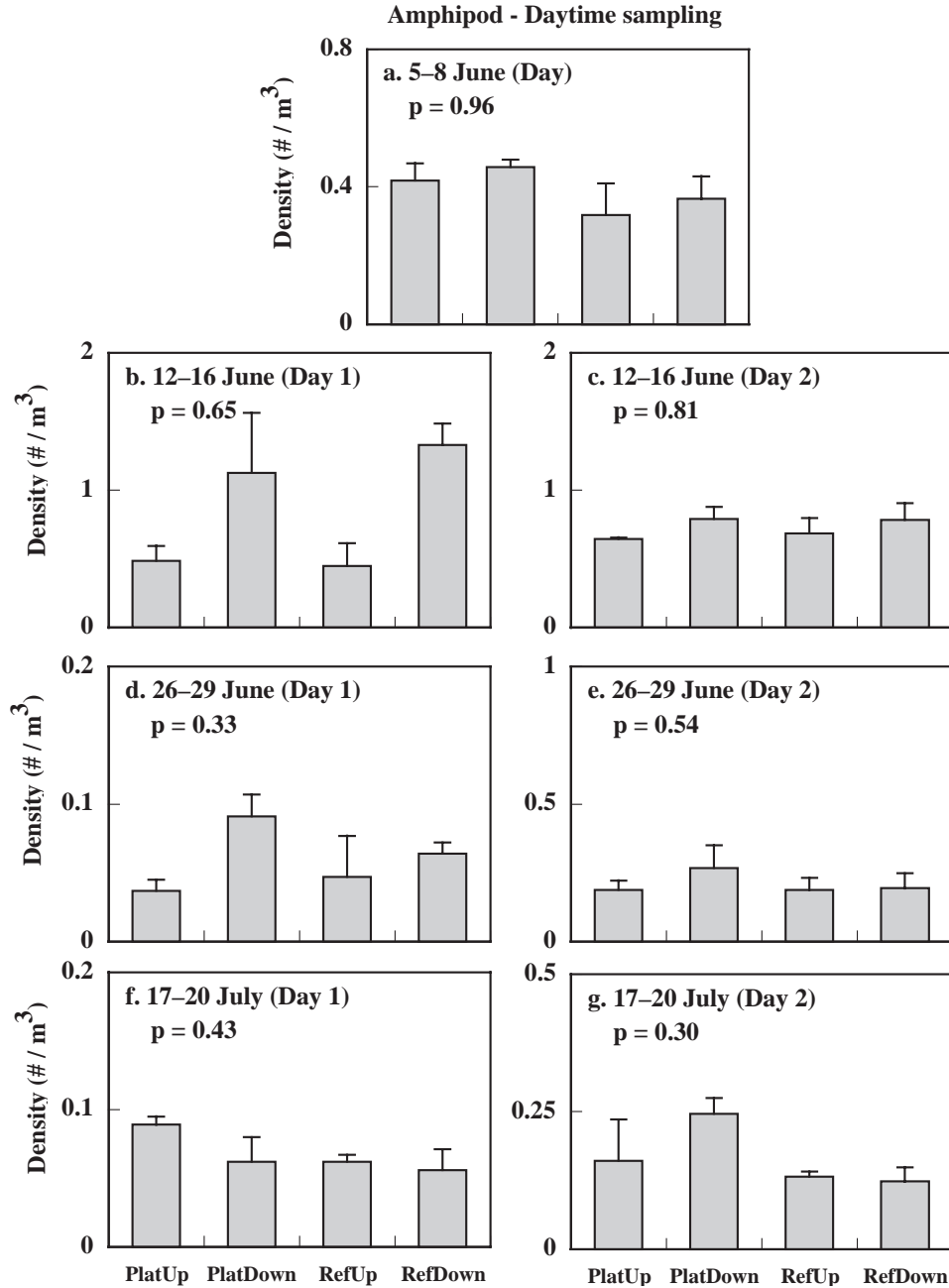**Gelatinous zooplankton - Daytime sampling**

Figure 35. Gelatinous zooplankton density (# / m³) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction; asterisks indicate significant difference between sites and letters indicate which sites are different from a Tukey test (proc glm, SAS v 6.12).

Figure 36. Egg density (# / m^3) from plankton net samples during each daytime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

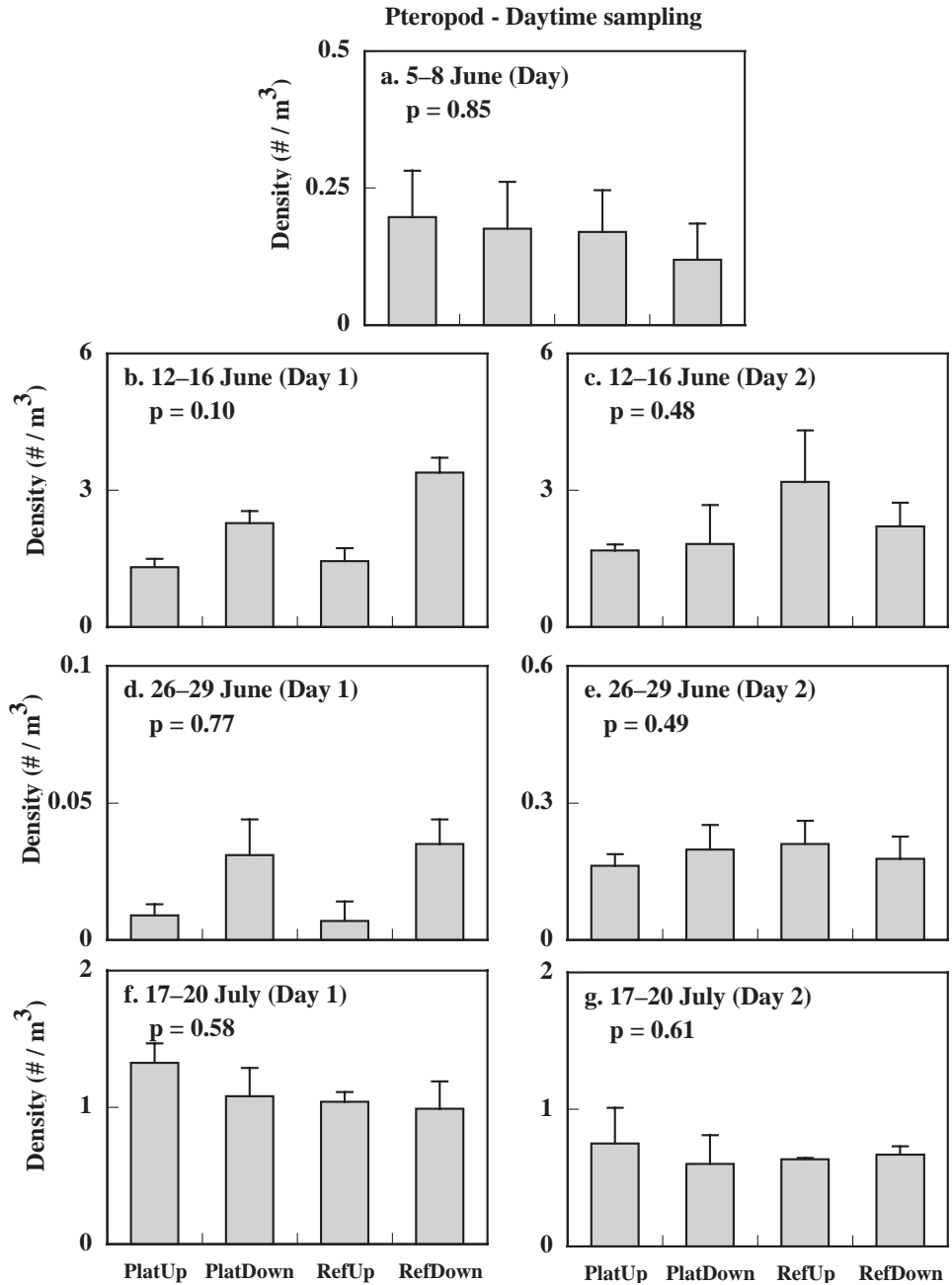Figure 37. Total zooplankton density (# / m³) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
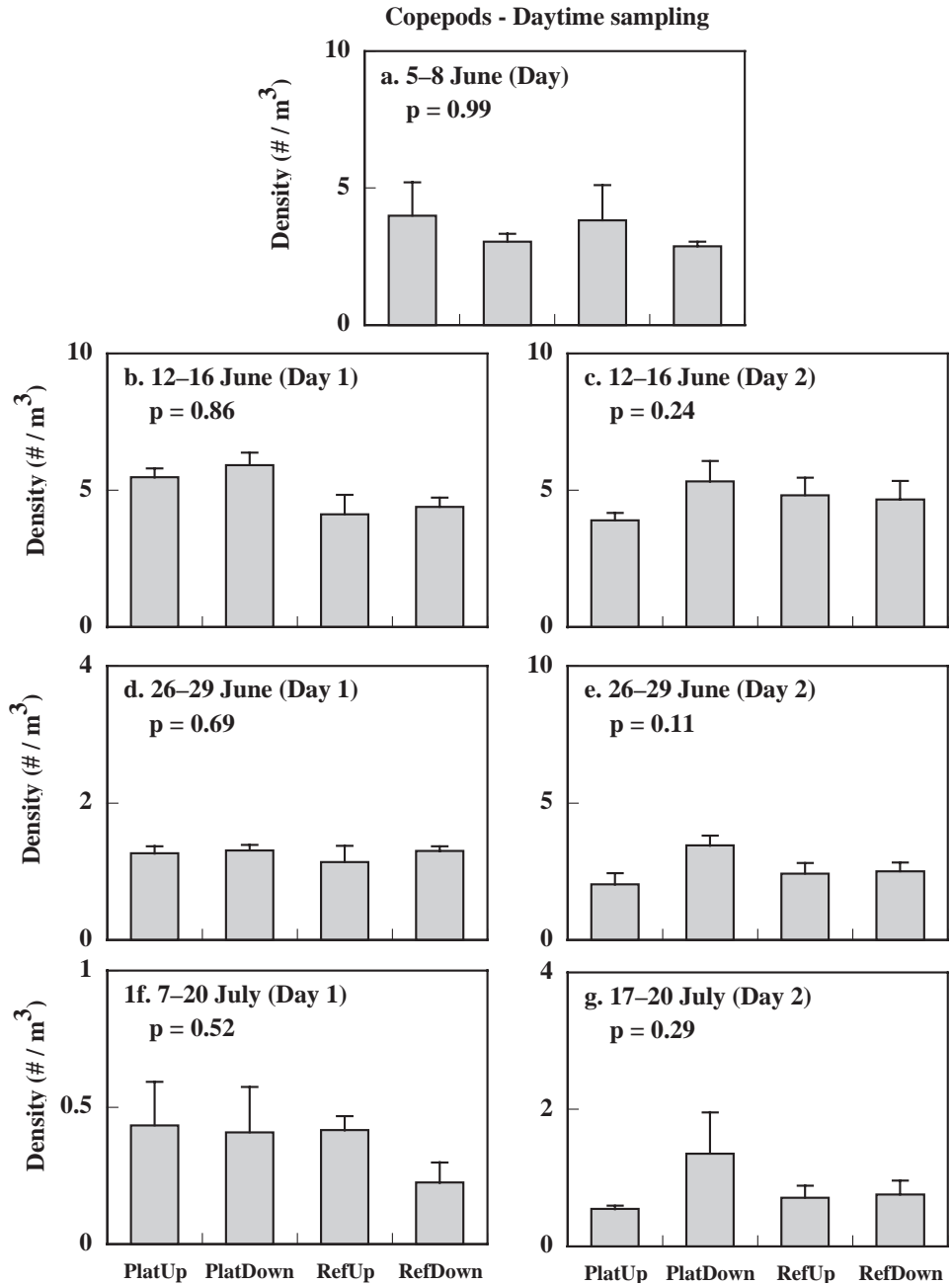
Fish - Nighttime sampling

Figure 38. Fish density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction; asterisks indicate significant difference by site and letters indicate which sites are different from a Tukey test.

Figure 39. Decapod/Stomatopod density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
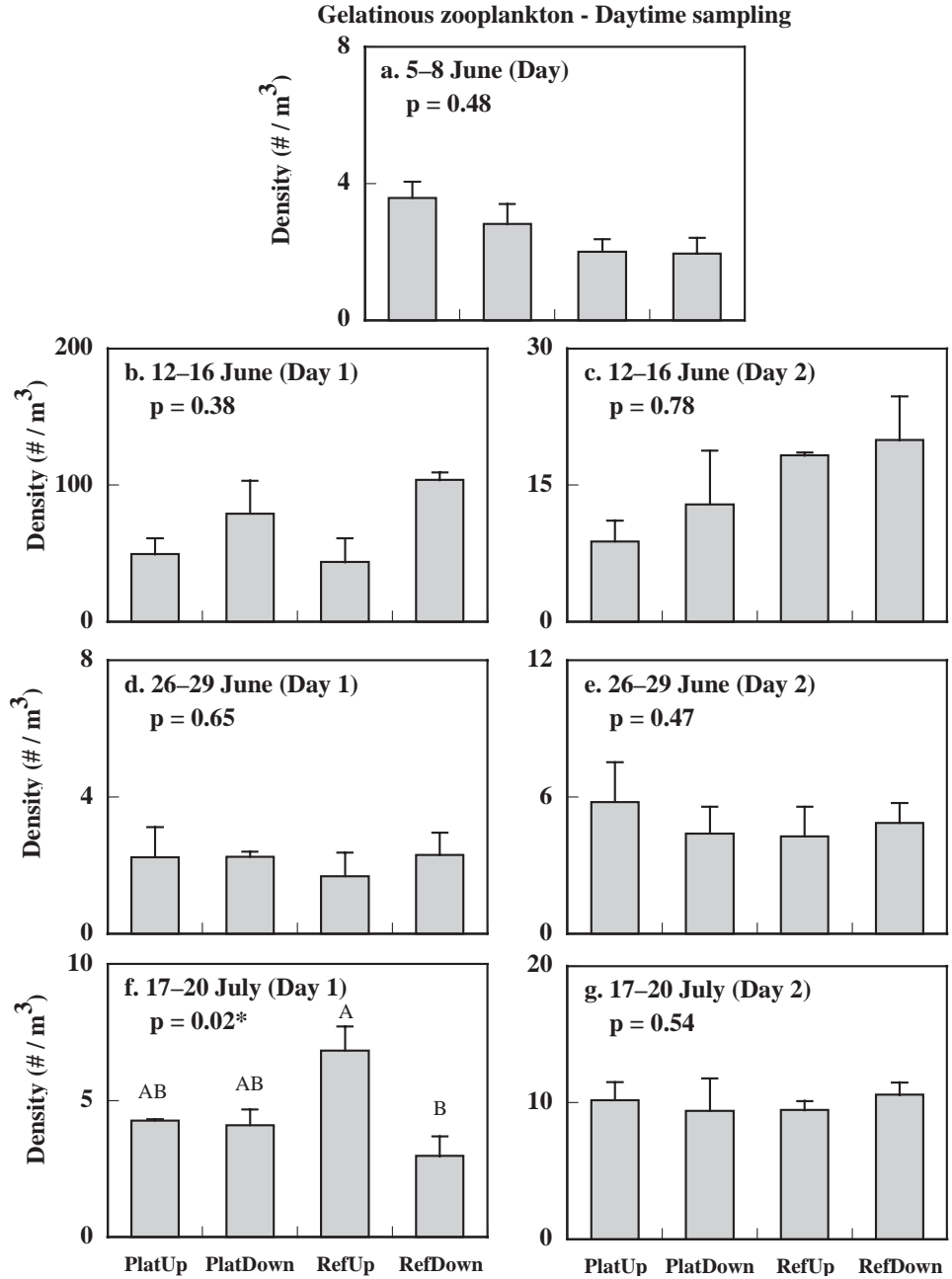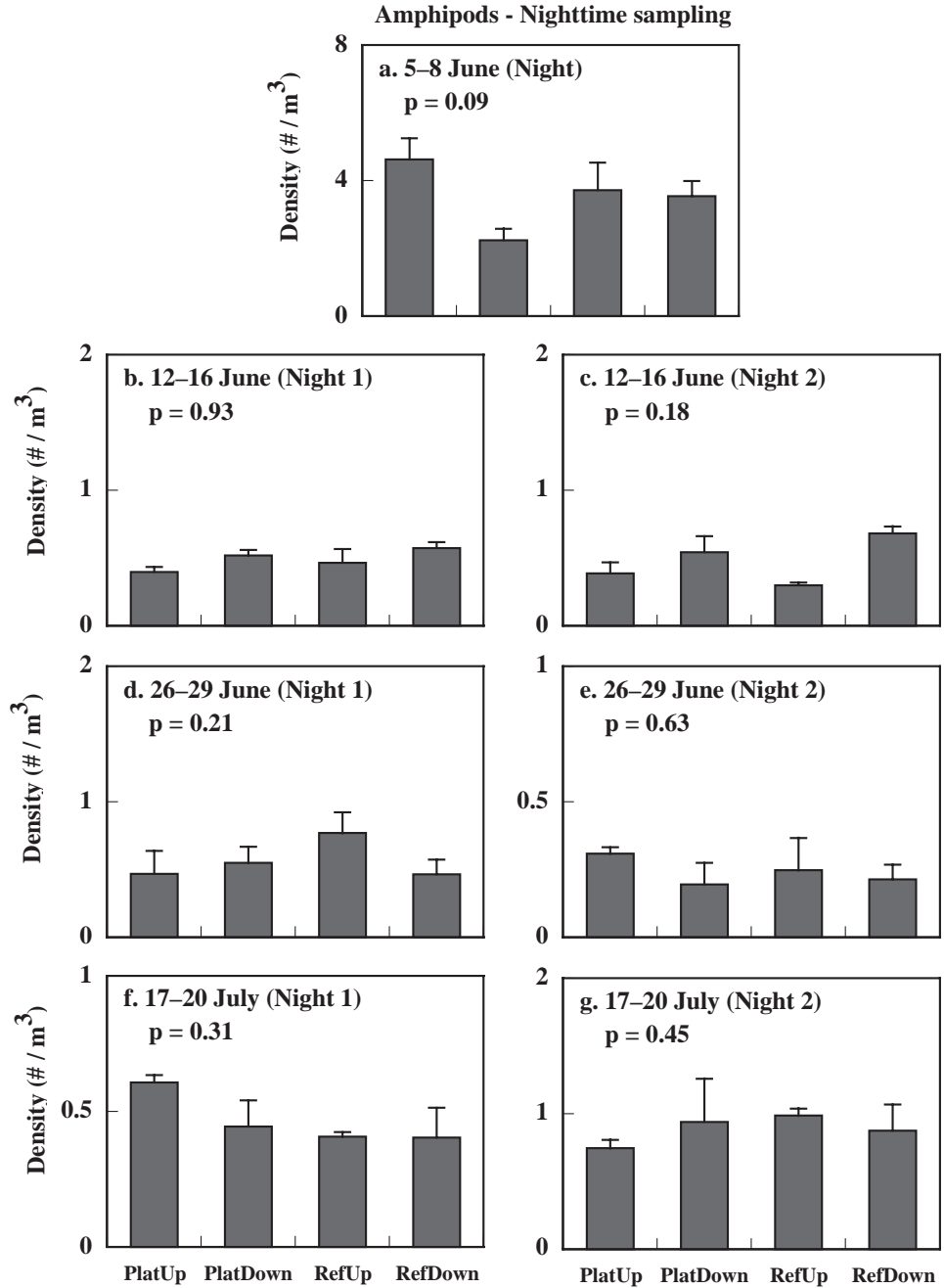
Figure 40. Amphipod density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
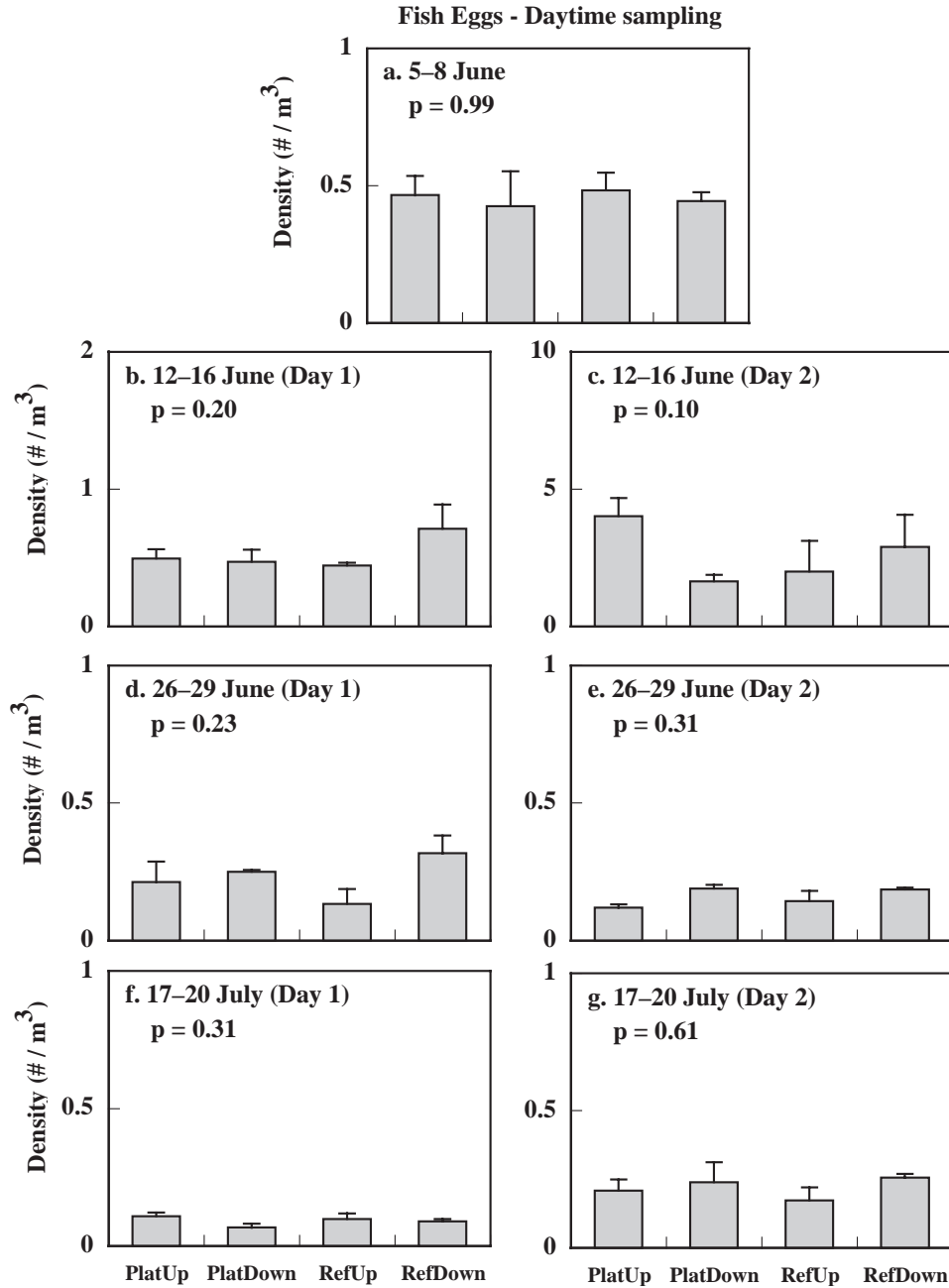
Chaetognaths - Nighttime sampling
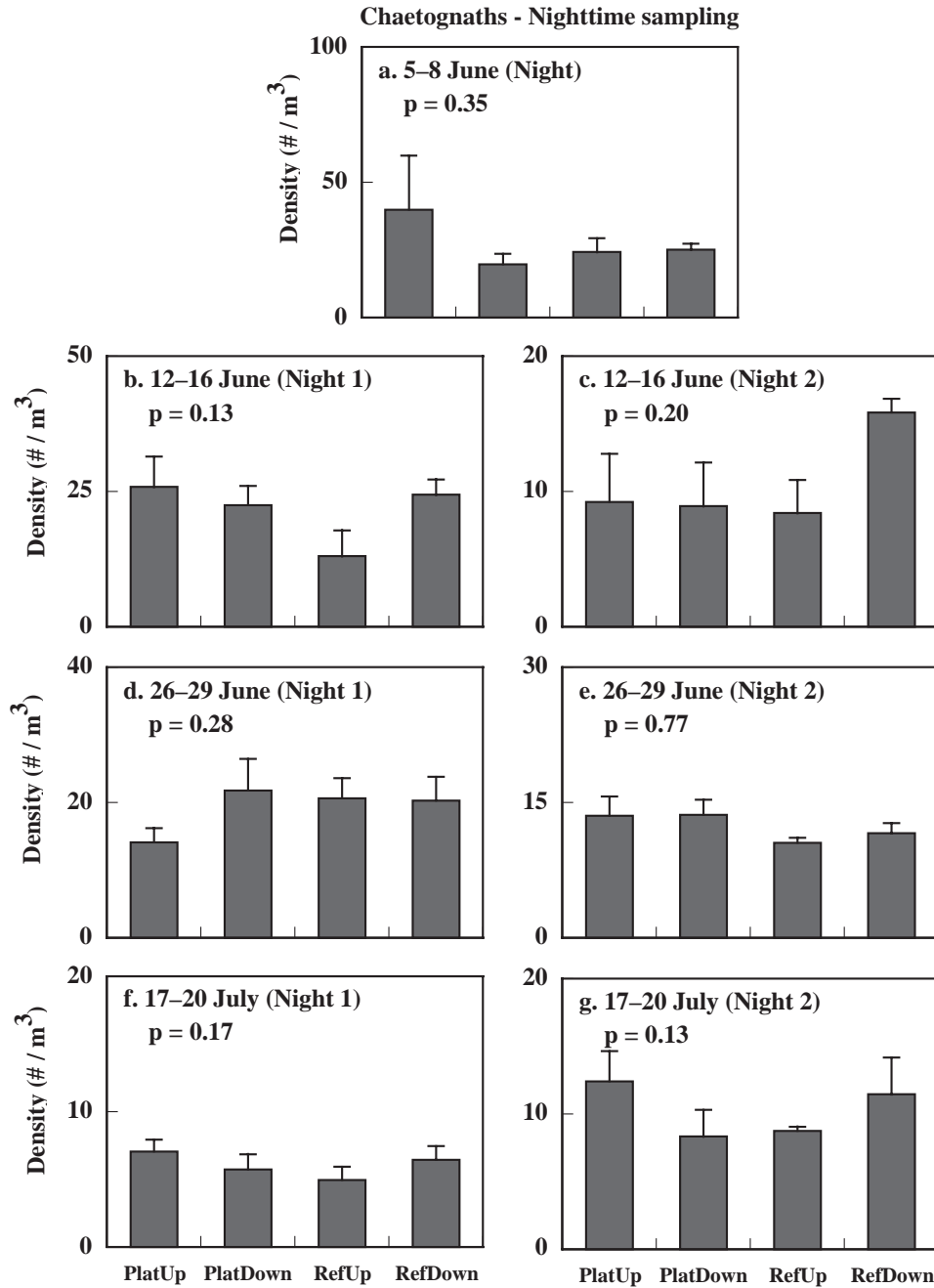
Figure 41. Chaetognath density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
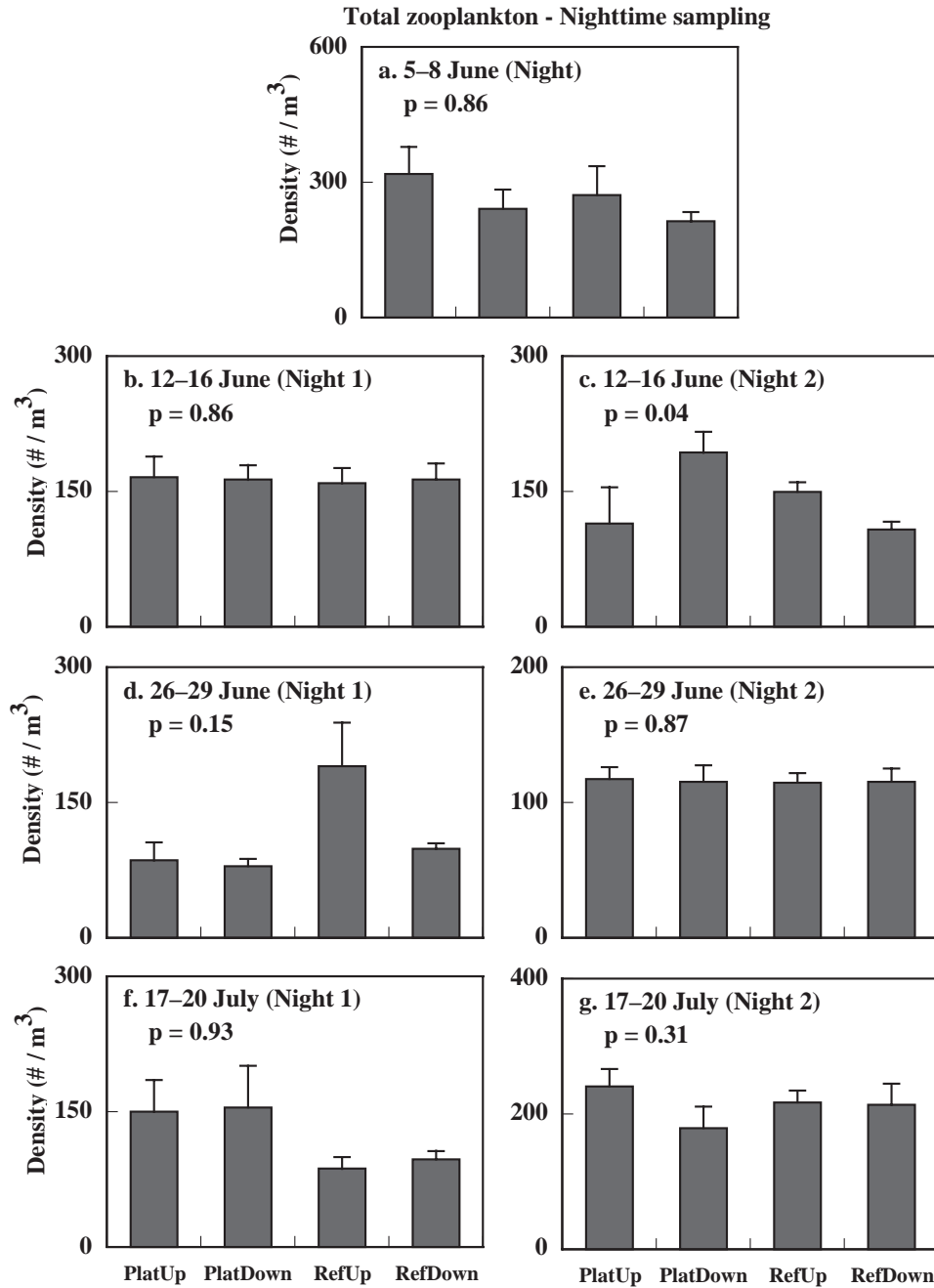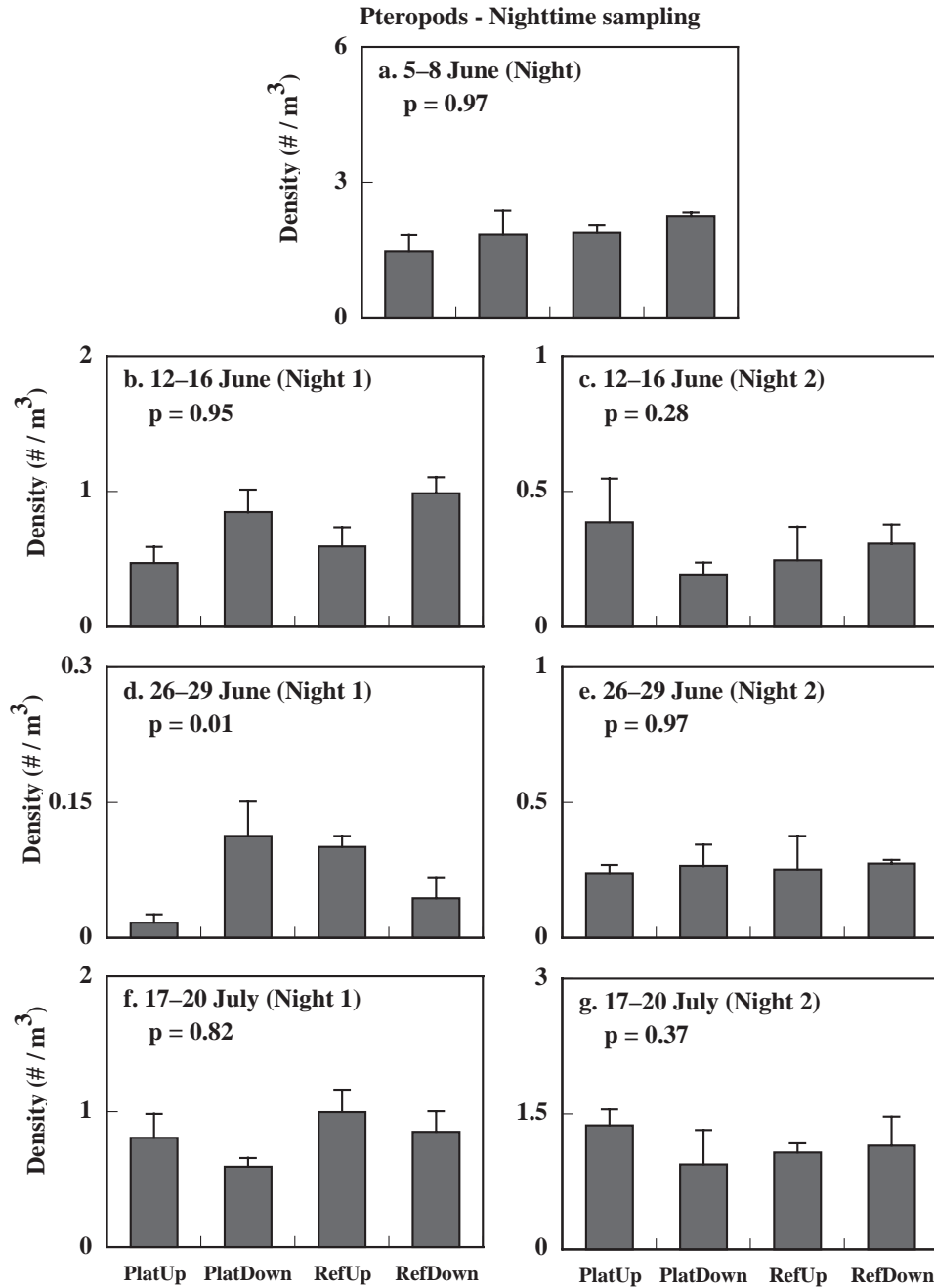
Figure 42. Pteropod density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

Copepods - Nighttime sampling
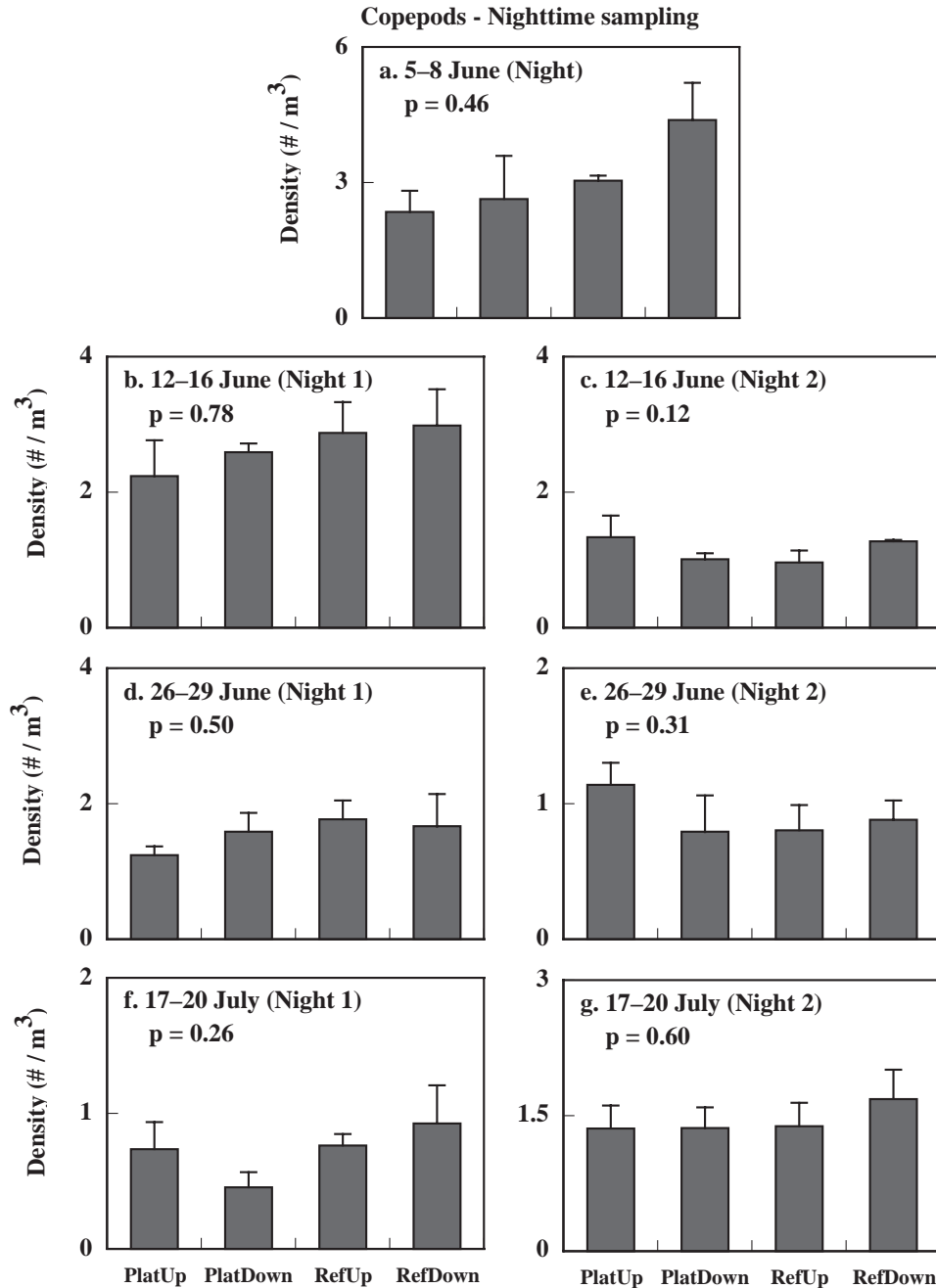
Figure 43. Copepod density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.
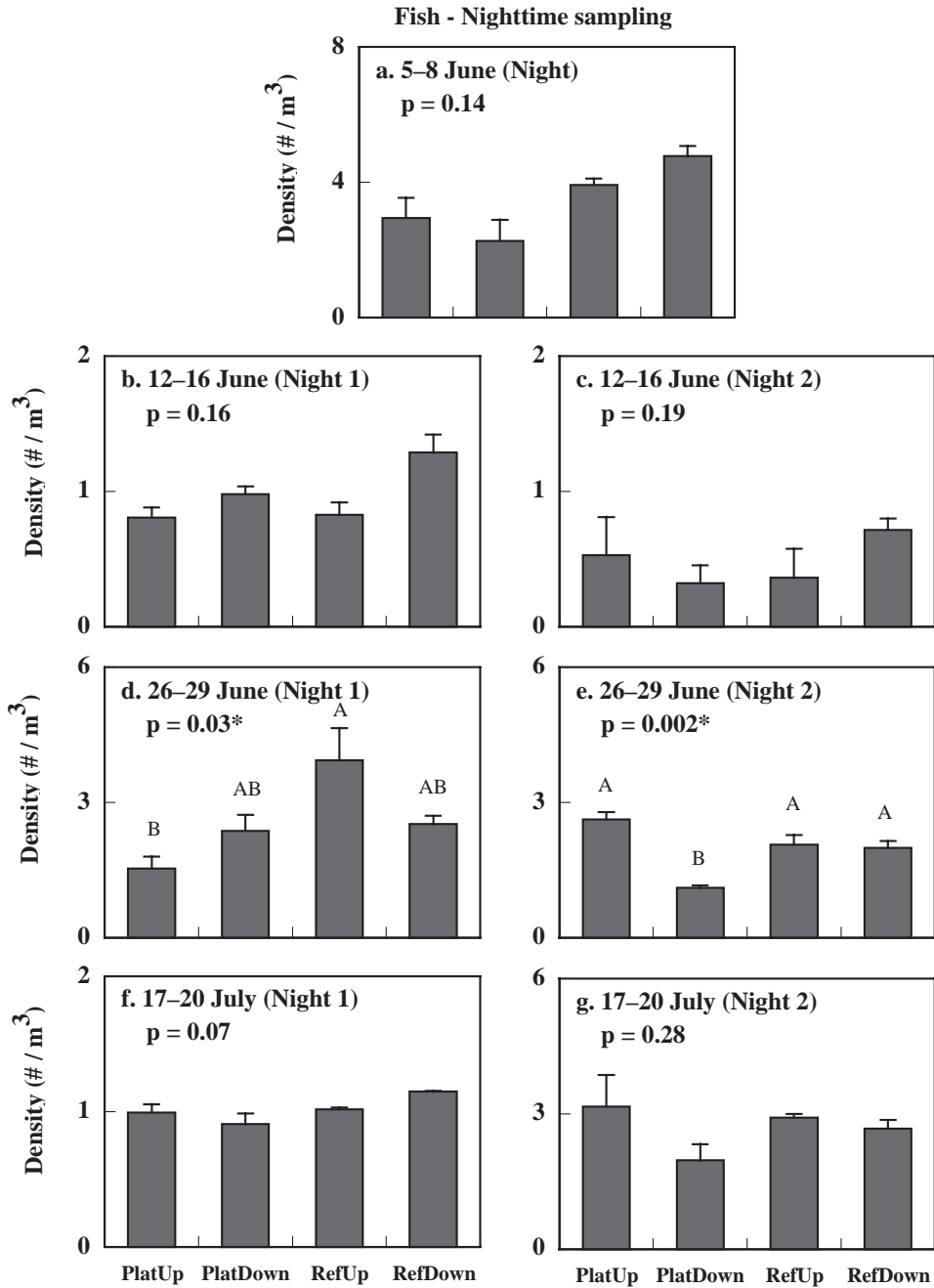
Gelatinous zooplankton - Nighttime sampling
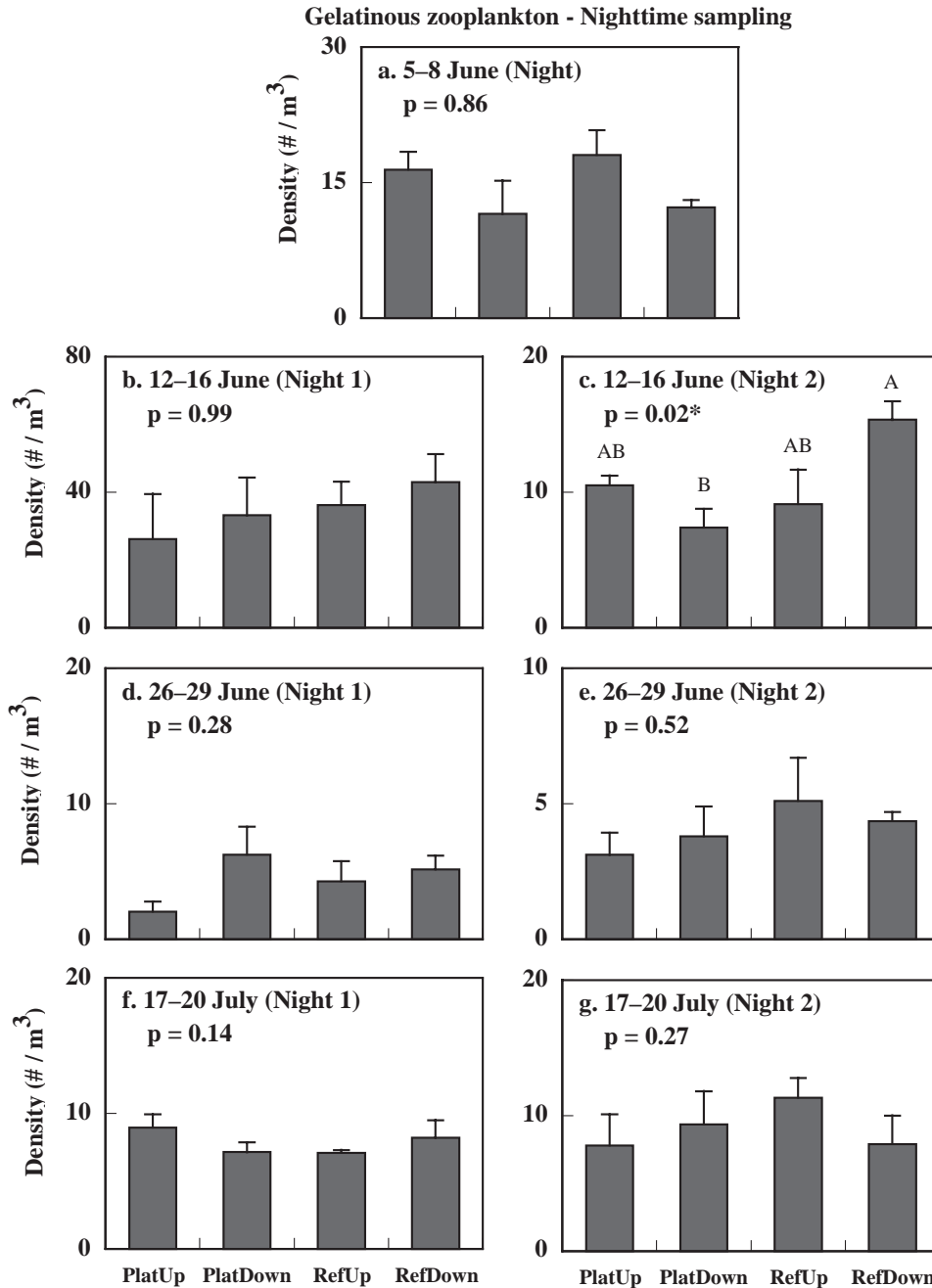
Figure 44. Gelatinous zooplankton density (# / m^3) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction; asterisks indicate a significant difference among sites and letters indicate which sites are different from a Tukey test.
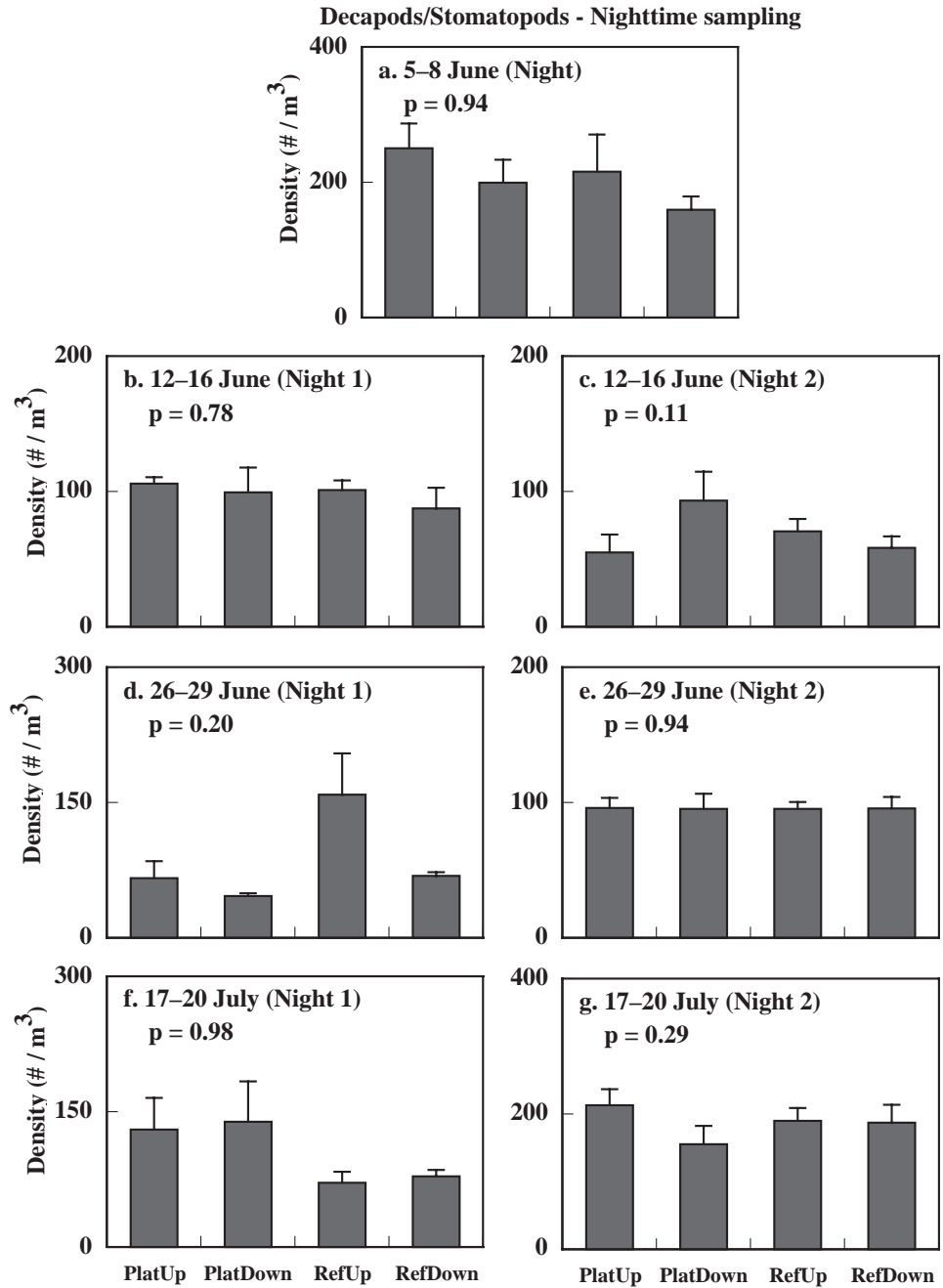
Fish Eggs - Nighttime sampling

Figure 45. Fish Egg density (# / m³) from plankton net samples during each nighttime set of net hauls (a–g) during each cruise. There were 12 net hauls during each set of tows: Platform Down-current (n=3), Platform Up-current (n=3), Reference Down-current (n=3), Reference Up-current (n=3). P-values indicate site-by-current interaction.

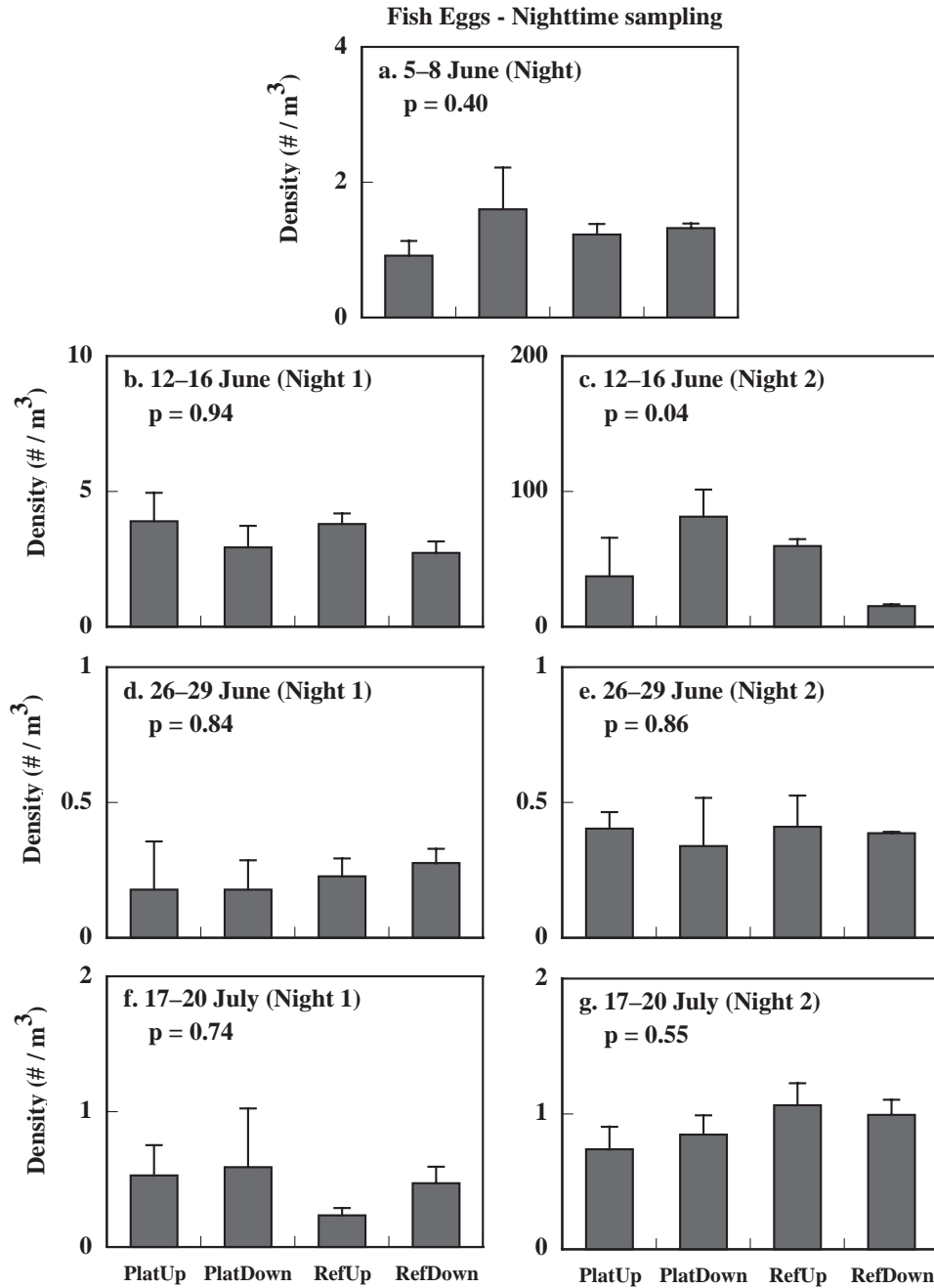Zooplankton density from daytime net tows did not show consistent trends with distance from the platform; however, for certain taxa and on some trips, there were significant relationships between density and distance from the platform. During the 5–8 June cruise to VK203A, the densities of total zooplankton, fish and decapods/stomatopods declined towards the platform, however none of the taxa displayed regressions with slopes that were significant (Fig. 46). On the 12–16 June cruise to MP140A total zooplankton densities also declined toward the platform, significantly so on the second day (Fig. 47). The total zooplankton density was driven primarily by the density of decapods/stomatopods on the second day and this taxon also had a significant declining slope toward the platform (Fig. 47). On the 26–29 June and 17–20 July cruises, total zooplankton densities increased towards the platform, with a significant regression on day one of the former trip (Fig. 48). Decapod/Stomatopod density decreased closer to the platform during many daytime collections and this patterns was near significant at the 9% level for the 5–8 June trip (Fig. 46) and again on day one of the 12–16 June cruise (p=0.01; Fig. 47). However, on 26–29 June, decapods/stomatopods showed significant negative relationship between distance from the platform and density (Fig. 48).

Linear regression slopes of fish abundance decreased near the platform during 5–8 June (Fig. 46), however, they increased or showed no pattern in all other daytime samples (Fig. 47–49). Slopes were not significantly different from zero for fish on all trips. Of the remaining taxa, the slope of chaetognaths density increased significantly towards MP140A on 26–29 June (day 2), and also increased towards VK203A on day two of the 17–20 July cruise (p = 0.07; Fig. 49). Copepods increased towards MP140A on day one of the 12–16 June cruise (Fig. 47).

For nighttime samples, the slopes of the regressions were non-significant for all cruises, although trends in total zooplankton densities were generally opposite to those noted during the daytime sampling. Densities appear to increase closer to the platform for the first two cruises (Fig. 50, 51) and decrease for the second two (Fig. 52, 53). Fish showed decreasing abundance or no trend near the platform for all nighttime collections. Decapods/Stomatopods, amphipods, chaetognaths and pteropods did not show distinct trends during the night sampling (Fig. 50-53). Copepods showed a significantly positive slope with increasing distance from the platform on night one of the 12–16 June cruise. Fish eggs were higher in abundance nearer to the platform only during the night 2 sampling of 12–16 June trip to MP140A (Fig. 51).
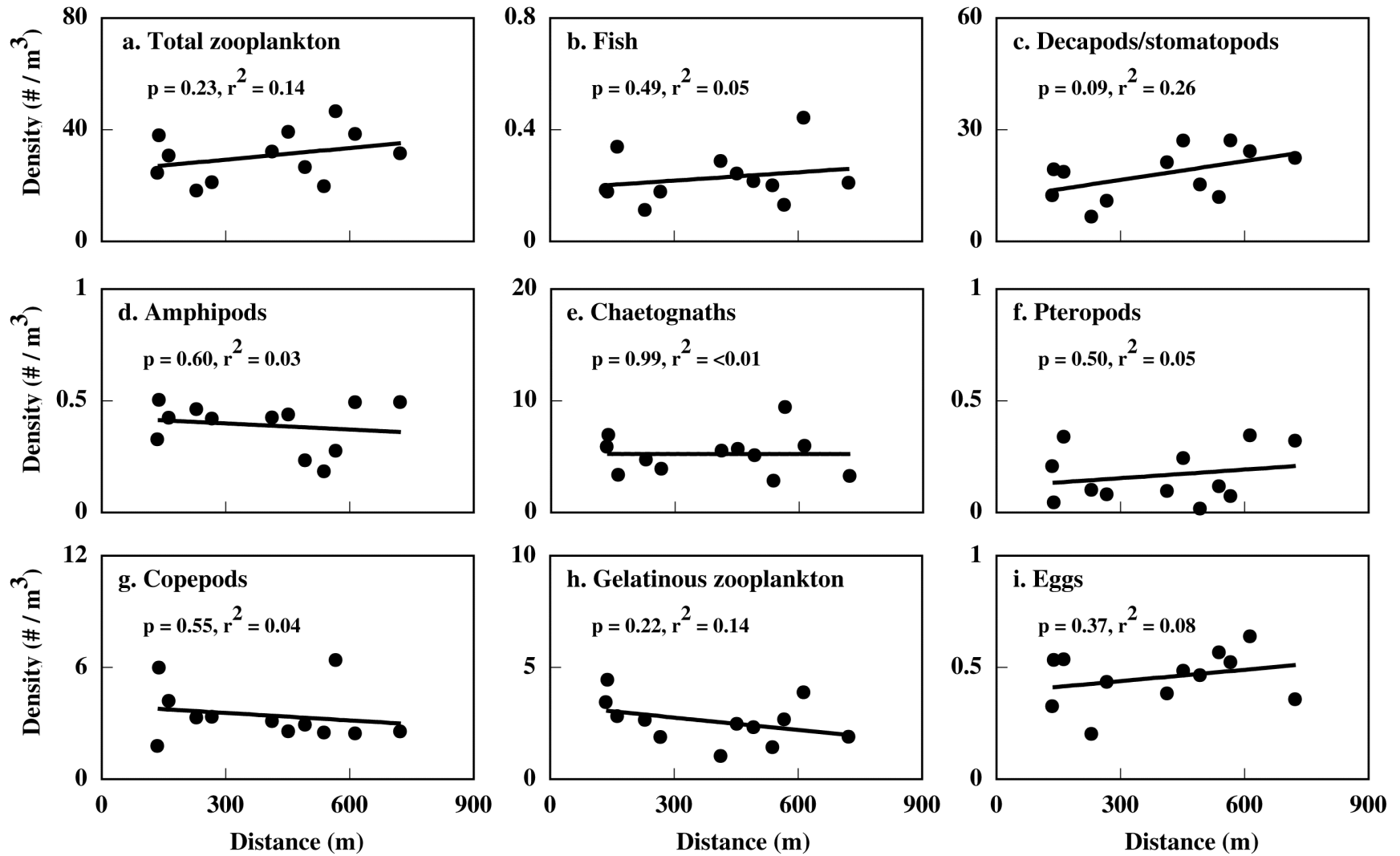
Figure 46. Regression of taxa density (# / m^3) from day net samples versus distance from VK203A during the 5–8 June cruise. Samples taken during only one day (n=12).

Figure 47. Regression of taxa density (# / m^3) from day net samples versus distance from MP140A during the 12–16 June cruise. Closed circles are day 1 samples (n=12) and open squares (p-values underlined) are day 2 samples (n=12). Asterisks (*) indicate a significant relationship.

Figure 48. Regression of taxa density (# / m^3) from day net samples versus distance from MP140A during the 26–29 June cruise. Closed circles represent day 1 samples (n=12) and open squares (p-values underlined) indicate day 2 samples (n=12). Asterisks (*) indicate a significant relationship.

Figure 49. Regression of taxa density (# / m³) from day net samples versus distance from VK203A during the 17–20 July cruise. Closed circles are for day1 samples (n=8) and open squares (p-values are underlined) are for day 2 samples (n=12).

Figure 50. Regression of taxa density (# / m^3) from night net samples versus distance from VK203A during the 5–8 June cruise. Samples taken only during one night (n=12).

Figure 51. Regression of taxa density (# / m³) from night net samples versus distance from MP140A during the 12–16 June cruise. Closed circles are for night 1 samples (n=12) and open squares (p-values underlined) indicate night 2 samples (n=12). Asterisks (*) indicate a significant relationship.

87

Figure 52. Regression of taxa density (# / m^3) from night net samples versus distance from MP140A during the 26–29 June cruise. Closed circles represent night 1 samples (n=12) and open squares (p-values underlined) indicate night 2 samples (n=12).
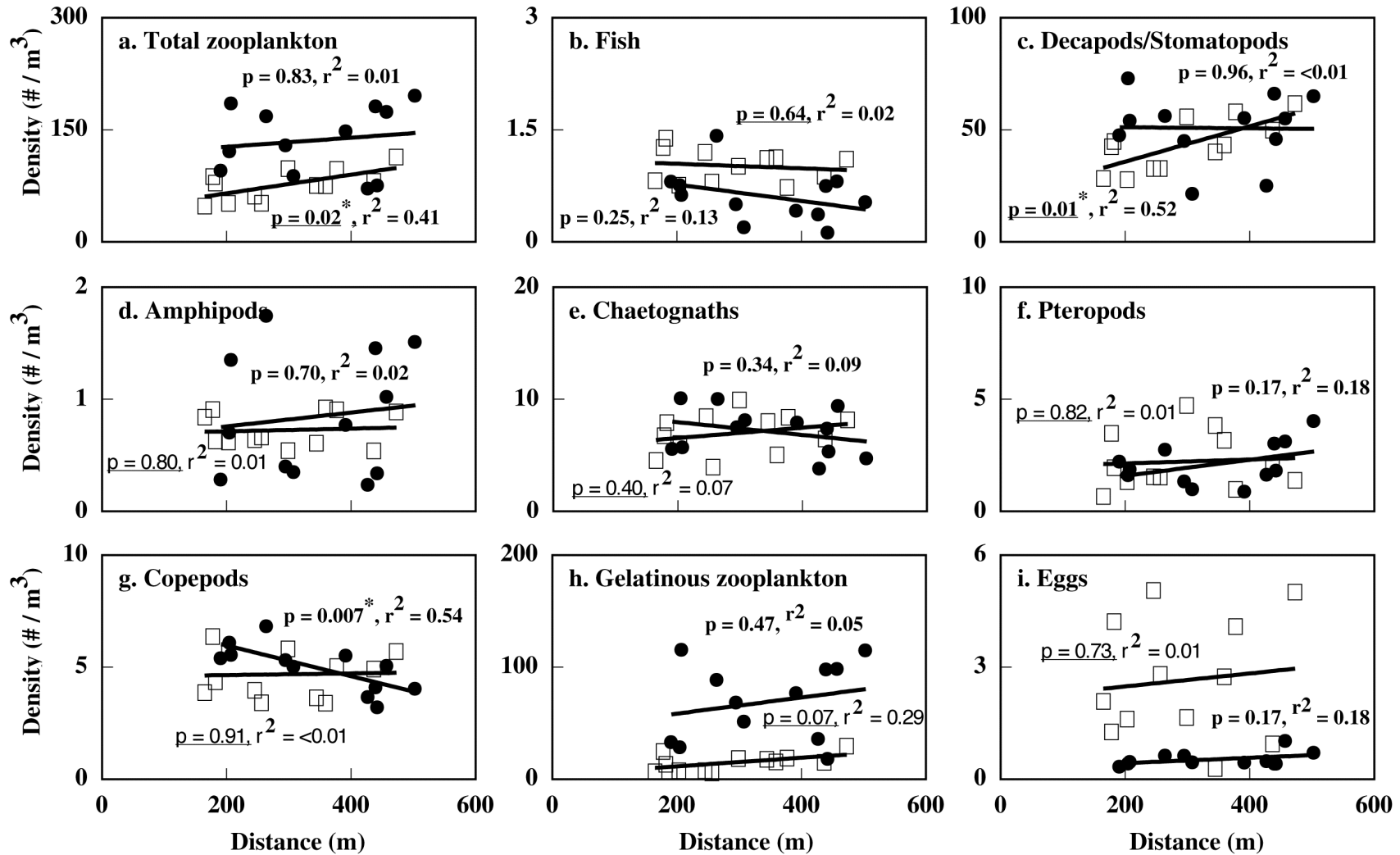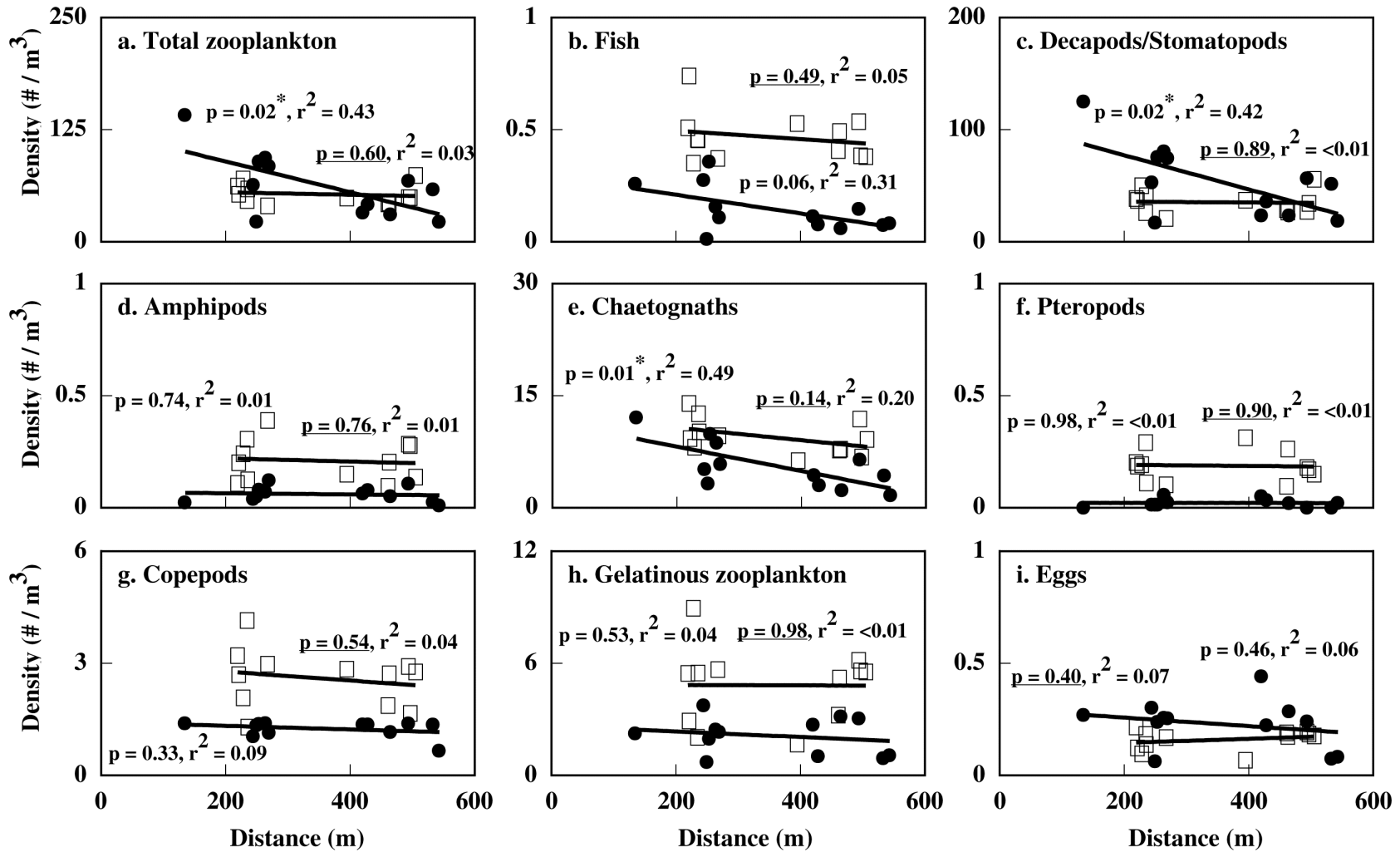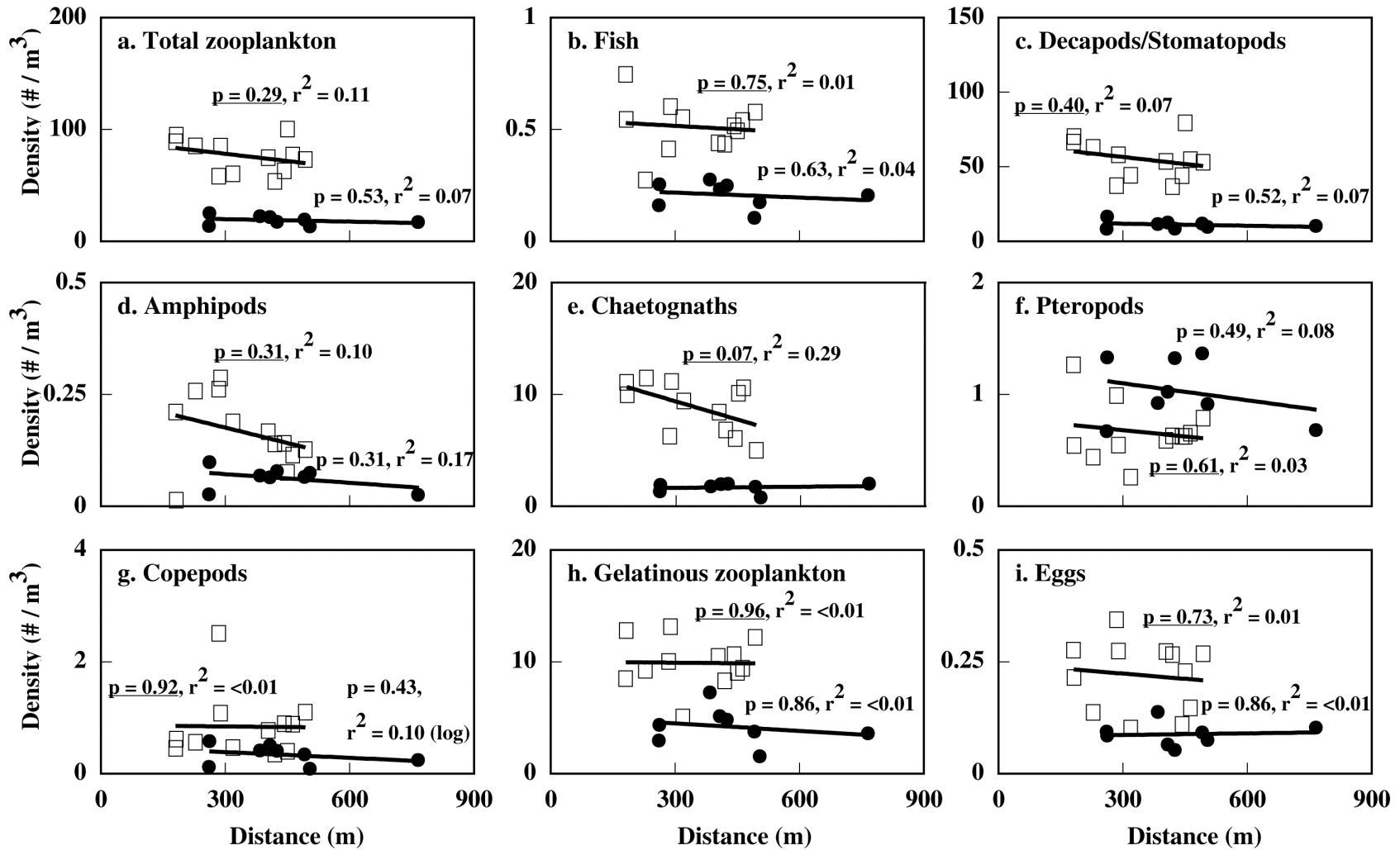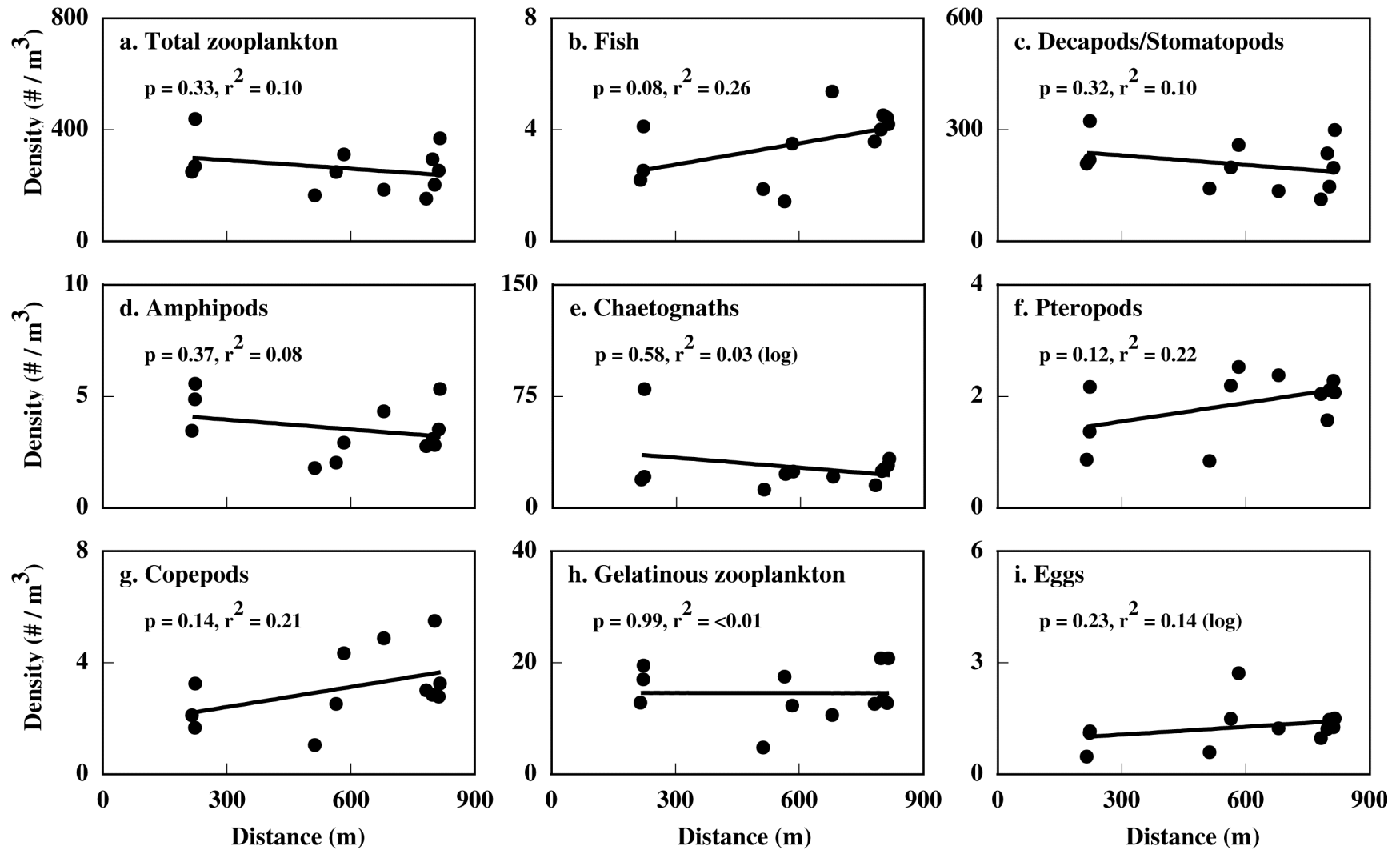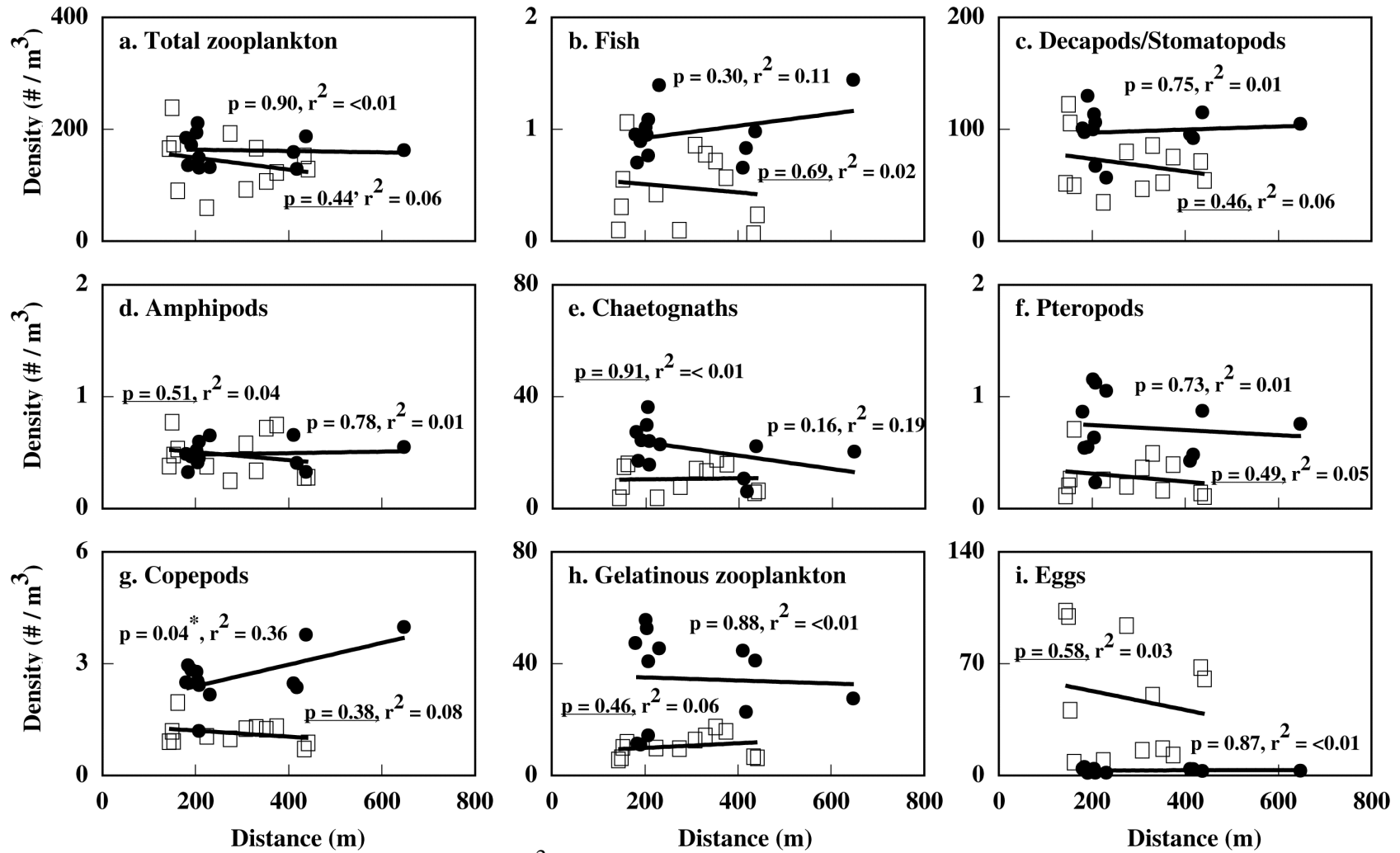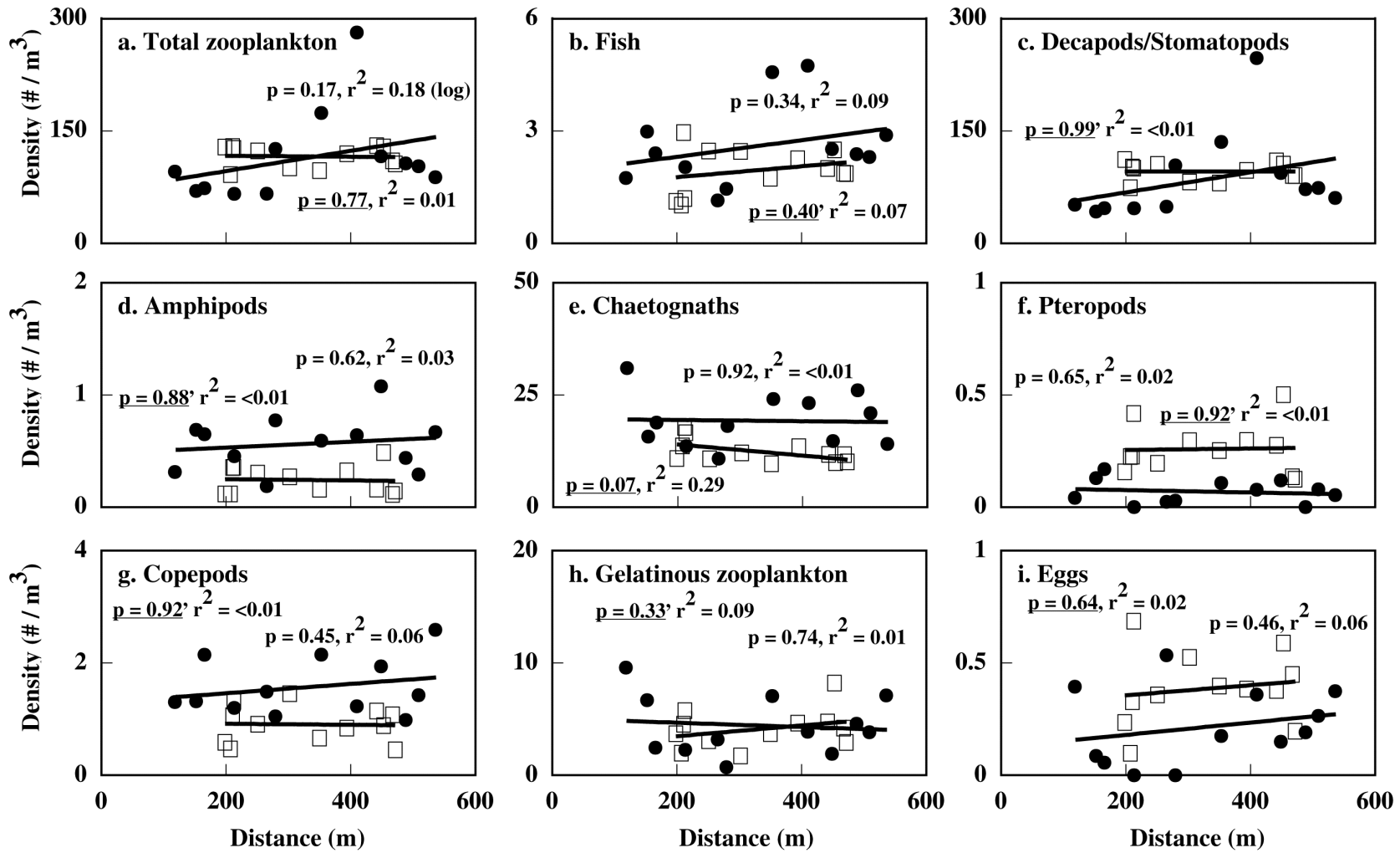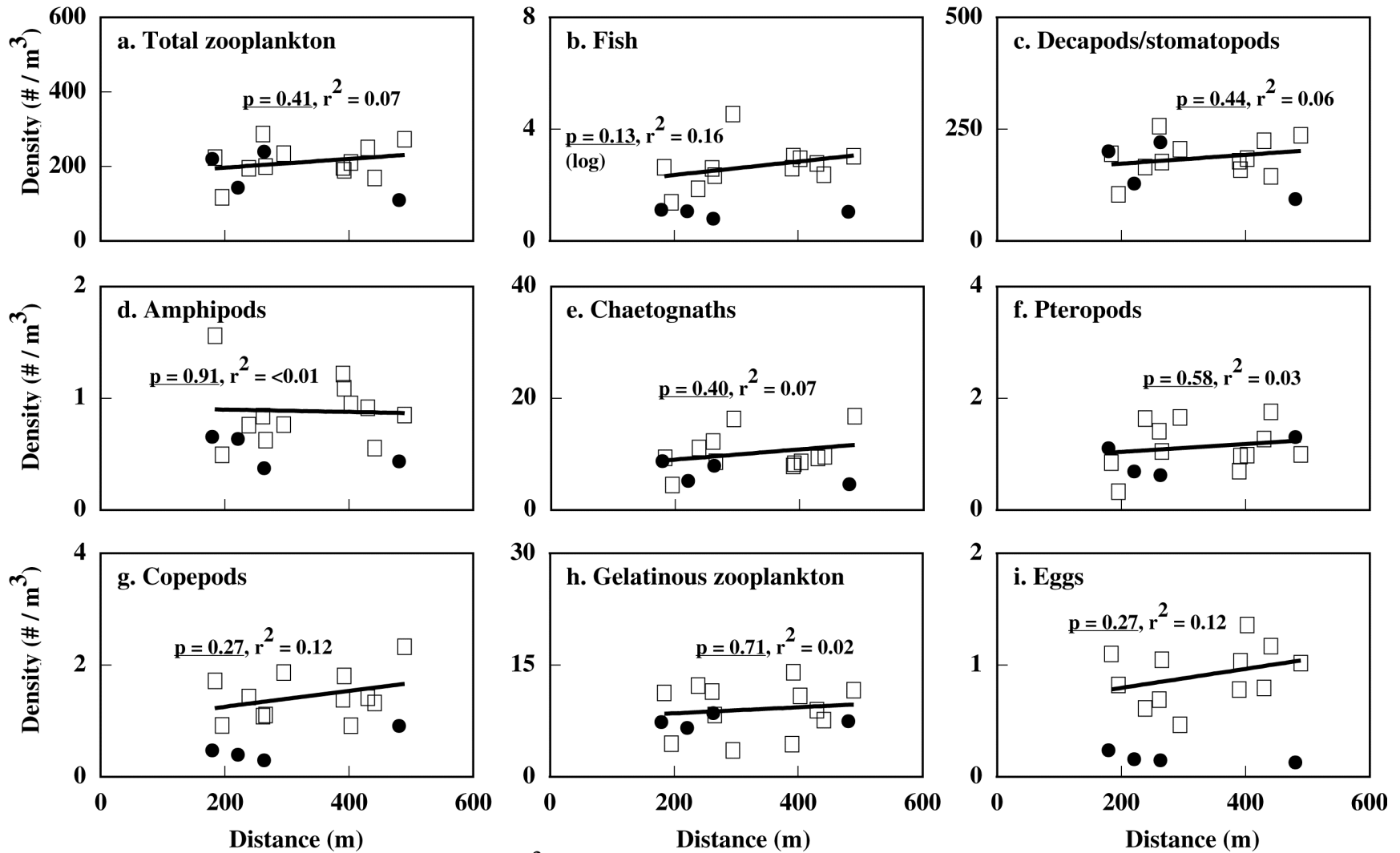
Figure 53. Regression of taxa density (# / m^3) from night net samples versus distance from VK203A during the 17–20 July cruise. Closed circles represent night 1 samples (n=4, no analysis) and open squares (p-values underlined) indicate night 2 samples (n=12).

Acoustic Results: Volume Scattering Strength and Plankton Density

Within each cruise, positive relationships existed between volume scattering strength and the logarithm of density for many taxa. During the daytime, those taxa capable of producing strong acoustic returns (i.e., fish and thecosomate pteropods) showed a positive relationship between volume scattering strength and density (Fig. 54–56). These regressions were significant for thecosomate pteropods during the 12–16 June (day 2) cruise (Fig. 56), but were not for fish during any of the daytime collections. The total zooplankton category failed to show a clear positive relationship with scattering. Results for moderately strong scatters such as decapods/stomatopods and amphipods suggested that their densities were not well correlated with the volume scattering strength during the day (Fig. 54–56). The densities of weakly scattering organisms such as chaetognaths, copepods, gelatinous plankton and fish eggs were not related to the volume scattering strength with the exception of fish eggs on the second day of sampling during the 12–16 June cruise when there was a significant negative relationship between egg density and volume scattering strength (Fig. 56).

At night, the relationship between density and S_v varied from generally positive and often significant regressions for 5–8 June (Fig. 57) to very weak and variable relationships on the first night of 12–16 June (Fig. 58), and neutral or negative relationships on the second night of 12–16 June (Fig. 59). Strong scatterers such as fish and pteropods did not significantly and positively associate with S_v (Fig. 58, 59). Moderately strong scatterers (decapods/stomatopods, amphipods) were significantly and positively related to S_v on 5–8 June (Fig. 57). On 12–16 June (night 1) there was no apparent relationships for decapods/stomatopods although amphipod densities were still significantly and positively related to S_v (Fig. 58). By the second night of 12–16 June, the densities of both groups were not significantly related to S_v (Fig. 59). Weakly scattering organisms demonstrated interesting, if contradictory results. Gelatinous zooplankton densities were significantly and positively related to S_v on 5–8 June and on 12–16 June (night 1) the relationship was positive but significant only at $p = 0.14$ (Fig. 58). By the next night, gelatinous zooplankton densities were significant but negatively related to S_v (Fig. 59). There was never a significant relationship between copepod densities and S_v for any of the nights (Fig. 57-59). Fish egg densities were positively related to S_v only on the second night of 12–16 June (Fig. 59).

Acoustic Results: Volume Scattering Strength and Wet Weight

Volume-specific total wet weight for six taxa in a sample (mg/m^3) were greater during the 12–16 June night net tows than day tows, four taxa significantly so (Fig. 60). Amphipods, pteropods, and copepods, however, showed a significant decrease in weight during the night tows relative to the day. The overall increase in wet weight was associated with a minor increase in S_v computed from the net tows (Fig. 61). Fewer net tows (n=23) were examined for correlation between backscattering strength and logarithm of wet weight, which made it difficult to evaluate relationships. During the day 2 net samples, only pteropods were significantly ($p = 0.05$, $r^2 = 0.33$) correlated with scattering (Fig. 61). Fish eggs collected during these samples showed a negative relationship with S_v, which is similar to the trends seen from egg density during the same day (Fig. 56). At night, fish, amphipod, copepod, and gelatinous zooplankton wet weight was positively correlated with S_v (Fig. 61), however only amphipod ($p = 0.001$, $r^2 = 0.71$) and gelatinous zooplankton wet weight were significant ($p = 0.03$, $r^2 = 0.43$).
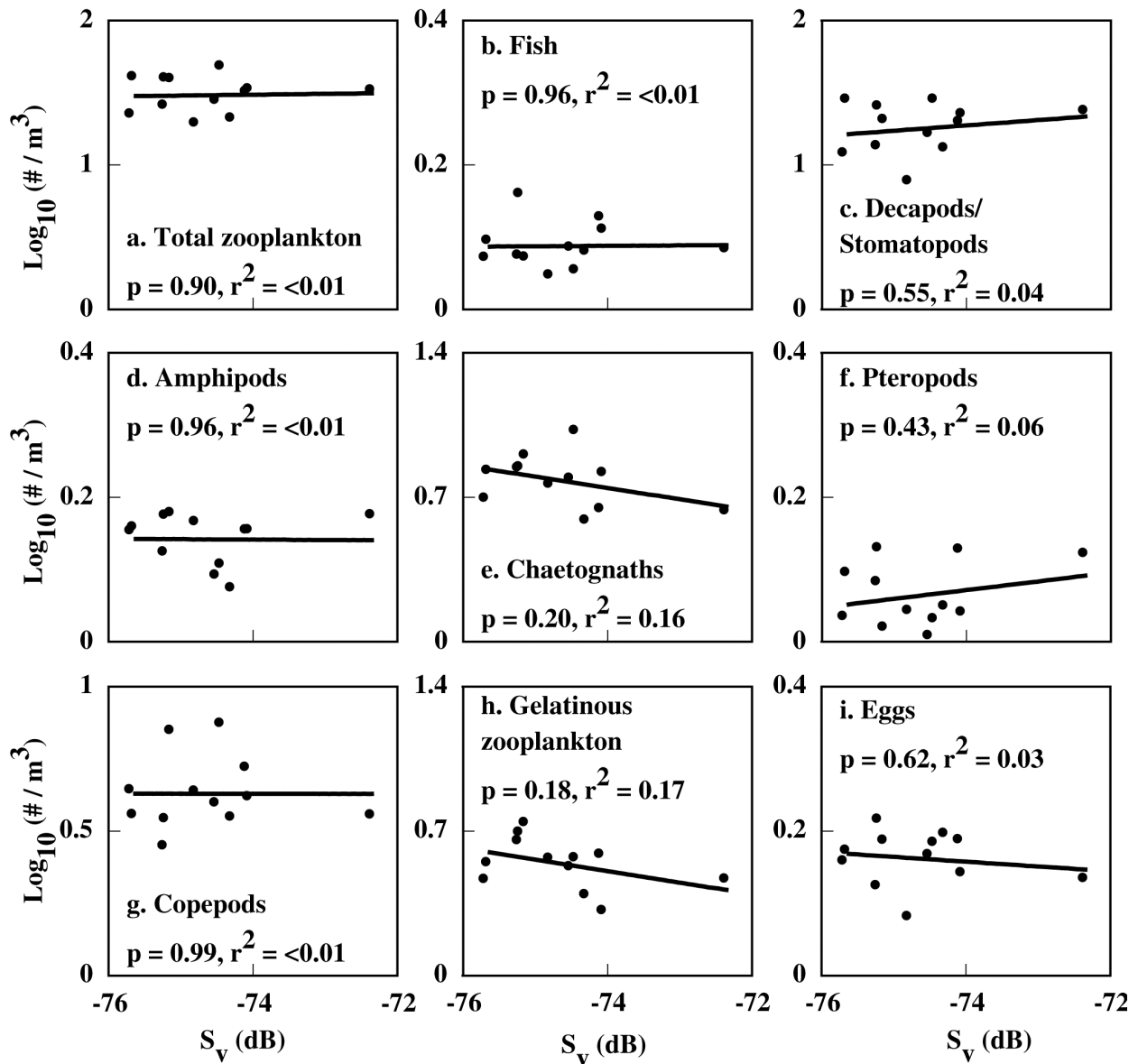
Figure 54. Regressions of volume backscatter (dB) to logarithm of density (# / m^3) for each taxon identified (a–i) from the daytime sampling during the 5–8 June cruise to VK203A (n = 12 tows).
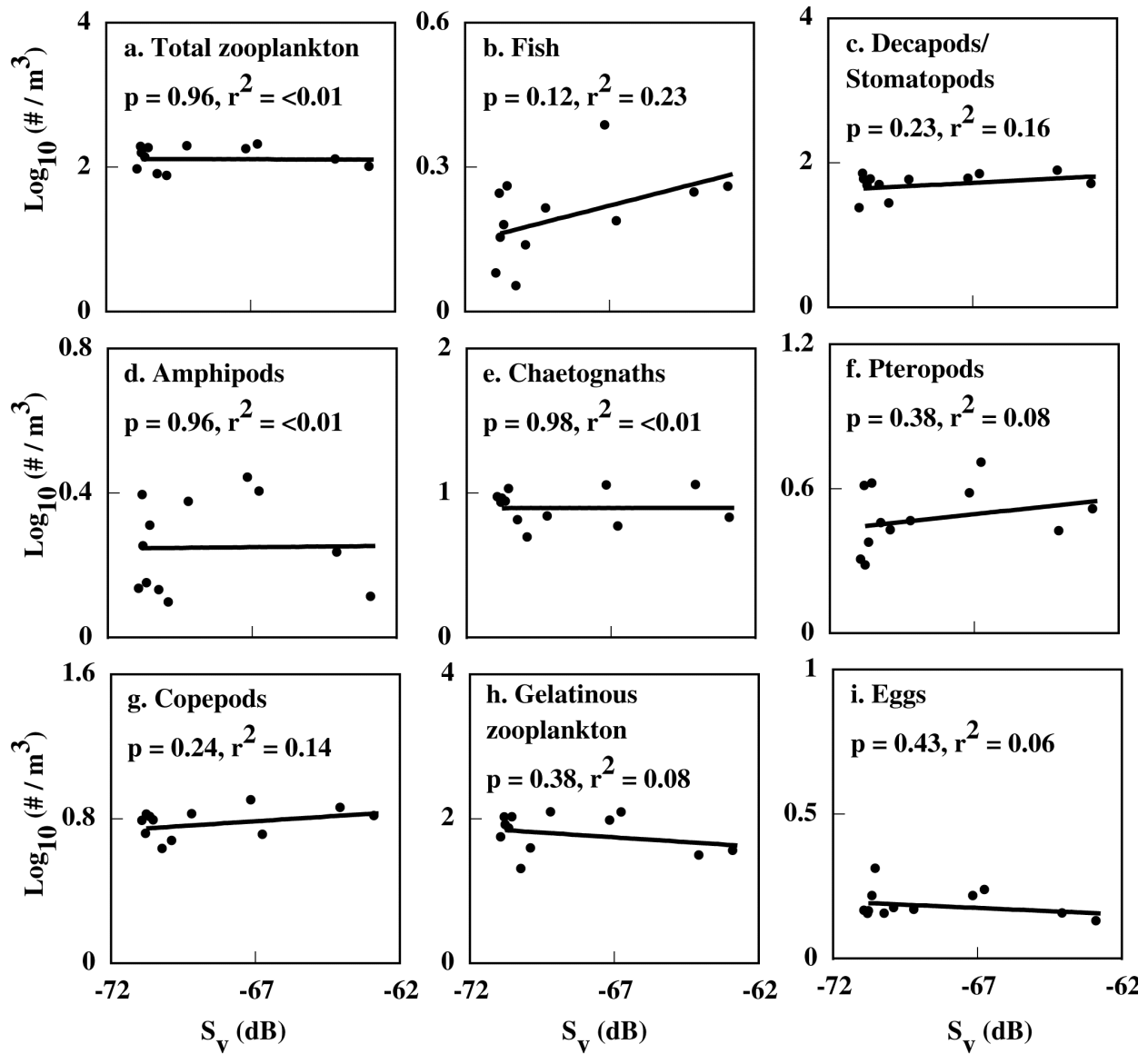
Figure 55. Regressions of volume backscatter (dB) to logarithm of density (# / m^3) for each taxon identified (a–i) from the day 1 sampling during the 12–16 June cruise to MP140A (n = 12 tows).
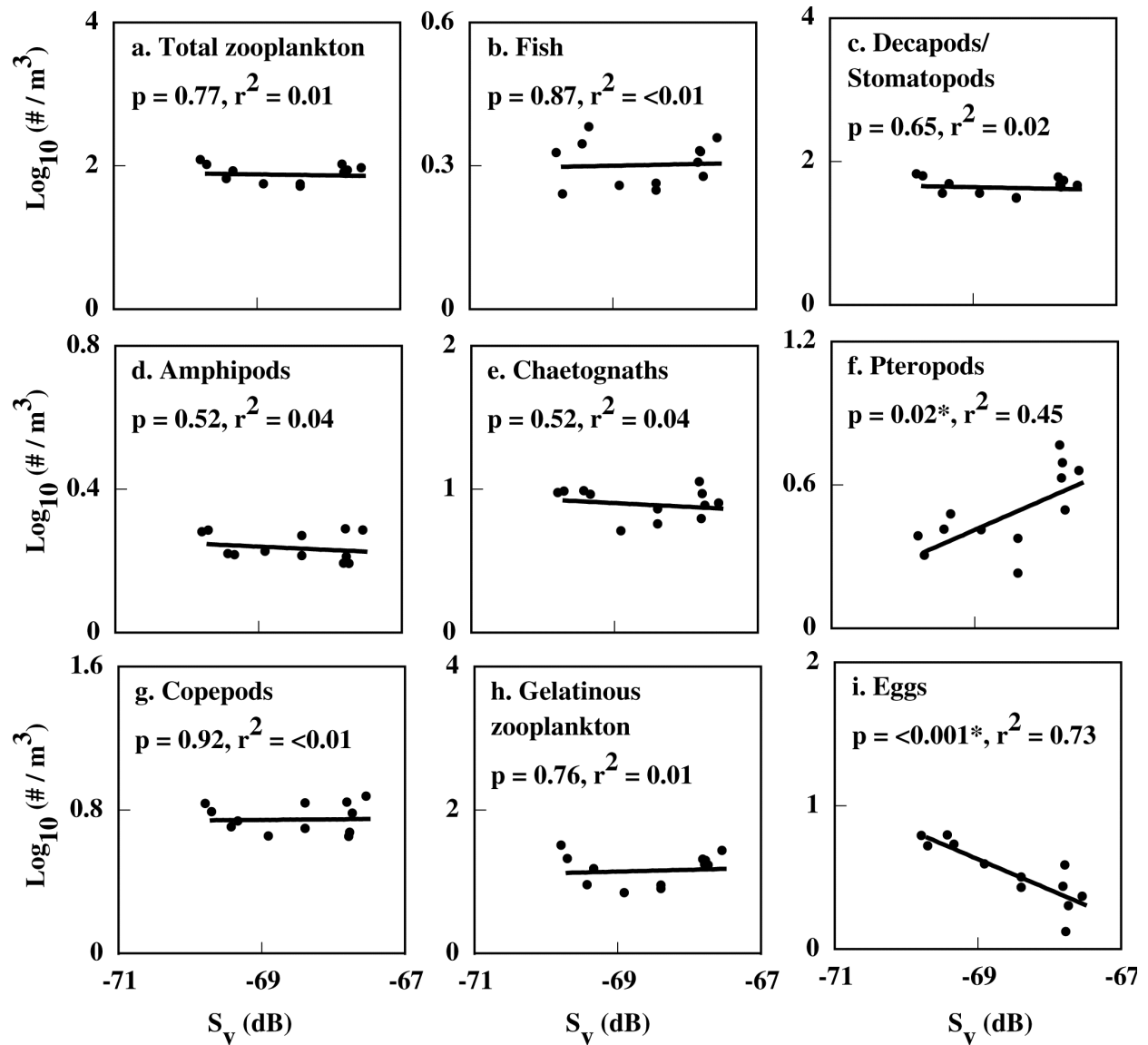
Figure 56. Regressions of volume backscatter (dB) to logarithm of density (# / m³) for each taxon identified (a–i) from the day 2 sampling during the 12–16 June cruise to MP140A (n = 12 tows). Asterisks (*) indicate significant relationship (p < 0.05).
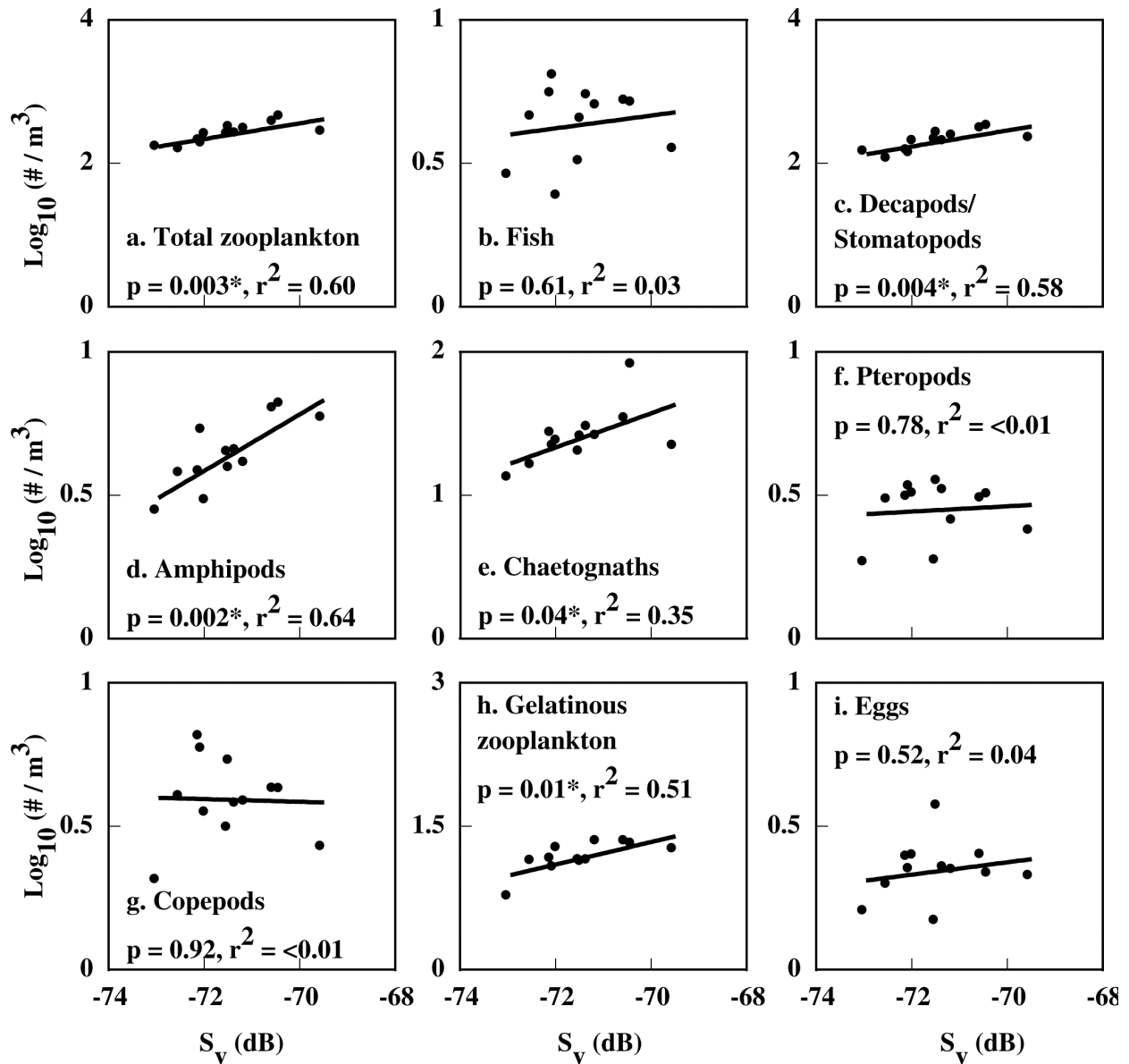
Figure 57. Regressions of volume backscatter (dB) to logarithm of density (# / m^3) for each taxon identified (a–i) from the nighttime sampling during the 5–8 June cruise to VK203A (n = 12 tows). Asterisks (*) indicate significant relationship (p < 0.05).
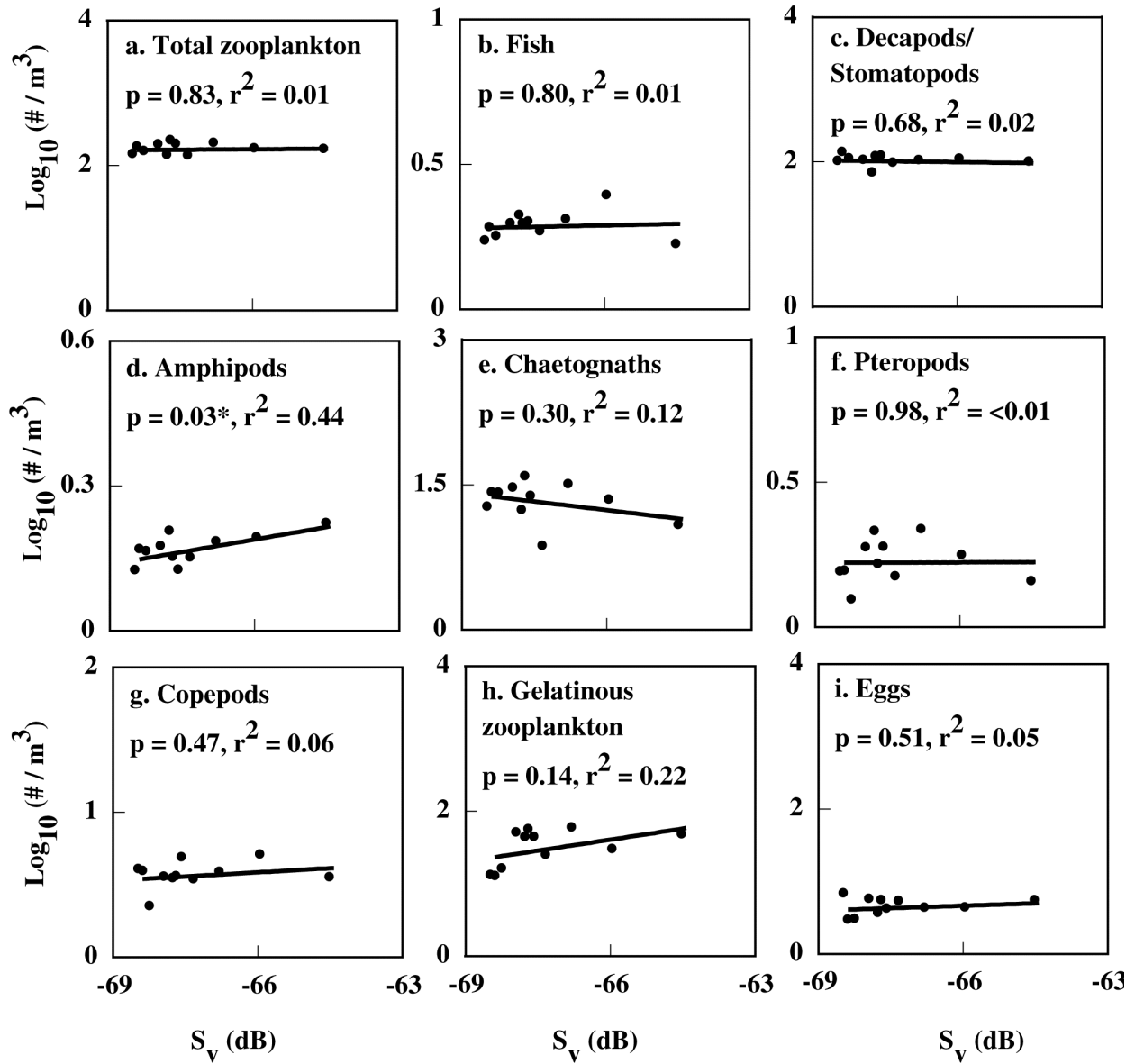
Figure 58. Regressions of volume backscatter (dB) to logarithm of density (# / m³) for each taxon identified (a–i) from the night 1 sampling during the 12–16 June cruise to MP140A (n = 11 tows). Asterisks (*) indicate significant relationship ($p < 0.05$).
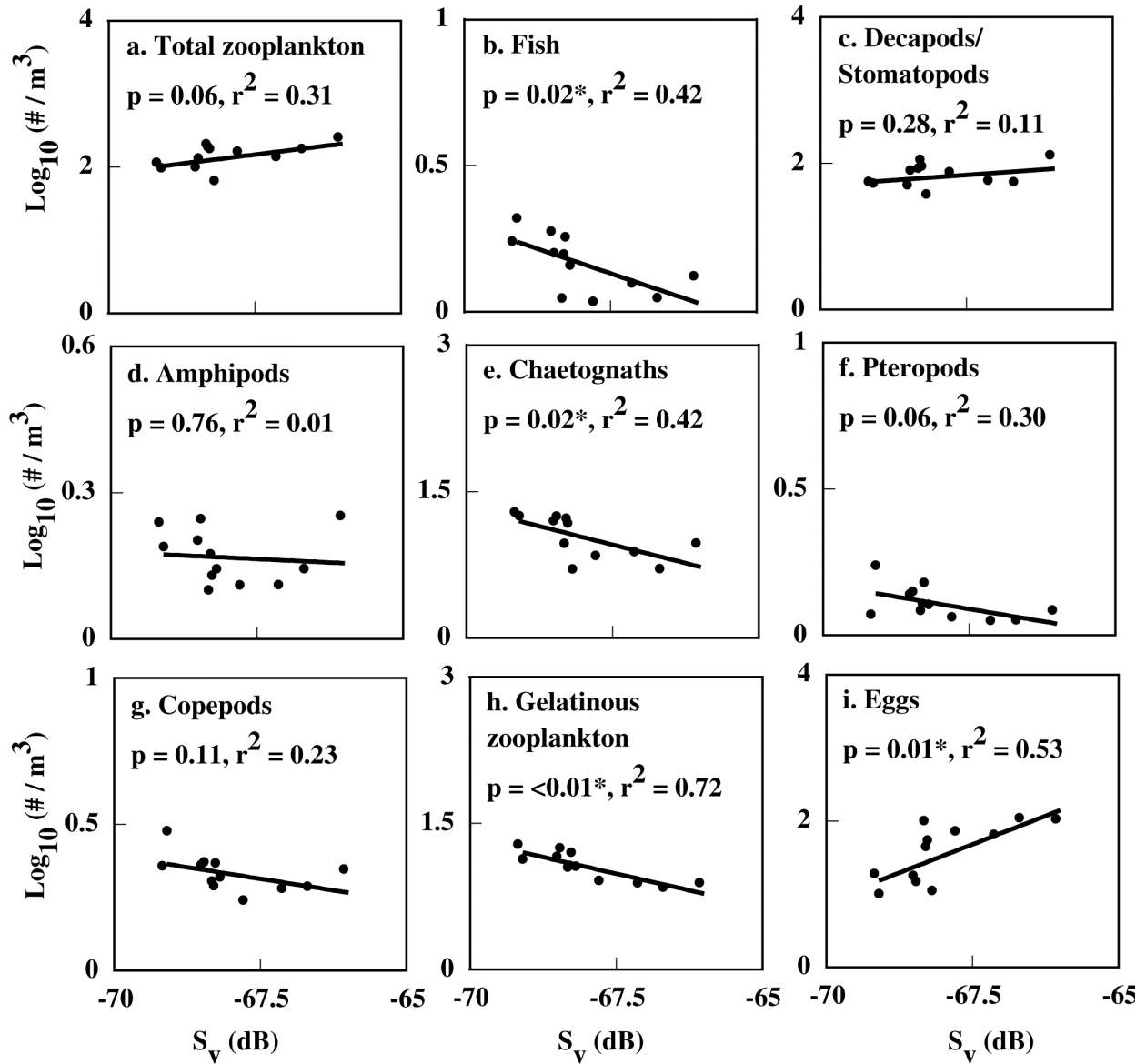
Figure 59. Regressions of volume backscatter (dB) to logarithm of density (# / m^3) for each taxon identified (a–i) from the night 2 sampling during the 12–16 June cruise to MP140A (n = 12 tows). Asterisks (*) indicate significant relationship ($p < 0.05$).
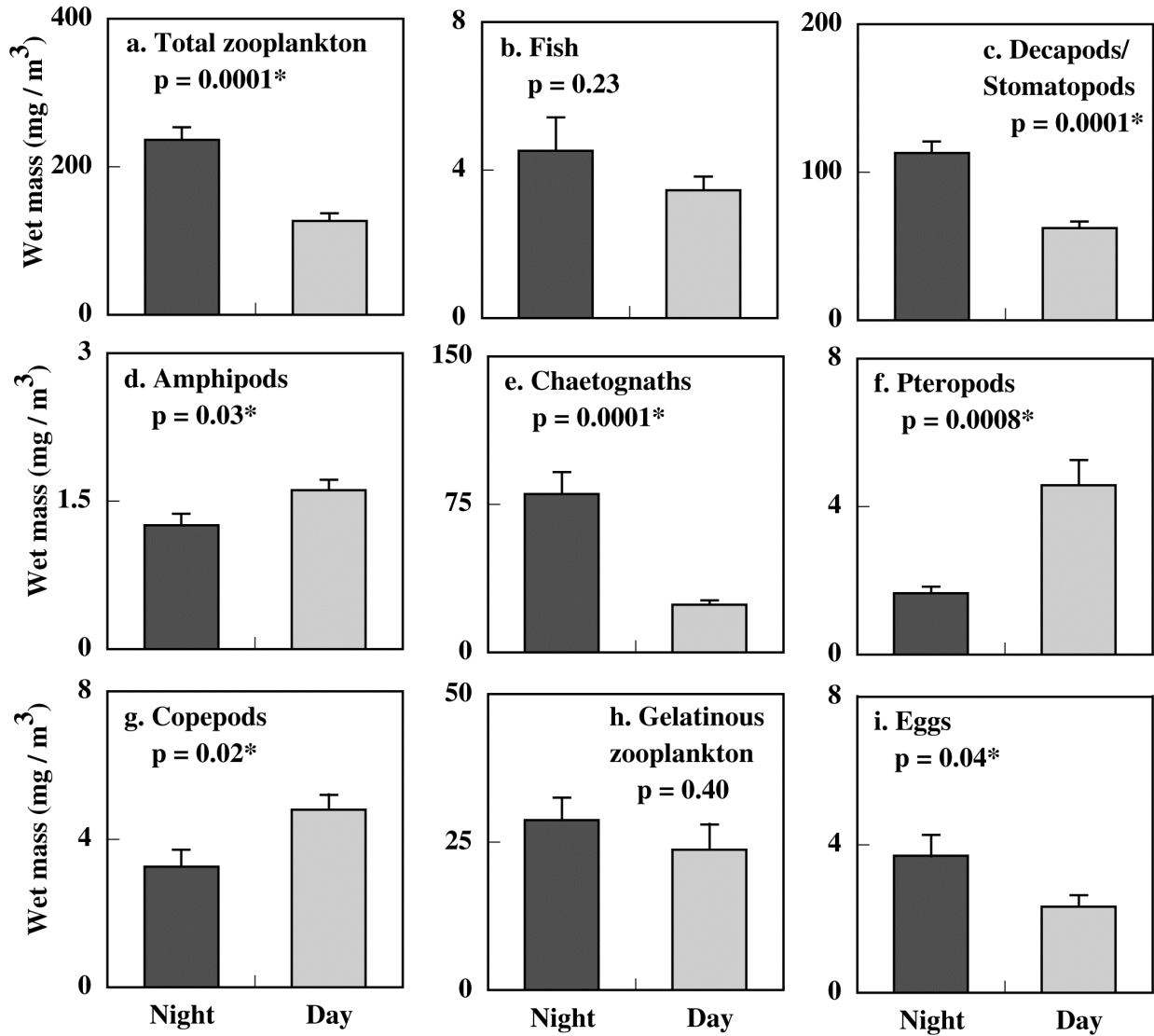
Figure 60. Volume-specific total wet weight (mg / m^3) of zooplankton taxa (a–i) taken from 12–16 June trip. Taxon weights were recorded for 11 samples from the night and 12 from the day. P-values indicate significance test from analysis of variance for each taxon.
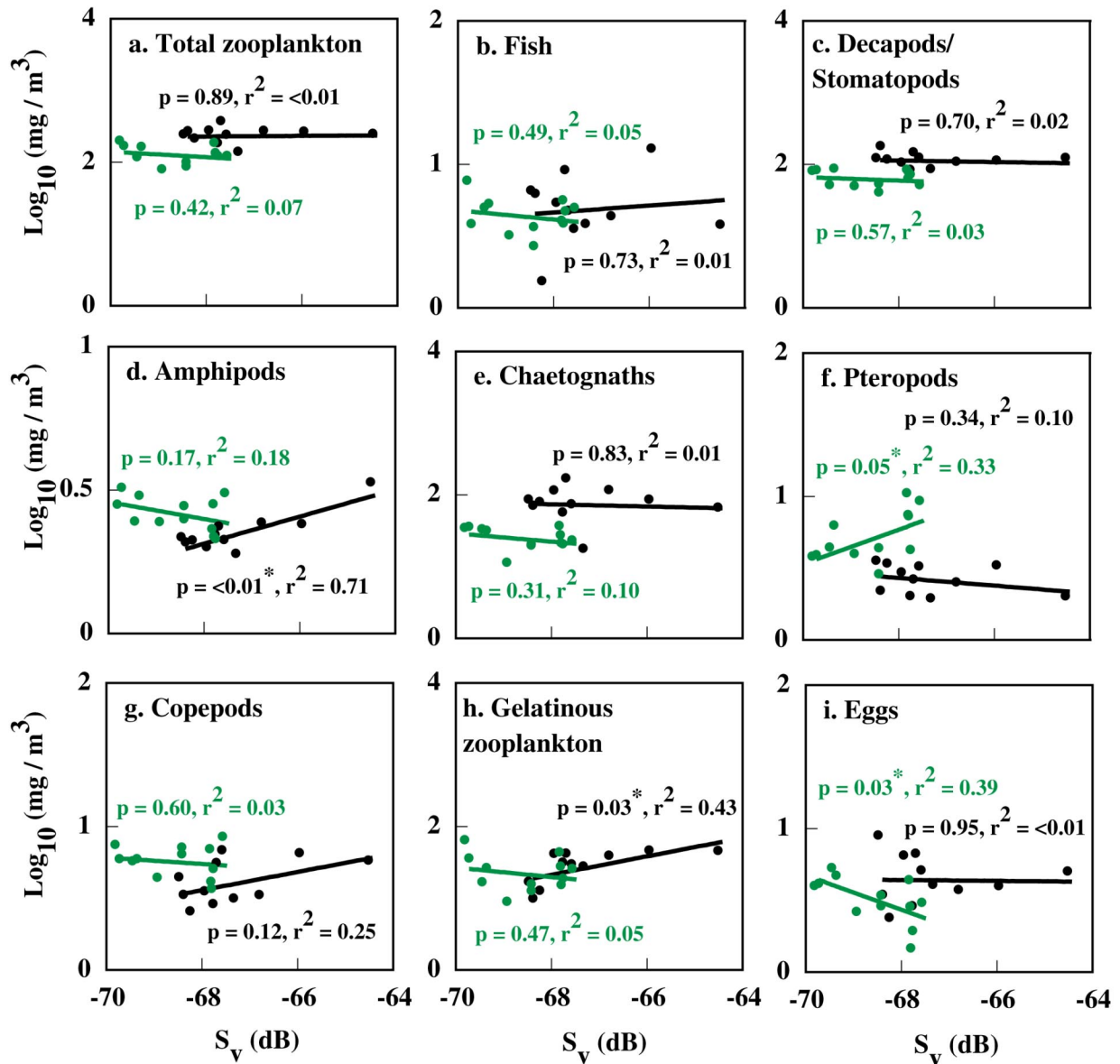
Figure 61. Linear regressions of logarithm of biomass (mg / m^3) to volume backscatter for each zooplankton category (a–i) during the day (green) and night (black) net tows of 12–16 June (MP140A). Asterisks (*) indicate significant relationship between the variables.

Acoustic Surveys

The acoustic surveys conducted during the June 5–8 cruise indicated that sound scattering was more intense during the night survey compared to the day (Fig. 62, 64). There was a large increase in zooplankton density between the day net tows and the night net tows during the same cruise (BR2; Fig. 26, 27). Day net tows averaged less than 50 organisms per m^3, however, night tows averaged over 250 organisms per m^3. The concentration of strong scatterers such as pteropods and larval fish also increased. Figure 63 illustrates the S_v record of each loop from the 5–8 June day survey around VK203A. Scattering appeared to be more intense from the inner and near-platform loops, which were both closer to the structure than the majority of net tows.

During the night, the pattern of scattering was more intense overall and less variable closer to the platform (Fig. 64, 65). Unlike the day survey a near-platform loop was not conducted at night. The dark bands observed during each loop were artifacts produced when the vessel made a turn. Interestingly, S_v appeared to be stronger during particular sections of each loop (i.e., northeastern and northwestern bearings), which was consistent within each loop from this survey. Our ADCP did not have bottom-tracking capability and the vessel was not equipped with a gyrocompass. The quality of our GPS data was insufficient to estimate current velocities from the ADCP. Thus, in the absence of data on current direction, it was difficult to hypothesize about the observed trend in S_v.

In contrast with the 5–8 June studies at VK203A, the surveys conducted during the 12–16 June (MP140A) cruise did not reveal a large increase in S_v from day to night surveys (Fig. 66, 68). This was supported by the zooplankton density results, which also failed to show a large increase between the day 1 and night 2 plankton net tows (approximately 135 and 141 total organisms / m^3, respectively; Fig. 28, 37).

The 12–16 June cruise was distinguished by a distinct scattering layer apparent from within both day and night surveys (Fig. 66, 68). During the day, the layer was concentrated between 3 and 5 m in the outer and middle loops, however, for the inner loop it reached 6-7 m (Fig. 67). The near-platform loop contained very high spikes in scattering, which was likely due to fish schools near the structure. At night, scattering occurred at 2-2.5 m and also from 4-9 m for all loops of the survey (Fig. 69). Fish schools were not apparent from the near-platform loop, further supporting that fish dispersed at night. There did not appear to be a distinct change in scattering distribution around the platform for either survey, however, information on current velocity is needed to evaluate a potential platform-effect.
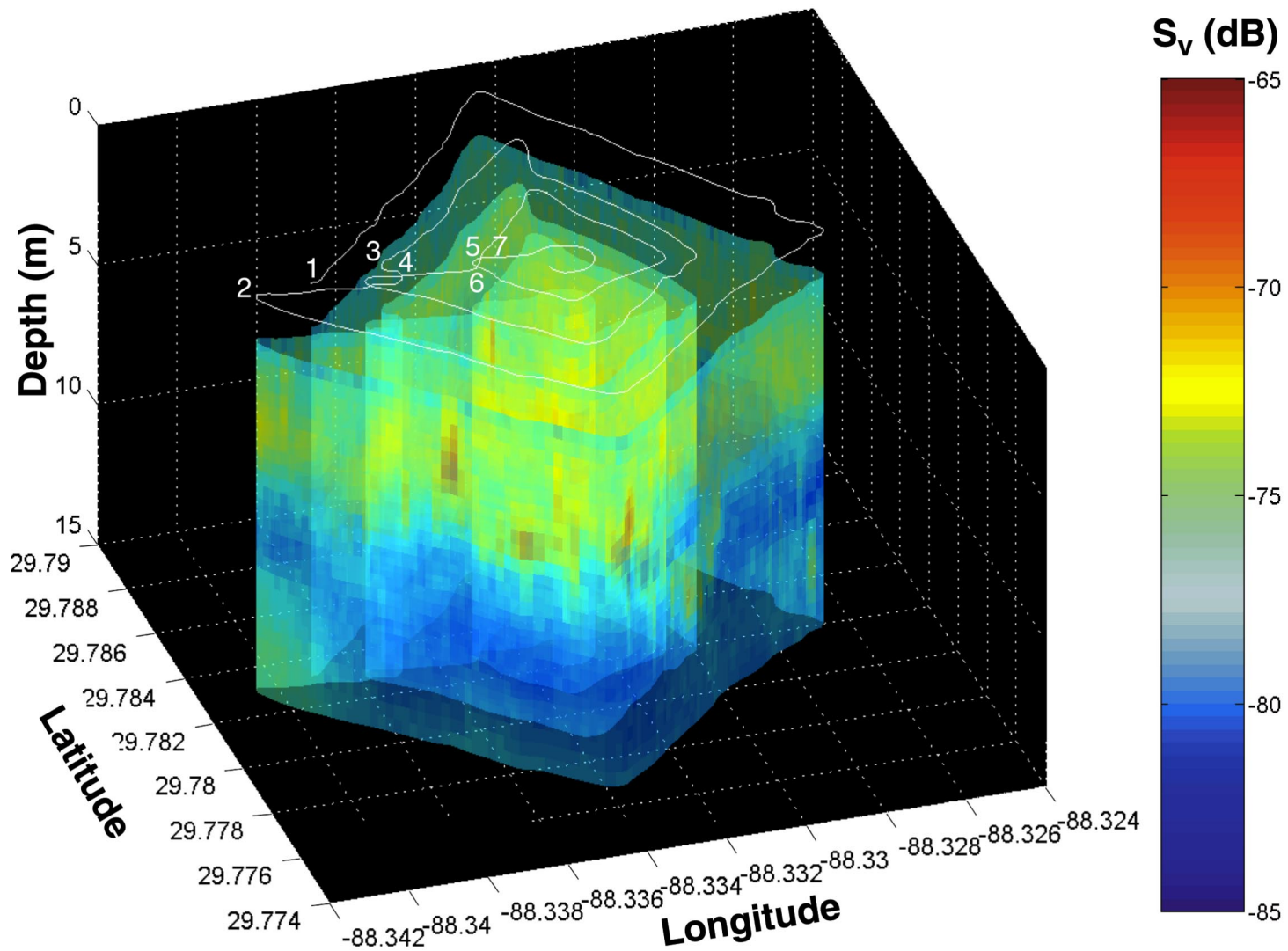
Figure 62. Three-dimensional perspective of the daytime acoustic survey during the 5–8 June cruise to VK203A. The GPS trackline indicates the geographical position of the vessel during the survey and the starting and ending points of each loop is indicated: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6), and near-platform loop (7 to 8).
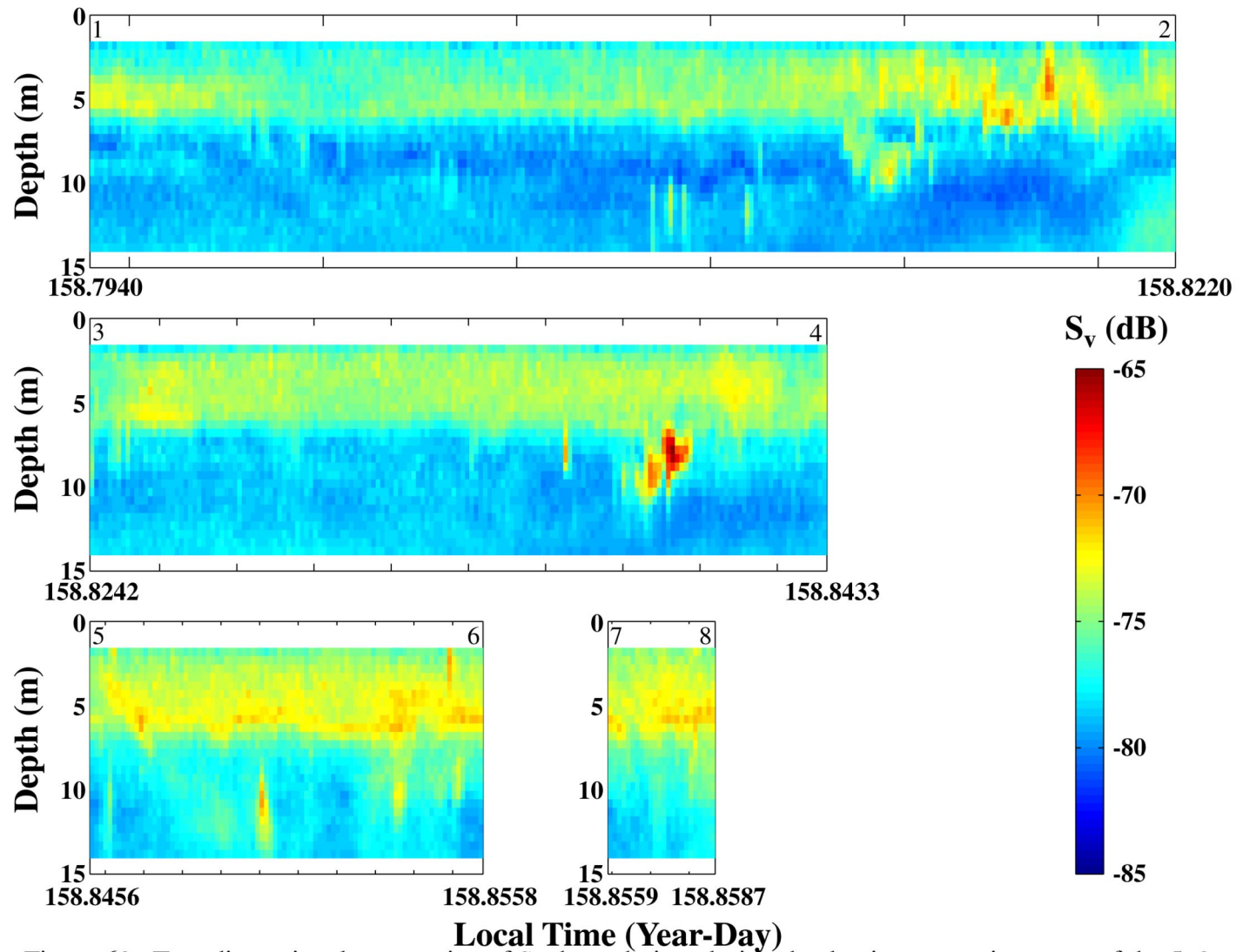
Figure 63. Two-dimensional perspective of Sv through time during the daytime acoustic survey of the 5–8 June cruise (VK203A) corresponding to Figure 62. The four panels represent the four loops of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6) and the near-platform loop (7 to 8).
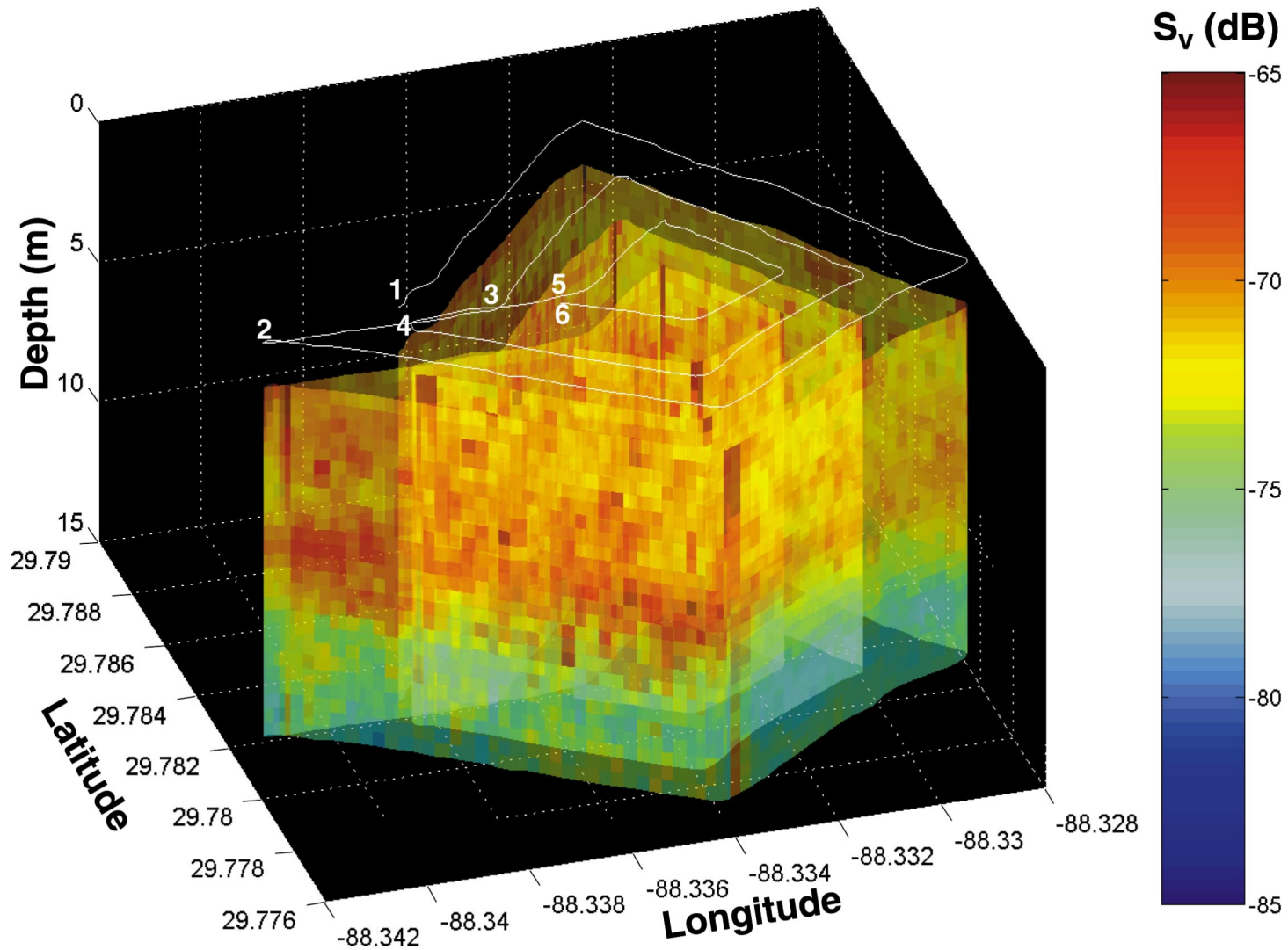
Figure 64. Three-dimensional perspective of the nighttime acoustic survey conducted during the 5–8 June cruise to VK203A. The GPS trackline indicates the geographical position of each loop of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6). This survey did not contain a near-platform loop.
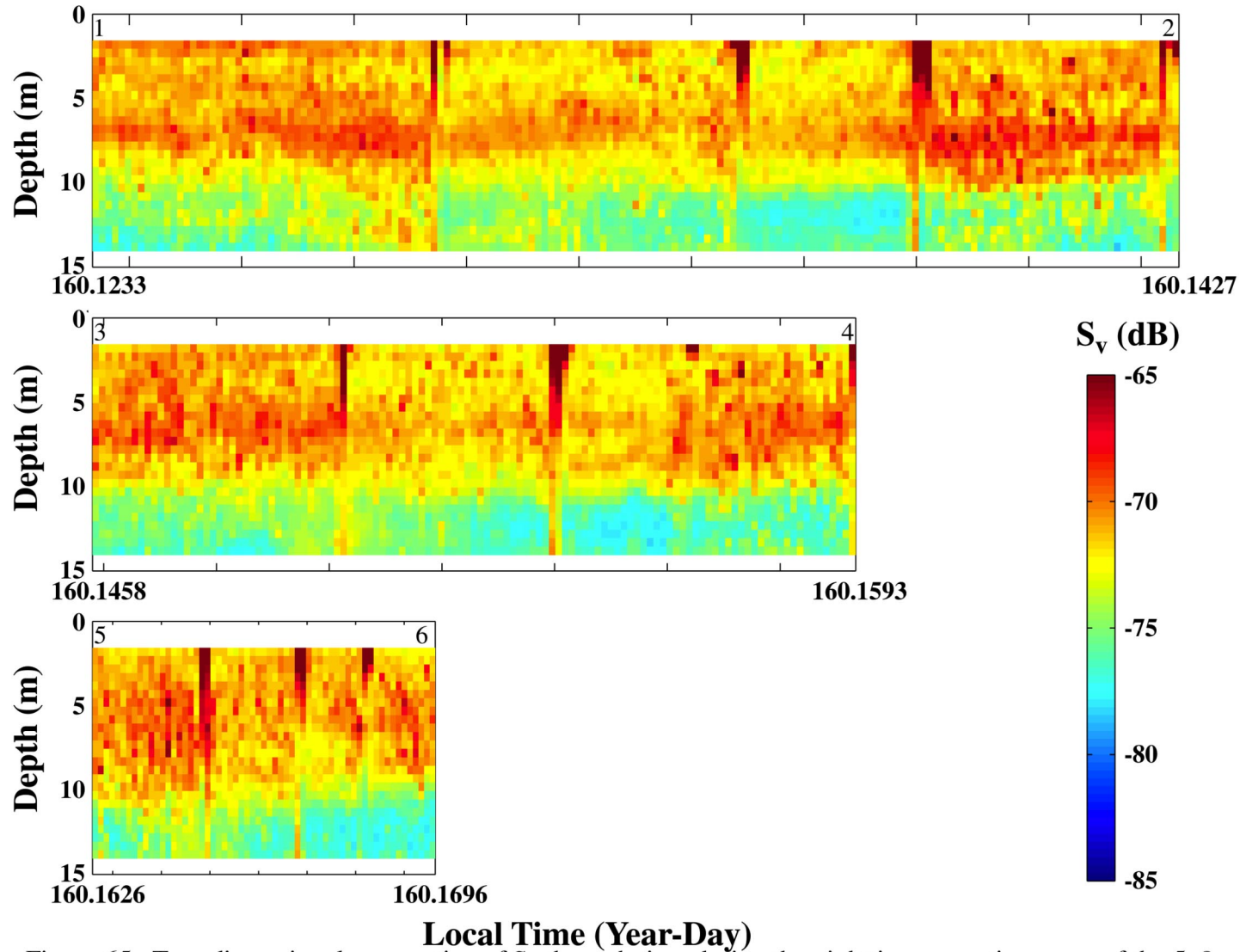
Figure 65. Two-dimensional perspective of Sv through time during the nighttime acoustic survey of the 5–8 June cruise (VK203A) corresponding to Figure 64. The four panels represent the four loops of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6). This survey did not contain a near-platform loop.
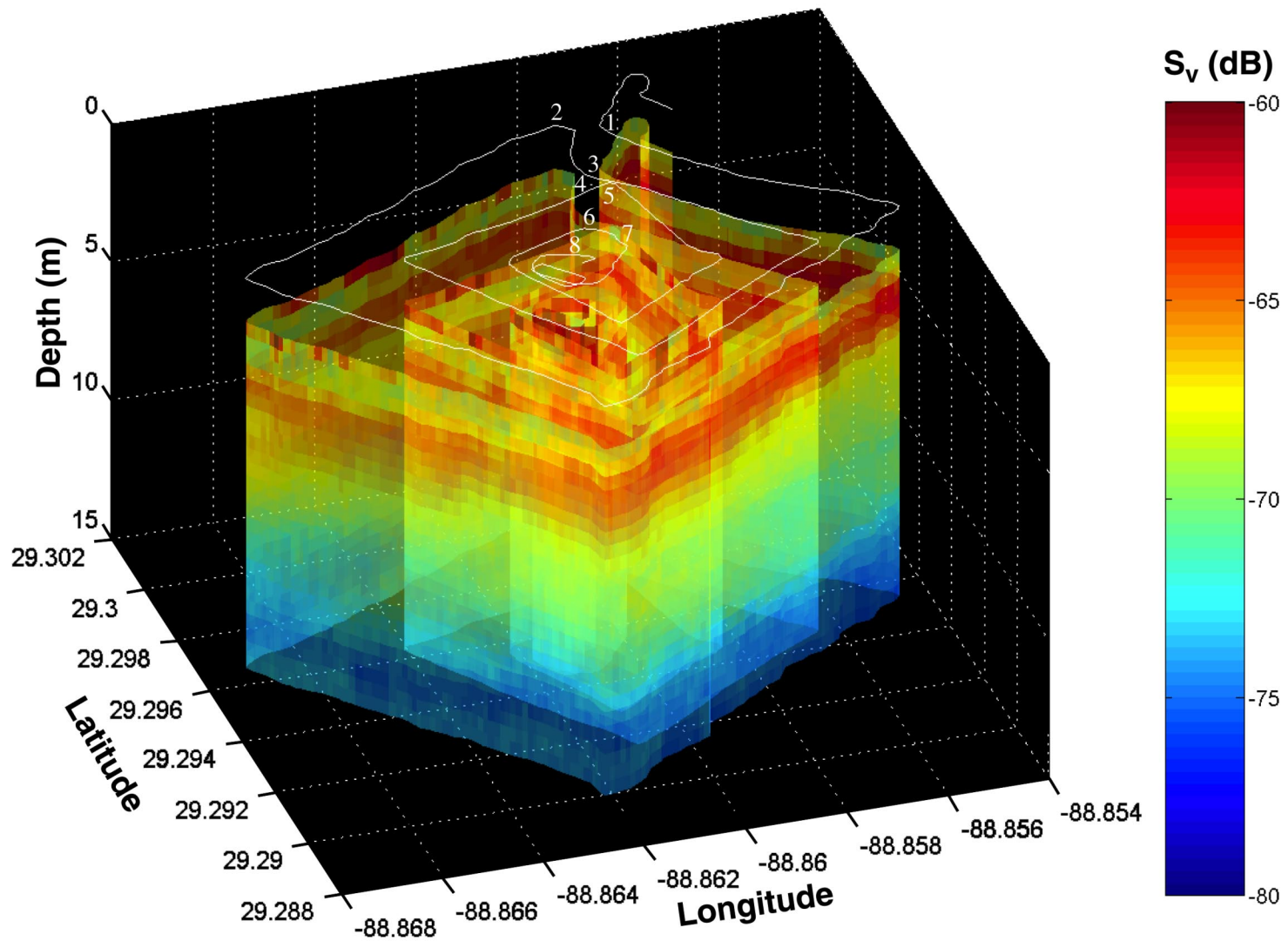
Figure 66. Three-dimensional perspective of the daytime acoustic survey conducted during the 12–16 June cruise to MP140A. The GPS trackline indicates the geographical position of each loop of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6) and near-platform loop (7 to 8).
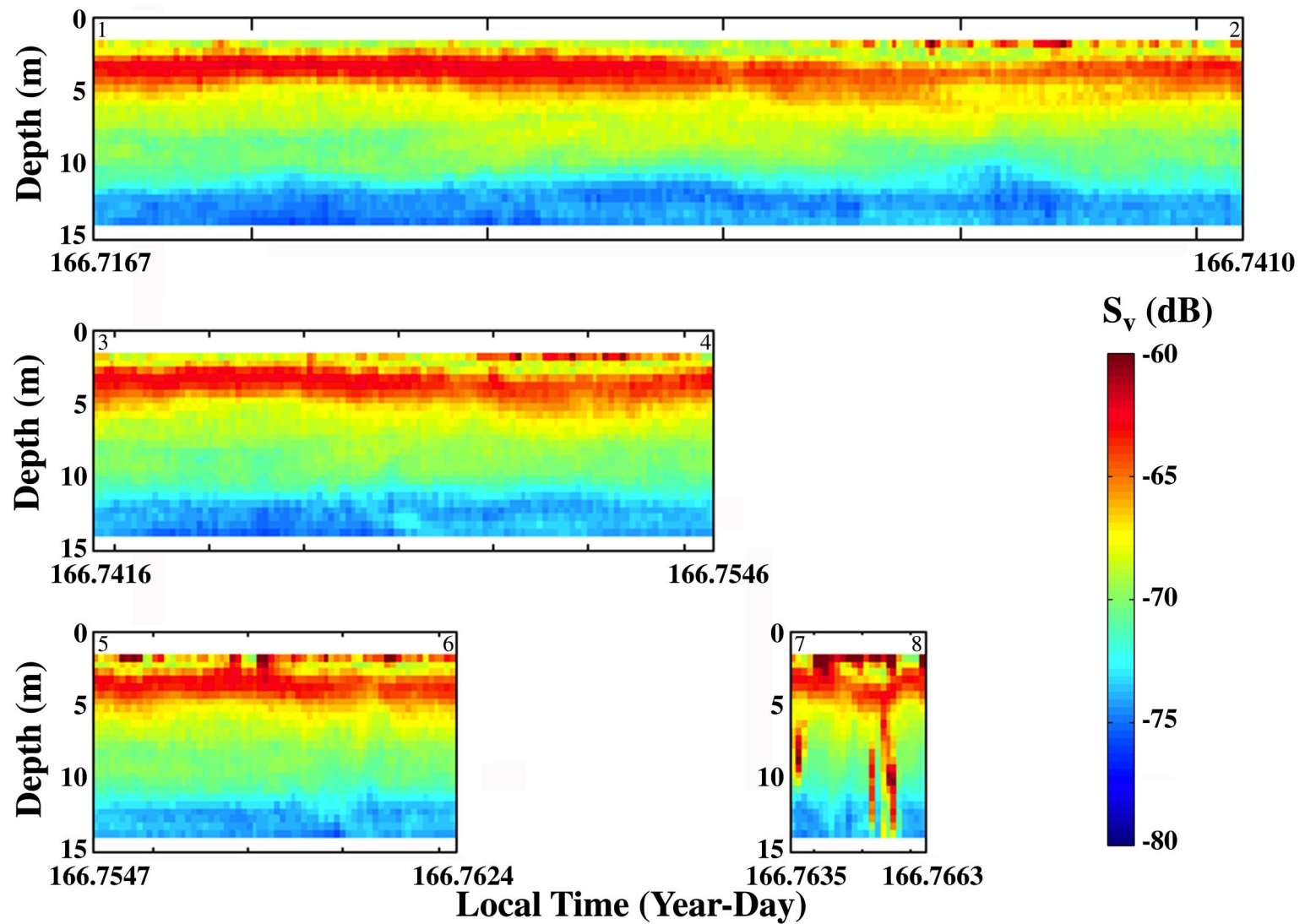
Figure 67. Two-dimensional perspective of Sv through time during the daytime acoustic survey of the 12–16 June cruise (MP140A) corresponding to Figure 66. The four panels represent the four loops of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6) and the near-platform loop (7 to 8).
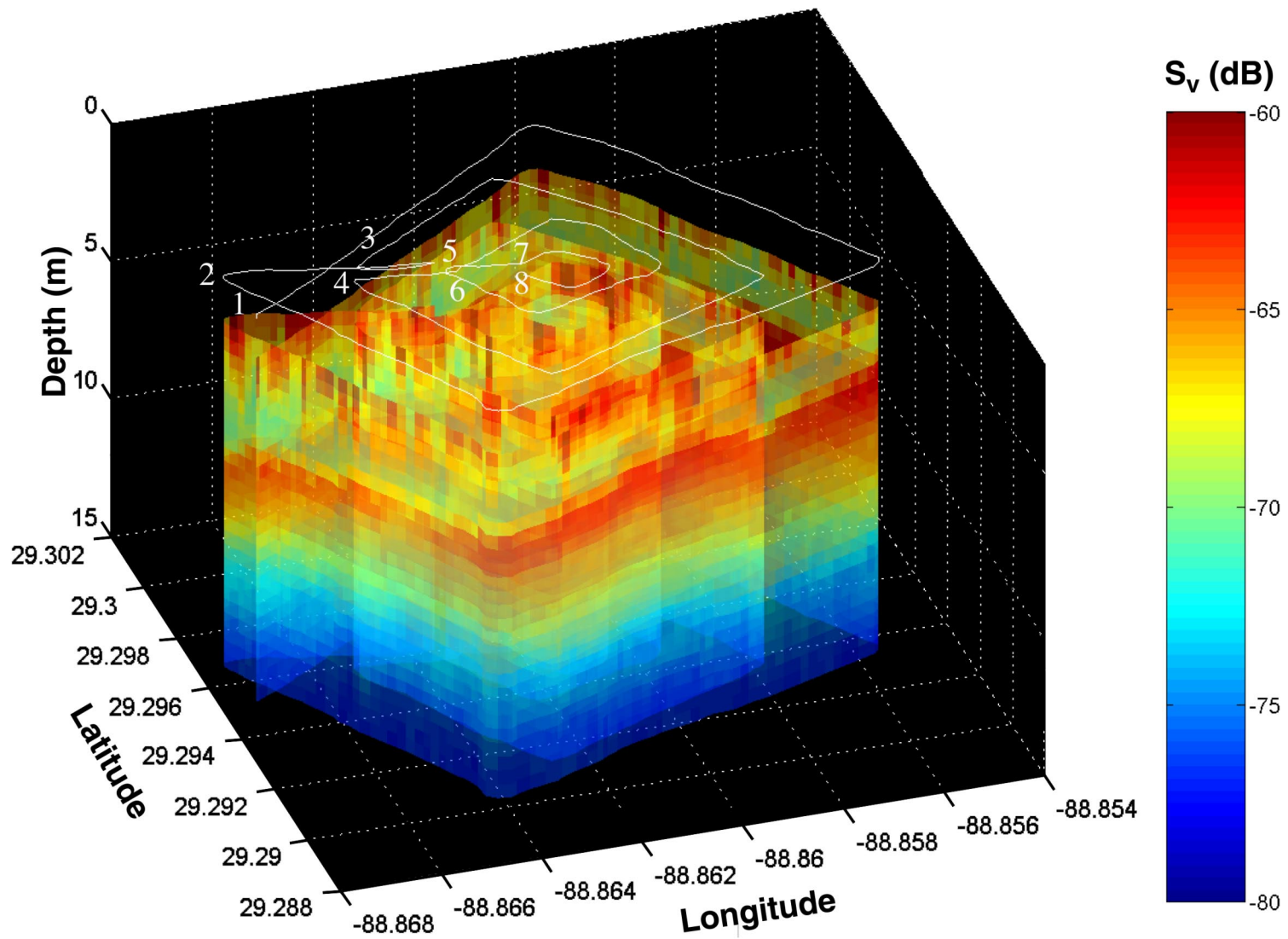
Figure 68. Three-dimensional perspective of the nighttime acoustic survey conducted during the 12–16 June cruise to MP140A. The GPS trackline indicates the geographical position of each loop of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6) and near-platform loop (7 to 8).
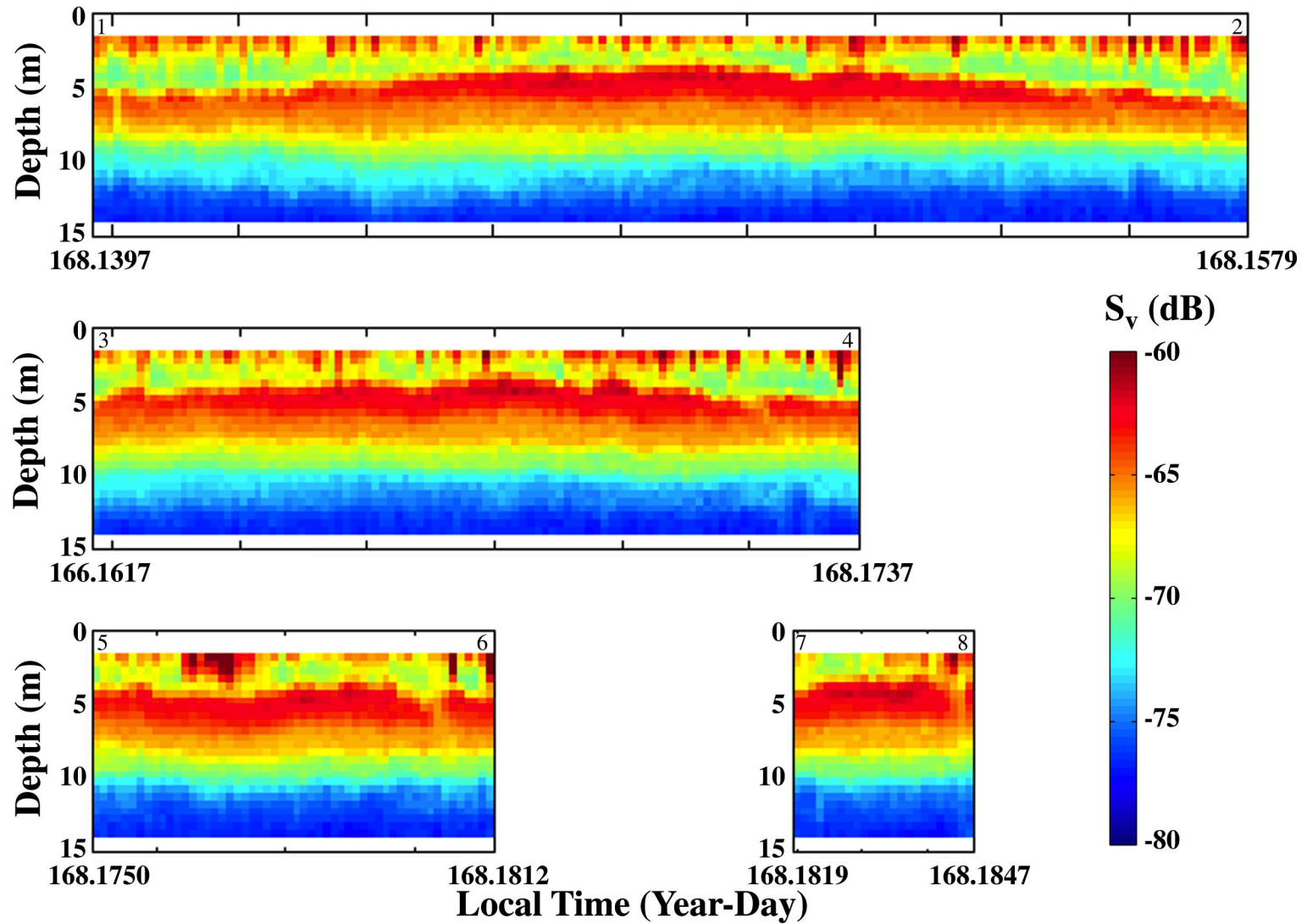
Figure 69. Two-dimensional perspective of Sv through time during the nighttime acoustic survey of the12–16 June cruise (MP140A) corresponding to Figure 68. The four panels represent the four loops of the survey: outer loop (points 1 to 2), middle loop (3 to 4), inner loop (5 to 6) and the near-platform loop (7 to 8).

107

Discussion

<u>Plankton net sampling</u>

   The purpose of this project was to determine if zooplankton distribution was altered by the presence of a platform. If zooplankton were aggregating around platforms then density and/or biomass would have been greater from the platform net tows compared to the reference open water sites. This pattern was evident for some taxonomic groups during some trips, however, it was not observed as a consistent trend. In addition, high levels of predation from platform-associated fishes, such as blue runner would likely have produced lower levels of zooplankton in platform down-current net tows, which also was not observed. Through this project, I observed both large-scale (cruise) and small-scale (platform up-current vs. platform down-current) variability in zooplankton distributions, however, net sampling failed to reveal clear evidence of a platform effect in the form of localized and consistent changes in zooplankton abundance. Cruise was the most important variable associated with zooplankton variability during sampling near the two platforms. These differences were compounded by within-cruise shifts in abundance of particular taxa, however the relative change varied from trip to trip. For example fish were most abundant during the daytime of the 12–16 June trip to MP140A, however, night abundances from this same trip were the lowest when compared to the other three trips. These discrepancies also occurred for other taxa such as decapods/stomatopods, pteropods, and amphipods. Thus, zooplankton density was not consistently greater near a particular platform and density often fluctuated widely between sampling sets within a single cruise.

   Densities were generally greater during nighttime sampling, however, is likely due to vertical migration of many of the taxa sampled. Diel vertical migration is a common factor contributing to the change in zooplankton abundance in surface waters between day and night and can vary widely between sampling stations (Checkley et al. 1992). Avoidance of the net also may have been more prevalent during the day sampling. My sampling occurred in relatively shallow (approximately 40 m), mid-shelf areas and contained both oceanic zooplankton (*Lucifer* spp., hyperiid amphipods, chaetognaths) and meroplanktonic forms (crustacean zoea and megalopae larvae and larval fish). Most taxa increased in abundance during the night, except for pteropods and copepods, in which cases, densities were low (approximately 5 /m^3) and varied little. Interestingly, these taxa are both documented vertical migrators (Boltovskoy 1999) suggesting their density could have been more affected by fine-scale patchiness. Temperature profiles indicated that the upper 15 m was well mixed (Fig. 8, Chapter 3), except during the 17–20 July (VK203A) cruise where there was a steep thermocline between 6 m (30 °C) and 15 m (22 °C). This, however did not appear to have a large influence on zooplankton abundance.

   The daytime net tows taken at the four sampling stations associated with each platform showed little evidence of a platform influence on zooplankton distribution, however, the spatial patterns varied for each taxa. The total zooplankton abundance category showed trends of decreasing abundance in daytime platform down-current tows from the VK203A trips, but this pattern was not evident from the trips to MP140A. The total zooplankton category is driven by the abundance of decapods and stomatopods, which are common prey for blue runner during the daytime. Deudero (2001) suggested that high densities of fishes near FADs in the Mediterranean Sea could negatively affect zooplankton biomass near these structures in a manner similar to the

"wall of mouths" hypothesis, whereby zooplanktivorous fish forage on the upstream side of a structure such as a coral reef, and clear the plankton before it reaches the reef (Hamner et al. 1988). During each of my trips, blue runner were observed schooling near the surface, up-current of the platform and feeding on zooplankton, however, platform down-current densities were not consistently lower as seen from the plankton net sampling.

There may be more of a platform enhancement on zooplankton distribution at nighttime, due to the influence of the light field. The light field may have a greater influence on photopositive zooplankton, such as some species of larval fish, hyperiid amphipods, decapods/stomatopods, chaetognaths, and copepods (Land 1992). Ditty et al. (2000) captured higher numbers of larval and juvenile fish in light trips fished beneath a platform than light traps positioned 20 m down-current of the structure. In a similar study, hyperiid amphipods collected from surface light traps taken beneath a platform were observed to increase in abundance over the course of a night, while decreasing in density from "off-rig" light traps that sampled down-current waters (Keenan et al. 2000). Hyperiid amphipods also are common parasites on gelatinous organisms such as medusae and siphonophores and little is known of how they would react to a structure such as a platform. When they were highest in density (5–8 June), hyperiid amphipods were more abundant from the platform up-current samples than platform down-current. This may be due to the platform functioning as a large, passive light-trap or increased predation was negatively affecting down-current density. Larger forms of these amphipods or juvenile fish may be able to retain position beneath the platform (Land 1992) especially if current velocity is reduced within the jacket structure as was observed by (Forristall 1996).

Current velocity may greatly affect the degree to which plankton may interact and aggregate with the platform structure, however, this factor has not been evaluated in this study. Likely, there were large differences in current velocity among the cruises, which may have confounded results. Under low current velocities, plankton may be more capable of retaining position at least temporarily beneath the structure, whereas high current flow likely causes zooplankton to more immediately pass through the structure. Current velocity can also affect the foraging response or effectiveness of predators. Lindquist and Pietrafesa (1989) observed schools of scad (*Decapterus punctatus*) aggregated on the up-current side of an artificial reef only under sufficient current velocities (0.25 to 0.50 m/s) whereas, when currents subsided, they rose to the surface.

Blue runner are active predators during the night around platforms and forage primarily on fish such as herrings, codlets, and also larval species and larger decapods (shrimp), however also feed to a lesser extent on other invertebrates (e.g. hyperiid amphipods and pteropods). Larval fish taken from the plankton net samples were often an order of magnitude more abundant during the night than day. Compared to the three other sites, however, fish densities were lower from platform down-current sites, which may be due to blue runner and other predators. Hastings et al. (1976) did not observe blue runner during night observations near platforms off Panama City, Florida and suggested that blue runner disperse during the night to feed in surrounding waters. During my nighttime sampling, however, blue runner were commonly observed and caught near the platform. Blue runner caught at night fed on larger decapods/stomatopods and fish prey than observed during the day (Fig. 16, 21). Stanley (1994) noted that target strengths of fishes near platforms generally were greater during low light

periods (i.e., dusk, night, dawn) suggesting that larger fishes visit the platform during these hours. This may contribute to increased predation pressure on large zooplankton such as larval fish, decapods/stomatopods, and hyperiid amphipods.

Platforms may function as more than just areas of increased predation. They have been cited as potential spawning areas (Ditty et al. 2000) and my sampling supports this platform-spawning ground concept. There were a large number of fish eggs collected during the 12–16 June trip to MP140A primarily from the platform down-current site during night sampling. This suggested nocturnal spawning activity of platform-associated fish. Studies of blue runner reproductive habits indicate the peak times of spawning occur during June, July and August in the northern Gulf, however, I did not record the state of gonadal tissue during blue runner dissection. Fish spawning is often related to lunar phase (Lam 1983; Crabtree 1995) and there was a full moon during this trip. Further examination of the fish eggs would be required to identify if they were from blue runner.

Distances from the platform revealed inconsistent relationships with zooplankton densities that varied among cruises and between day and night sampling. While density of certain taxa decreased near one platform, the same taxa increased in abundance closer to the other platform; and this pattern often changed from cruise to cruise. The 5–8 June trip to VK203A showed decreased zooplankton density closer to the platform during the day, while the 17–20 July trip indicated the opposite. Since evaluating the distance from the platform was not an objective of these cruises, the exact tow locations (and therefore distance) varied from cruise to cruise. Most of the tows from the 17–20 July cruise were conducted between 100 and 500 m from VK203A, while many tows from the 5–8 June cruise were over 600 m away. The patterns observed may be more difficult to detect due to inconsistencies in tow distance among the cruises.

Both platforms possessed many floodlights, which produced a light field at night, however, the influence of this light field was not apparent from plankton net samples. All the tows were conducted over 100 m from the structure, which was generally beyond the light field and it was unclear to what extent the light field would affect plankton density. With the exception of one trip, fish density from plankton nets decreased closer to the platforms at night. This trend, albeit non-significant at the 5% level, may have been due to increased predation pressure from predators such as blue runner. However, the fish potentially could have been attracted closer to the structure than my nets reached. Other phototaxic organisms such as decapods/stomatopods and amphipods only showed greater numbers around the platform during the 5–8 June trip to VK203A. My observations during the trips were that the lights from the VK203A platform appeared brighter than the MP140A platform, however, the light field was not evaluated quantitatively. Larger zooplankton that may be attracted to the platform lights likely can also detect and avoid the plankton net, creating a bias in the net results. The high variability in natural density of zooplankton distribution as well as net avoidance is documented and likely influenced results (Fleminger and Clutter 1965; Omori and Hamner 1982). Non-invasive sampling methods such as high frequency acoustics provide a way to address this bias.

Acoustic Relationships

The use of ADCPs as high frequency echosounders has become very common to evaluate large scale patterns of sound scattering particles (e.g., Flagg and Smith 1989; Zhou et al. 1998) and these scattering particles are presumed to be zooplankton and micronekton (Stanton et al. 1994). ADCPs have been used with success to evaluate patterns in zooplankton distribution in warm- and cold-core eddies and in relation to Mississippi River input in the Gulf (Zimmerman and Biggs 1999; Wormuth et al. 2000; Ressler 2001). Heywood et al. (1990) used an ADCP to examine zooplankton distributions around an oceanic island and determined that zooplankton were more abundant on the down-current side of the island. In addition to using the ADCP, the above studies also incorporated traditional net sampling. Wiebe et al. (1996) stated that using acoustics alone to estimate overall plankton biovolume was problematic without knowledge of the taxonomic composition of the ensonified water. Relationships between taxon-specific zooplankton density and mass were suggested as the most appropriate method to form predictive models (Wiebe et al. 1996). Regression between zooplankton biomass or volume and acoustic backscattering strength (S_v) are most common in ADCP studies (Heywood et al. 1991; Flagg and Smith 1989; Wiebe et al. 1996), however, studies also have shown acoustic backscattering strength positively correlated with zooplankton concentration (Ressler 2001).

Through examination of a subset of my plankton net samples, I observed mixed results in relationships between S_v and net tow contents. The concentration of organisms such as fish, decapods/stomatopods, thecosomate pteropods, and hyperiid amphipods were often positively related to S_v as expected, however this result was not consistent during sampling. Significant ($p < 0.05$) positive relationships occurred rarely and sometimes there were opposite trends (e.g., Fig. 58 f, pteropods). In addition I observed significantly positive relationships from weak scattering taxa such as gelatinous organisms (e.g., salps, doliolids, siphonophores) during the night sampling from the 5–8 June cruise, which is difficult to explain. The siphonophores were not physonect taxa, which possess a gas inclusion and are strong acoustic scatterers (Warren et al. 2001). Although the calycophore siphonophores are not considered to be strong scatterers, Ressler (2001) also observed significant correlation ($p = 0.002$, Spearman's rank correlation) between S_v and calycophore siphonophores, common components of my gelatinous zooplankton category.

Overall zooplankton wet mass doubled from daytime net tows to night tows, however, backscattering strength increased only 1-2 dB, a factor associated with a 1.3–1.6 fold increase. Not all taxa increased in wet mass between the two sampling sets, which could contribute to discrepancies in S_v measurements. One of these taxa, pteropods, was more abundant during the day (>4 mg/m^3) and exhibited significant positive correlation with S_v during this sampling set. When pteropod wet mass (and concentration) decreased in night samples, however there was no relationship to S_v, which indicates that scattering was due to another source. The only positive, significant relationships observed during night sampling were for amphipods and gelatinous zooplankton. It is likely that many of the organisms that contributed to scattering were large enough to avoid my net, leading to an underestimation of the biomass of these strong scatterers.

Scattering is affected greatly by the size, orientation, and material properties of the organism causing the reverberation of sound (Stanton et al. 1994; Wiebe et al. 1996). Thecosomate pteropods are termed elastic-shelled organisms and contribute orders of magnitude

111

more to sound scattering than weaker scattering organisms such as gelatinous salps, fish eggs, or decapods. Ressler (2001), however, did not detect significant relationships between pteropod concentration and S_v. Since my project did not classify organisms beyond general taxonomic categories, further identification of strong scattering net plankton may be required to refine predictive relationships. Additional information on length frequency distributions of the collected zooplankton would also provide inputs to develop scattering models (Stanton et al. 1994). These considerations are planned for future investigations.

Acoustic Surveys

Results from the acoustics surveys generally agreed with the density results from the corresponding plankton net tows. The sharp increase in total zooplankton density between day and night net tows from the 5–8 June cruise was complimented by an increase in S_v between day and night surveys. Net tows occurred not more than 4 hours prior to, and within the same area covered by the acoustic survey. Further, when there was not much change in zooplankton density as seen during day and night tows from 12–16 June (MP140A), the acoustic record showed little variation. These results suggest that the source of scattering was most likely attributable to zooplankton. It was not the goal of this project, however, to predict zooplankton density or biomass from backscatter intensity patterns.

Evidence for a platform effect on zooplankton density was difficult to evaluate from the surveys, however, increased scattering near the platform was evident from one of the four surveys (5–8 June day survey). This trend was not anticipated, since more of a platform effect was expected during the night due to influence of the platform light field. It is unclear why scattering would be elevated around a platform during the day. It is possible that the elevated scattering close to the platform was due to averaged-down echoes from fish, however, this is unlikely for two reasons. First, the most enhanced region of scattering is in the form of a uniform layer from 2-6 m and if this layer were fish, they would have avoided the vessel and should not have appeared in the echogram. Second, the returns from individual transducers on the ADCP were highly consistent suggesting that the targets producing the elevated returns were broadly distributed – something consistent with zooplankton but not with individual fishes. The two night surveys did not demonstrate conclusive increasing or decreasing scattering close to the respective platform as scattering in each night survey was similar in the near-platform and the outer loop. Unfortunately, data on current velocity was not available for this analysis, thus the influence of current cannot be evaluated here. This is another aspect that will be examined in the future.

Chapter V
General Summary

Blue runner in proximity to offshore petroleum platforms feed primarily on holo- and mero-planktonic, meso- and macro-zooplankton during the day and macro-zooplankton and fish at night. The feeding results were comparable from the four platforms studied, however the seasonal shifts from decapods/stomatopods to fish that were observed in 1996 at GI94B were not observed at the other platforms. Blue runner in open waters appeared to forage on similar organisms as platform-associated fish as well as other abundant taxa (e.g., chaetognaths). The sample size of open-water blue runner was extremely limited, making it difficult to draw definitive conclusions about their diets. This aspect of their feeding dynamics requires further examination. Based on the results I have gathered for platform-associated fish, it is clear that zooplankton and ichthyoplankton are important dietary components. This raised the question of whether or not the availability of prey is enhanced around platforms.

One way that platforms may provide an enhanced foraging resource for a visual predator such as blue runner is by providing an opportunity to extend their feeding period beyond daylight hours. My results clearly show that blue runner near platforms feed after dark. There was evidence that their feeding strategy varied over the diel cycle. Results from prey type selectivity and size selectivity suggest that platform-associated blue runner consume larger, potentially more conspicuous organisms during the night when light levels are low. Feeding periodicity results show, however, that stomach fullness levels are comparable throughout the day and night, indicating that blue runner feed on smaller but more numerous organisms during the day (decapod and stomatopod crustaceans) and larger, less abundant organisms at night (larval and juvenile fishes). This pattern suggests a shift from a daytime "searcher" feeding strategy to a nighttime "pursuer" strategy as described by Optimal Foraging Theory (Hughes 1980). Blue runner were often seen schooling near the surface on the up-current side of platforms during the day, where they exhibited feeding behavior such as striking the surface where they were likely striking at prey that contrasted against the water's surface. Blue runner schools disperse into surrounding waters at night and likely alter their feeding behavior to pursue larger organisms while also evading increased number of nighttime predators such as king mackerel (*Scomberomorus cavalla*), jack crevalle (*Caranx hippos*), and barracuda (*Sphyraena barracuda*).

Both platform and open water blue runner appear to be generalists that can feed opportunistically. The open water blue runner exhibited stomach fullness values and weight proportions of fish and decapod prey comparable to platform-associated blue runner caught during the same time of day. Open water specimens differ from platform fish, however, via increased proportions of chaetognaths in their stomachs. The tenfold increase in chaetognath IRI values over platform-associated blue runner was driven by the increased frequency of occurrence of this prey (85% of fish caught in open waters contained this prey). Preliminary examination of plankton tows indicated that chaetognaths were greater in abundance near the open water school compared to daytime concentrations near platforms, while decapod and fish prey were much lower. This may suggest a dietary response to exploit patches of more available prey. It also may explain the dietary shift from decapods/stomatopods to fish observed in 1996 at GI94B, though without concurrent zooplankton abundance data, this is speculative. Blue runner are considered particulate feeders and while prey and size-selectivity has been demonstrated, a non-

discriminate ram filter-feeding strategy should not be ruled out, since literature exists on ram suspension feeding in other medium-sized carangids (Sanderson et al. 1996 and Sazima 1998). Ram suspension feeding occurs when a fish swims with open mouth and flared opercles for periods from a second to several minutes (Sazima 1998). No studies were found on behavioral observations in blue runner feeding.

Another mechanism by which platforms may provide an enhanced foraging environment is through localized accumulation of blue runner prey. During the day, this may occur through passive entrainment within eddies beneath the platform. At night a combination of hydrodynamic entrainment, vertical shear, and active attraction to the platform light field may enhance prey densities. Plankton net sampling was able to demonstrate significant differences in meso-zooplankton abundance and composition between cruises and between day and night within particular cruises. The patterns of zooplankton abundance were not linked to the two platforms sampled (VK203A & MP140A) as abundance was not consistently greater near either platform. The collections made at the four sites in relation to the platform and prevailing surface current did not indicate a significant platform effect on zooplankton distribution. Data from the net samples did not clearly demonstrate accumulation of zooplankton at the platforms relative to the reference sites, however plankton sampling generally occurred greater than 100 m from the platform. This may have been beyond the range of detecting a platform-associated enhancement effect.

During the night, the light field of platforms may combine with possible hydrodynamic influences to further enhance zooplankton accumulation. Again, the net tow data did not provide definite evidence of a platform effect. Night fish densities were generally lower in net tows conducted closer to the platforms, however, the minimum distance (100 m) may have been far enough to mask a localized impact. While the lights likely attract photopositive organisms, it is also possible that increased predation pressure may have offset any concentration of prey. This suggests that future net tows be conducted closer to the platform.

Blue runner tend to aggregate on the up-current side of the platform during the day. Predation by blue runner might be expected to reduce prey densities on the down-current side of the platform, which may also be detectable at night if blue runner are feeding close to the platform. My platform down-current net tows did suggest decreased fish densities down-current of the platform in the majority of nighttime samples, however, the results during the day were ambiguous. Hyperiid amphipods, commonly consumed by blue runner at night, were also less abundant in platform down-current tows. These organisms, however, have been documented to increase in abundance beneath a platform as the night progressed (Keenan et al. 2000), likely due to attraction to the lights.

Although a reduction in prey densities down-current of the platform might be expected, if blue runner are actively removing prey from the water that flows past the platform, it is worth estimating whether the reduction might be measurable given the level of sampling that I conducted. Data collected during day one of the 12–16 June cruise (MP140A) show approximately 50 decapods/stomatopods per m^3 pass through the platform. I estimated the platform area of influence (20 m depth X 100m wide = 2000 m^2) and current velocity (0.15 m/s).

$$\text{prey influx} = \text{density X area X current velocity} = 5.40 \text{ X } 10^7 \text{ decapods / h} \qquad (8)$$

Fourteen blue runner caught during the same time the net was collected averaged 29 decapods in their stomachs and I estimated 1h for evacuation. Stanley and Wilson (2000a) reported blue runner density to range from 2,200 to 62,000 near GI94B during 1996-1997. The low-end of the range was used here to form a conservative estimate.

$$\text{feeding rate} = \text{No. of blue runner X prey consumed / h} = 6.38 \text{ X } 10^4 \text{ decapods / h} \qquad (9)$$

A percentage reduction of decapods/stomatopods from predation can be estimated by:

$$\% \text{ predation effect} = \frac{\text{feeding rate}}{\text{prey influx}} = \frac{6.38 X 10^4}{5.40 X 10^7} X\ 100 = 0.18\% \text{ reduction} \qquad (10)$$

This suggests that predation by blue runner would potentially reduce decapod/stomatopod density by much less than 1%. For a 25% reduction of decapod/stomatopod prey, over 400,000 blue runner would be required. It should be noted that these values are conservative estimates because some blue runner examined have contained over 200 decapods in their stomach.

Although the net measurements may not have been conducted sufficiently close to the platforms to detect an enhancement signal, the hydroacoustic surveys provide an alternative methodology for examining this signal. The inner and near-platform loops around the structure were generally closer to the platform than the net tows. Volume scattering strength measurements, collected with a 1200 kHz ADCP, were used to examine the distribution of sound scattering particles in waters around VK203A and MP140A. Hydroacoustic data are inherently ambiguous because of differences in the material properties of biological and abiotic sources of scattering. My data suggests that zooplankton and ichthyoplankton were contributing to the measured S_v. Positive relationships were observed between S_v and total zooplankton density and biomass and as expected these correlations were most convincing for the strong scattering pteropods, hyperiid amphipods, and larval fish. This was expected because the morphological characteristics of these organisms (i.e., hard shell, swim bladder) provide a stronger density and sound velocity contrast that produces a disproportionately strong echo compared to organisms that contain tissue that is closer in density to water (e.g., salps, doliolids, and fish eggs). Diel and between-cruise changes in zooplankton density were detected by acoustic surveys conducted around the platforms. These surveys demonstrated the utility of an ADCP to examine small-scale patterns in sound scattering layers in surface waters around platforms. The preliminary analysis of the acoustic surveys presented here did not demonstrate consistently elevated (or depleted) levels of scattering near the platform (<100 m). It is unfortunate that the ADCP current velocity data could not be reliably analyzed. Such data are essential for determining the up-current and down-current sides of the platform in each depth stratum. A lower frequency ADCP (e.g., 300 kHz) would provide sufficient range for bottom tracking while still detecting organisms of the size range consumed by blue runner. Examination of more surveys along with including data on current velocity will provide further insight into the localized effects of these structures.

<u>Future Considerations</u>

Through this project, I've demonstrated that adult blue runner in proximity to offshore petroleum platform supplement their diet with zooplankton, however, I was unable to detect consistent trends of enhanced prey distribution around these structures. Further examination of blue runner diets from open waters would contribute to the understanding of diet shifts. Short-term movement patterns of platform-associated blue runner would provide greater detail on residence time near these structures. Determining the degree to which these fish utilize platforms seems a difficult, but ultimately manageable and intriguing question to address.

Further examination of the net contents and measurement of size frequencies and material properties would provide variables needed for additional acoustic modeling. This will help to further address the question of which taxa are responsible for the S_v measured by the ADCP. Additional acoustic surveys as well as data on current velocities would be useful to evaluate the distribution of sound scatterers in relation to platforms. Spatial interpolation procedures such as kriging (Maynou et al. 1996) would provide a better image of fine-scale patterns of scattering near platforms.

LITERATURE CITED

Andaloro, F. and C. Pipitone, 1997. Food and feeding habits of the amberjack, *Seriola dumerili* in the Central Mediterranean Sea during the spawning season. Cah. Biol. Mar. 38:91-96.

Andersen, N.G., 1999. The effects of predator size, temperature, and prey characteristics on gastric evacuation in whiting. Journal of Fish Biology 54:287-301.

Benfield, M.C., D.E. McGehee, S.F. Keenan, and K.L. Deines. In Prep. Calibration and use of a broadband acoustic Doppler current profiler for collection of volume scattering strength measurements of zooplankton. Manuscript for Marine Ecology Progress Series.

Bohnsack, J.A., 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science 44:631-645.

Bohnsack, J.A., A.-M. Ecklund and A.M. Szmant, 1997. Artificial Reef Research: Is there more than the Attraction-Production Issue? Fisheries 22:14-16.

Boltovskoy, D., editor. 1999. South Atlantic Zooplankton, Backhuys Publishers, Leiden, The Netherlands.

Bowen, S.H. 1996. Quantitative Description of the Diet, 513-532 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques. 2nd edition, American Fisheries Society, Bethesda, Maryland.

Bowman, T.E. and H.E. Gruner. 1973. The families and genera of Hyperiidae (Crustacea: Amphipoda). Smithsonian Contributions to Zoology. 146:1-64.

Brewer, D.T., S.J.M. Blaber and J.P. Salini, 1989. Feeding biology of *Caranx bucculentus* Alleyne and Macleay (Teleostei: Carangidae) in Albatross Bay, Gulf of Carpentaria, with special reference to predation on penaeid prawns. Australian Journal of Marine and Freshwater Research 40:657-668.

Brock, R.E., 1985. Preliminary study of the feeding habits of pelagic fish around Hawaiian fish aggregation devices or can fish aggregation devices enhance local fisheries productivity? Bulletin of Marine Science 37:40-49.

Buckel, J.A. and D.O. Conover, 1996. Gastric evacuation rates of piscivorous young-of-the-year bluefish. Transactions of the American Fisheries Society 125:591-599.

Buckel, J.A., M.J. Fogarty and D.O. Conover, 1999. Foraging habits of bluefish, *Potatomus saltatrix*, on the U.S. east coast continental shelf. Fishery Bulletin 97:758-775.

Cervigón, F., R. Cipriani, W. Fisher, L. Garibaldi, M. Hendrickx, A.J. Lemus, R. Márquez, J.M. Poutiers, G. Robaina and B. Rodriguez. 1993. Field guide to the commercial marine and

brackish-water resources of the northern coast of South America. FAO species identification sheets for fishery purposes. Rome, FAO. 513p.

Checkley Jr., D.M., M.J. Dagg, M.M. Mullin, M. Omori, T. Onbe and M.-y. Zhu, 1992. Diel variation of the zooplankton and its environment at neritic stations in the Inland Sea of Japan and the north-west Gulf of Mexico. Journal of Plankton Research 14:1-40.

Chesson, J., 1983. The estimation and analysis of preference and its relationship to foraging models. Ecology 64:1297-1304.

Christmas, J.Y., A. Perry and R.S. Waller, 1974. Investigations of coastal pelagic fishes, completion report, Gulf Coast Research Laboratory, Ocean Springs, Mississippi.

Cortes, E., 1997. A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. Canadian Journal of Fisheries and Aquatic Sciences 54:726-738.

Crabtree, R.E., 1995. Relationship between lunar phase and spawning activity of tarpon, *Megalops atlanticus*, with notes on the distribution of larvae. Bulletin of Marine Science 56:895-899.

DeMartini, E.E., F.A. Parrish and D.M. Ellis, 1996. Barotrauma-associated regurgitation of food: implications for diet studies of Hawaiian pink snapper, *Pristipomoides filamentosus* (Lutjanidae). Fishery Bulletin 94:250-256.

Deudero, S., 2001. Interspecific trophic relationships among pelagic fish species underneath FADs. Journal of Fish Biology 58:53-67.

Deudero, S. and B. Morales-Nin, 2001. Surface mesozooplankton in open waters of the western Mediterranean. Ophelia 54:1-13.

Dicks, B., 1982. Monitoring the biological effects of North Sea Platforms. Marine Pollution Bulletin 13:221-227.

Ditty, J., R.F. Shaw and T. Farooqi, 2000. Cross-Shelf Gradient of Larval Fish: Importance to Platform Productivity. Pages 29-32 *in* M. McKay and J. Nides editors, Proceedings: eighteenth annual Gulf of Mexico information transfer meeting, December 1998. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. OCS Study MMS 2000-030.

Donaldson, P.L. and I.E. Clavijo, 1994. Diet of round scad (*Decapterus punctatus*) on a natural and an artificial reef in Onslow Bay, North Carolina. Bulletin of Marine Science 55:501-509.

Druce, B.E. and M.J. Kingsford, 1995. An experimental investigation on the fishes associated with drifting objects in coastal waters of temperate Australia. Bulletin of Marine Science 57:378-392.

Flagg, C.N. and S.L. Smith, 1989. On the use of the acoustic Doppler current profiler to measure zooplankton abundance. Deep Sea Research 36:455-474.

Fleminger, A. and R.I. Clutter, 1965. Avoidance of towed nets by zooplankton. Limnology and Oceanography 10:96-104.

Foote, K.G. and T.K. Stanton, 2000. Acoustical methods, Pages 223-258 *in* R. Harris, P.H. Wiebe, J. Lenz, H.R. Skjoldal and M. Huntley editors, Zooplankton Methodology Manual. Academic Press, San Diego, California.

Forristall, G.Z., 1996. Measurements of current blockage by the Bullwinkle Platform. Journal of Atmospheric and Oceanic Technology 13:1247-1266.

Gallaway, B.J., 1980. Pelagic, reef and demersal fishes, and macro-crustaceans / biofouling communities. Volume 2 *in* W.B. Jackson and E.F. Wilkens. Editors. Environmental assessment of Buccaneer gas and oil field in northwestern Gulf of Mexico, 1975-1980. NOAA Technical Memorandum NMFS-SEFC 48.

Gallaway, B.J., L.R. Martin, R.L. Howard, G.S. Boland and G.D. Dennis, 1981. Effects on artificial reef and demersal fish and macrocrustacean communities. Volume 14. Pages 237-299 *in* B.S. Middleditch, Editor. Environmental effects of offshore oil production: The Buccaneer gas and oil field study. Plenum Press. New York, N.Y.

Gerking, S.D., 1994. Particulate Feeding. Pages 111-137 *in* Feeding Ecology of Fishes. Academic Press, Inc., San Diego, California.

Gerlotto, F., C. Bercy and B. Bordeau. 1989. Echo integration survey around offshore oil extraction platforms off Cameroon: Observations of the repulsive effect on fish of some artificially emitted sounds. Proceedings of the Institute of Acoustics 19:79-88.

Gooding, R.M. and J.J. Magnuson, 1967. Ecological significance of a drifting object to pelagic fishes. Pacific Science 21:486-497.

Goodwin, I., J.M. and J.H. Finucane, 1985. Reproductive biology of blue runner (*Caranx crysos*) from the eastern Gulf of Mexico. Northeast Gulf Science 7:139-146.

Greene, C.H., K.M. Fristrup, T.K. Stanton, R. Gisiner and R.C. Tipper, 1998. Bioacoustical Oceangraphy: An Introduction. Deep-Sea Research II. 45:1151-1153.

Grossman, G.D., G.P. Jones and J. Seaman, W.J., 1997. Do artificial reefs increase regional fish production? A review of existing data. Fisheries 22:17-23.

Hamner, W.M., M.S. Jones, J.H. Carleton, I.R. Hauri and D.M. Williams, 1988. Zooplankton, planktivorous fish, and water currents on a windward reef face: Great Barrier Reef, Australia. Bulletin of Marine Science 42:459-479.

Hastings, R.W., L.H. Ogren and M.T. Mabry, 1976. Observations on the fish fauna associated with offshore platforms in the northeastern Gulf of Mexico. Fishery Bulletin 74:387-402.

Haywood, M.D.E., 1995. Rates at which post-larval prawns are digested by a small predatory fish and the implications for predation studies. Journal of Fish Biology 47:337-340.

Hernandez Jr., F.J. 2001. The across-shelf distribution of larval, postlarval, and juvenile fishes collected at oil and gas platforms and a coastal jetty off Louisiana West of the Mississippi River Delta. Doctoral dissertation. Louisiana State University, Baton Rouge.

Heywood, K.J., E.D. Barton and J.H. Simpson, 1990. The effects of flow disturbance by an oceanic island. Journal of Marine Research 48:55-73.

Heywood, K.J., S. Scrope-Howe and E.D. Barton, 1991. Estimation of zooplankton abundance from shipborne ADCP backscatter. Deep-Sea Research 38:677-691.

Hobson, E.S., 1968. Predatory Behavior of Some Shore Fishes in the Gulf of California, U. S. Department of the Interior, Washington.

Holliday, D.V. and R.E. Pieper, 1995. Bioacoustical oceanography at high frequencies. ICES Journal of Marine Science 52:279-296.

Hughes, R.N., 1980. Optimal foraging theory in the marine context. Oceanography and Marine Biology: An Annual Review. 18:423-481.

Hunter, J.R., 1968. Effects of light on schooling and feeding of jack mackerel, *Trachurus symmetricus*. Journal of Fisheries Research Board of Canada 25:393-407.

Hyslop, E.J., 1980. Stomach contents analysis - a review of methods and their application. Journal of Fish Biology 17:411-429.

Ibrahim, S., M. Azmi Ambak, L. Shamusudin and M. Zaini Samsudin, 1996. Importance of fish aggregating devices (FADs) as substrates for food organisms of fish. Fisheries Research 27:265-273.

Jennings, S., M.J. Kaiser, J.D. Reynolds. 2001. Acoustic methods Pages 209-210. *in* Marine Fisheries Ecology. Blackwell Science Ltd. Malden, Massachusetts.

Juanes, F. and D.O. Conover, 1994. Rapid growth, high feeding rates, and early piscivory in young-of-the-year bluefish (*Pomatomus saltatrix*). Canadian Journal of Fisheries and Aquatic Sciences 51:1752-1761.

Kasprzak, R.A., 1998. Use of oil and gas platforms as habitat in Louisiana's artificial reef program. Gulf of Mexico Science 37-45.

Keenan, S.F., M.C. Benfield, R.F. Shaw and H.L. Haas, 2000. Importance of Zooplankton to Platform Productivity. Pages 33-41 *in* M. McKay and J. Nides editors, Proceedings: eighteenth annual Gulf of Mexico information transfer meeting, December 1998. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. OCS Study MMS 2000-030.

Keenan, S.F., M.C. Benfield, and R.F. Shaw. In press. Zooplanktivory by Blue Runner: An Energetic Subsidy to Gulf of Mexico Fish Populations at Petroleum Platforms. Transactions of the American Fisheries Society special publication.

Klima, E.F. and D.A. Wickham, 1971. Attraction of coastal pelagic fishes with artificial structures. Transactions of the American Fisheries Society 100:86-99.

Lam, T.J., 1983. Environmental influences on gonadal activity in fish, Pages 65-101. *in* W.S. Hoar, D.J. Randall and E.M. Donaldson editors, Fish Physiology, Vol. IX, Academic Press, Inc.

Land, M.F., 1992. Locomotion and visual behaviour of mid-water crustaceans. Journal of the Marine Biological Association of the United Kingdom 72:41-60.

Lindberg, W.J., 1997. Can Science Resolve the Attraction-Production Issue? Fisheries 22:10-13.

Lindquist, D.G. and L.J. Pietrafesa, 1989. Current vortices and fish aggregations: The current field and associated fishes around a tugboat wreck in Onslow Bay, North Carolina. Bulletin of Marine Science 44:533-544.

Love, M.S., J. Caselle and L. Snook, 1999. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara channel and Santa Maria Basin. Bulletin of Marine Science 65:497-513.

Love, M.S., J.E. Caselle and L. Snook, 2000. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. Fishery Bulletin 98:96-117.

Macer, C.T., 1977. Some aspects of the biology of the horse mackerel [*Trachurus trachurus* (L.)] in waters around Britain. Journal of Fish Biology 10:51-62.

Macy, W.K., S.J. Sutherland and E.G. Durbin, 1998. Effects of zooplankton size and concentration and light intensity on the feeding behavior of Atlantic mackerel *Scomber scombrus*. Marine Ecology Progress Series 172:89-100.

Manooch, C.S. and M. Haimovici, 1983. Foods of greater amberjack, *Seriola dumerili*, and almaco jack, *Seriola rivoliana* (Pisces: Carangidae), from the south Atlantic Bight. The Journal of the Elisha Mitchell Scientific Society 99:1-9.

Maynou, F., G.Y. Conan, J.E. Cartes, J.B. Company and F. Sarda, 1996. Spatial structure and seasonality of decapod crustacean populations on the northwestern Mediterranean slope. Limnology and Oceanography 41:113-125.

McKenney, T.W., E.C. Alexander and G.L. Voss, 1958. Early development and larval distribution of the Carangid fish, *Caranx crysos* (Mitchill). Bulletin of Marine Science of the Gulf and Caribbean 8:167-200.

National Marine Fisheries Service, 2000. Fisheries of the United States. Office of Science and Technology, Fisheries Statistics and Economics Division. M.C. Holiday, chief, B.K. O'Bannon, editor. Silver Springs, Maryland.

Nelson, B.D. and S.A. Bortone, 1996. Feeding guilds among artificial-reef fishes in the Northern Gulf of Mexico. Gulf of Mexico Science 66-80.

Omori, M. and W.M. Hamner, 1982. Patchy distribution of zooplankton: Behavior, population assessment and sampling problems. Marine Biology 72:193-200.

Parker, J., R.O., D.R. Colby and T.D. Willis, 1983. Estimated amount of reef habitat on a portion of the U.S. South Atlantic and Gulf of Mexico continental shelf. Bulletin of Marine Science 33:935-940.

Patterson III., W.F., J.C. Watterson, R.L. Shipp and J. Cowan, J.H., 2001. Movement of tagged red snapper in the northern Gulf of Mexico. Transactions of the American Fisheries Society 130:533-545.

Popova, O.A. and L.M. Sierra, 1985. Feeding of Black Jack, *Caranx ruber*, in the Gulf of Batabano on the Cuban Shelf. II. Digestion Rates and Daily Rations. Journal of Ichthyology 25:105-118.

Postel, L., H. Fock and W. Hagen, 2000. Biomass and abundance, Pages 83-192 *in* R. Harris, P.H. Wiebe, J. Lenz, H.R. Skjoldal and M. Huntley editors, Zooplankton Methodology Manual. Academic Press, San Diego, California.

Randall, J.E., 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography 5:867pp.

Reggio, V.C. 1987. Rigs-to-Reef: the use of obsolete petroleum structures as artificial reefs. U.S. Dept. of the Interior. Minerals Management Service. Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 87-0015. 17 pp.

Ressler, P.H., 2001. Acoustic estimates of zooplankton and micronekton biomass in cyclones and anticyclones in the northeastern Gulf of Mexico. Doctoral dissertation, Texas A&M University, Galveston.

Schekter, R.C., 1972. Food habits of some larval and juvenile fishes from the Florida Current, near Miami, Florida. Rosenstiel School of Marine and Atmospheric Science, University of Miami.

Sanderson, S.L., C.R. Chesnutt and P.S. Lobel, 1996. Evidence for ram suspension feeding by the piscivore, *Seriola dumerili* (Carangidae). Environmental Biology of Fishes 46:365-373.

Sazima, I., 1998. Field evidence for suspension feeding in *Pseudocaranx dentex*, with comments on ram filtering in other jacks (Carangidae). Environmental Biology of Fishes 53:225-229.

Seaman Jr., W., W.J. Lindberg, C.R. Gilbert and T.K. Frazer, 1989. Fish habitat provided by obsolete petroleum platforms off southern Florida. Bulletin of Marine Science 44:1014-1022.

Shipp, R.L., 1999. The artificial reef debate: Are we asking the wrong questions? Gulf of Mexico Science 51-55.

Singh-Renton, S. and P.J. Bromley, 1996. Effects of temperature, prey type and prey size on gastric evacuation in small cod and whiting. Journal of Fish Biology 49:702-713.

Skjoldal, H.R., P.H. Wiebe and K.G. Foote, 2000. Sampling and experimental design, Pages 33-54 *in* R. Harris, P.H. Wiebe, J. Lenz, H.R. Skjoldal and M. Huntley editors, Zooplankton Methodology Manual. Academic Press, San Diego, California.

Smith-Vaniz, W.F., 1986. Carangidae, Pages 815-825 *in* P.J.P. Whitehead, M.L. Bauchot, J.C. Hureau, J. Nielsen and E. Tortones editors, Fishes of the North-eastern Atlantic and the Mediterranean Vol. II. United Nations Educational, Scientific and Cultural Organization, Paris.

Sokal, R.R. and F.J. Rohlf, 1981. Biometry, 2nd edition, W.H. Freeman and Company.

Sonnier, F., J. Teerling and H.D. Hoese, 1976. Observations on the offshore reef and platform fish fauna of Louisiana. Copeia 1976:105-111.

Stanley, D.R. 1994. Seasonal and spatial abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico, Doctoral dissertation. Louisiana State University, Baton Rouge, La.

Stanley, D.R. and C.A. Wilson, 1990. A fishery-dependent based study of fish species composition and associated catch rates around oil and gas structures off Louisiana. Fishery Bulletin 88:719-730.

Stanley, D.R. and C.A. Wilson, 1991. Factors affecting the abundance of selected fishes near oil and gas platforms in the northern Gulf of Mexico. Fishery Bulletin 89:149-159.

Stanley, D.R. and C.A. Wilson, 1996. Abundance of fishes associated with a petroleum platform as measured with dual-beam hydroacoustics. ICES Journal of Marine Science 53:473-475.

Stanley, D.R. and C.A. Wilson, 1997. Seasonal and spatial variation in the abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences 54:1166-1176.

Stanley, D.R. and C.A. Wilson, 1998. Spatial variation in fish density at three petroleum platforms as measured with dual-beam hydroacoustics. Gulf of Mexico Science 73-82.

Stanley, D.R. and C.A. Wilson, 2000a. Seasonal and spatial variation in the biomass and size frequency distribution of the fish associated with oil and gas platforms in the northern Gulf of Mexico, Coastal Marine Institute, Louisiana State University, Baton Rouge, La.

Stanley, D.R. and C.A. Wilson, 2000b. Variation in the density and species composition of fishes associated with three petroleum platforms using dual beam hydroacoustics. Fisheries Research 47:161-172.

Stanton, T.K., P.H. Wiebe, D. Chu, M.C. Benfield, L. Scanlon, L. Martin and R.L. Eastwood, 1994. On acoustic estimates of zooplankton abundance. ICES Journal of Marine Science 51:505-512.

Starck, I., W.A and W.P. Davis, 1966. Night habits of fishes of Alligator Reef, Florida. Ichthyologica. The Aquarium Journal 38:313-356.

Swaby, S.E., G.W. Potts and J. Lees, 1996. The first records of the blue runner *Caranx crysos* (Pisces: Carangidae) in British waters. Journal of the Marine Biological Association of the United Kingdom 76:543-544.

Taylor, P.H., 1991. Current blockage: Reduced forces on offshore space-frame structures, Pages 199-205. *in* 23rd Annual Offshore Technology Conference, volume 1, Houston, Texas.

Temming, A. and J.P. Herrmann, 2001. Gastric evacuation of horse mackerel. II. The effects of different prey types on the evacuation model. Journal of Fish Biology 58:1246-1256.

Videler, J.J., 1993. The costs of swimming, Pages 185-205, *in* Fish Swimming. Chapman and Hall, New York.

Vindgradov, M.E., A.F. Volkov and T.N. Semenova, 1996. Hyperiid Amphipods (Amphipoda, Hyperiidae) of the World Oceans, Skarlato, O.A. editor. Smithsonian Institution Libraries, Washington, D.C.

Vinyard, G.L. and W.J. O'Brien, 1976. Effects of light and turbidity on the reactive distance of Bluegill (*Lepomis macrochirus*). Journal of Fisheries Research Board of Canada 33:2845-2849.

Warren, J.D., T.K. Stanton, M.C. Benfield, P.H. Wiebe, D. Chu, M. Sutor, 2001. In situ measurements of acoustic target strengths of gas-bearing siphonophores. ICES Journal of Marine Sciences 58:740-749.

Wiebe, P.H., D.G. Mountain, T.K. Stanton, C.H. Greene, G. Lough, S. Kaartvedt, J. Dawson and N. Copley, 1996. Acoustical study of the spatial distribution of plankton on Georges Bank and relationship between volume backscattering strength and the taxonomic composition of the plankton. Deep Sea Research II 43:1971-2000.

Wormuth, J.H., P.H. Ressler, R.B. Cady and E.J. Harris, 2000. Zooplankton and micronekton in cyclones and anticyclones in the Northeast Gulf of Mexico. Gulf of Mexico Science 23-34.

Zhou, M., W. Nordhausen and M. Huntley, 1994. ADCP measurements of the distribution and abundance of euphausiids near the Antarctic Peninsula in winter. Deep-Sea Research II 41:1425-1445.

Zimmerman, R.A. and D.C. Biggs, 1999. Patterns of distribution of sound-scattering zooplankton in warm- and cold-core eddies in the Gulf of Mexico, from a narrowband acoustic Doppler current profiler survey. Journal of Geophysical Research 104:5251-5262.

Appendix: Letter Requesting Permission

May 15, 2002

Dr. David Stanley
Beak International Inc.
14 Abacus Rd.
Brampton, Ontario
Canada L6T 5B7

Dr. Stanley:

The purpose of this letter is to request permission to include the submitted paper:
Zooplanktivory by Blue Runner *Caranx crysos*: An Energetic Subsidy to Gulf of Mexico Fish
Populations at Petroleum Platforms.
As a chapter in my thesis at Louisiana State University. This manuscript was submitted for peer
review and deemed acceptable for publication by the American Fisheries Society. This will be
published as a special publication entitled "Gulf of Mexico Fish and Fisheries; Bringing
Together New and Recent Research".

Sincerely,

Sean F. Keenan
Dept. of Oceanography
and Coastal Sciences
Louisiana State University

Appendix: Letter Granting Permission

beak
international
incorporated

14 Abacus Road   Tel   (905) 794-2325
Brampton,Ontario   Fax   (905) 794-2338
Canada   L6T 5B7   1-800-361-BEAK (2325)

Mr. Sean Keenan
School of Coast and Environment
Louisiana State University
Baton Rouge, Louisiana
70803

Mr. Keenan:

As requested you have permission to include:
Zooplanktivory by Blue Runner Caranx crysos: An Energetic Subsidy to Gulf of Mexico Fish Populations at Petroleum Platforms.
As a chapter in your thesis for Louisiana State University. Note the manuscript has been accepted by the American Fisheries Society as a paper to be included in their special publication "Gulf of Mexico Fish and Fisheries; Bringing Together New and Recent Research" for future publication. Note that Dr. Ann Bull (Minerals Management Service) and I are coeditors of the proceeding . If you have any questions please do not hesitate to contact me.

Regards,

Dr. David Stanley
Project Manager

VITA

Sean Francis Keenan was born on January 19, 1974, in Leesburg, Florida. He is the son of Phyllis B. Keenan and Francis D. Keenan and the brother of Allan Keenan and Debbie Almy. Sean graduated as valedictorian from Mount Dora High School in 1992. He moved to Baton Rouge, Louisiana, and received a Bachelor of Science degree in zoology with a marine science concentration from Louisiana State University in December 1996. Sean worked as a research associate under the direction of Dr. Kenneth Brown in the Department of Biology at Louisiana State University until August 1999 when he became a graduate assistant under Dr. Mark C. Benfield in the Department of Oceanography and Coastal Sciences at Louisiana State University. Sean received a Master of Science degree in oceanography and coastal sciences in August 2002.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.