Exxon Valdez Oil Spill
Restoration Project Annual Report

Sound Ecosystem Assessment: Juvenile Salmon Predation

Restoration Project 96320E
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil spill Trustee Council Restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Sound Ecosystem Assessment: Juvenile Salmon Predation

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Study History: This project was initiated under Restoration project 94320E. An annual report was issued in 1994 by Willette, M., E. Debevec, Jay Johnson under the title Sound Ecosystem Assessment: Salmon Predation. The project effort was continued under Restoration Project 96320E, the subject of this annual report. In 1996, this project was merged with project 96320A. A final report will be prepared for both projects in FY98.

Abstract: This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort designed to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). This project collected data needed to test several hypotheses related to predator-prey interactions affecting the mortality of pink salmon (*Oncorhynchus gorbuscha*) in PWS. Our efforts in 1996 focused on estimation of predator abundance, as well as predator behavior and feeding rates in nearshore habitats. Results from the first two years of research suggest that predation in nearshore areas may have been underestimated. Studies were conducted at six nearshore sites during each of three time periods in northwest PWS during May and June. Otolith marked juvenile salmon were recovered at each site to estimate stock composition and test for differences in size and growth of wild and hatchery salmon fry. Dolly varden trout, age 1-2 pollock, Pacific cod and tomcod appeared to be the most important fish predators on juvenile salmon in nearshore habitats in 1996. However, abundances of age 3+ pollock in the upper 50 m of the water column were much lower than in previous years. Pacific herring appeared to switch to feeding on juvenile salmon after the decline of the zooplankton bloom. This behavior had not been observed in previous years. We also examined the feasibility of using fixed uplooking video cameras to study salmon fry and fish predator behavior and estimate fish abundances in nearshore habitats not easily surveyed using acoustic methods. Two cameras were operated at three sites during May and June. Results indicated a strong inshore movement of salmon fry at night. We also examined the feasibility of sonic tagging age 3+ walleye pollock to study diel feeding behavior. One fish was successfully tagged and tracked for two days. It exhibited a diel vertical migration, apparently moving inshore to feed at night and returning to the bottom during the day. A second fish was tracked for one day at which time it either regurgitated the tag or died. Net pen studies will be conducted to examine the mortality of fish tagged by various methods. Results from field studies conducted since 1994 will be used to construct the SEA pink salmon recruitment model and conduct tests of the SEA predator/prey hypotheses.

Key Words: *Clupea pallasi*, *Exxon Valdez* oil spill, food habits, *Microgadus proximus*, mortality, *Oncorhynchus gorbuscha*, Pacific herring, Pacific tomcod, pink salmon, predation, *Theragra chalcogramma*, walleye pollock.

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Executive Summary

This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). Pink salmon runs to PWS failed in 1992 and 1993, and herring biomass dropped sharply in 1993. These run failures have drastically affected the economy of the PWS region which is largely based on the salmon and herring resources. This project collected data needed to test several hypotheses related to predator-prey interactions affecting the mortality of pink salmon (*Oncorhynchus gorbuscha*) in PWS. This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort designed to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). This project collected data needed to test several hypotheses related to predator-prey interactions affecting the mortality of pink salmon (*Oncorhynchus gorbuscha*) in PWS. These hypotheses include the following: (1) predation on juvenile salmon and other age-0 fish is inversely related to the abundance of large calanoid copepods, (2) predation risk is related to the daily foraging times of juvenile salmon, and (3) predation on wild salmon fry is greater when wild fry are mixed with larger hatchery-reared fish. This project was designed to achieve the following objectives: (1) estimate the juvenile salmon consumption rate of fish predators in western PWS, (2) estimate the species/size composition of fish predators, and (3) conduct preliminary tests of predator/prey hypotheses. This project also provided logistical support (personnel and equipment) to the SEA herring program.

Our efforts in 1996 focused on estimation of predator abundance, as well as predator behavior and feeding rates in nearshore habitats. Results from the first two years of research suggest that predation in nearshore areas may have been underestimated. Studies were conducted at six nearshore sites during each of three time periods in northwest PWS during May and June. Each nearshore study site consisted of an approximately 3000 m long segment of shoreline. Fish sampling was generally conducted at two stations every 3 hours throughout a 12-hour period spanning the night. Otolith marked juvenile salmon were recovered at each site to estimate stock composition and test for differences in size and growth of wild and hatchery salmon fry. Dolly varden trout, age 1-2 pollock, Pacific cod and tomcod appeared to be the most important fish predators on juvenile salmon in nearshore habitats in 1996. However, abundances of age 3+ pollock in the upper 50 m of the water column were much lower than in previous years. Pacific herring appeared to switch to feeding on juvenile salmon after the decline of the zooplankton bloom. This behavior had not been observed in previous years. We also examined the feasibility of using fixed uplooking video cameras to study salmon fry and fish predator behavior and estimate fish abundances in nearshore habitats not easily surveyed using acoustic methods. Two cameras were operated at three sites during May and June. Results indicated a strong inshore movement of salmon fry at night. We also examined the

feasibility of sonic tagging age 3+ walleye pollock to study diel feeding behavior. One fish was successfully tagged and tracked for two days. It exhibited a diel vertical migration, apparently moving inshore to feed at night and returning to the bottom during the day. A second fish was tracked for one day at which time it either regurgitated the tag or died. Net pen studies will be conducted to examine the mortality of fish tagged by various methods. Results from field studies conducted since 1994 will be used to construct the SEA pink salmon recruitment model and conduct tests of the SEA predator/prey hypotheses.

Introduction:

This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). Pink salmon runs to PWS failed in 1992 and 1993, and herring biomass dropped sharply in 1993. These run failures have drastically affected the economy of the PWS region which is largely based on the salmon and herring resources. In 1992, pink salmon returns were low in Kodiak, Lower Cook Inlet, and PWS, but pink salmon returns in 1993 were low only in PWS. Low returns of hatchery-produced salmon in both years indicates that the failures were likely caused by processes occurring during the juvenile lifestage. Damage assessment studies on juvenile pink salmon in PWS have demonstrated that growth during the juvenile lifestage is related to survival to adult (Willette et al. 1994). Growth rates of juvenile salmon were estimated in 1991 and 1992 after the fish were released from hatcheries. Juvenile growth and ocean temperatures were low in PWS during the early marine period in 1991. However, in 1992 juvenile growth and ocean temperatures were near average; although, zooplankton abundance was very low. The growth of juvenile fishes is believed to be related to survival, because slow-growing individuals are vulnerable to predators for a longer time (Parker 1971; Healey 1982; West and Larkin 1987). The growth and mortality rates of juvenile salmon released into PWS in 1992 suggests that a change in predation rate may have contributed to the observed run failures.

During phase I of SEA, pink salmon research focused on identification of the principal species preying on pink salmon and the processes affecting rates of predation. Phase I results indicate that predation by pelagic pollock (age 3+) and seabirds may account for only 15-25% of probable losses of juvenile salmon (Willette et al. 1995b). However, results from an experimental release of large juvenile pink salmon from Wally H. Noerenberg Hatchery suggests that high mortality likely occurred among an early release of small juvenile pink salmon during May, 1994 (Willette et al. 1995a). Age 3+ pollock and squid were the most abundant species in net catches during May, 1994 (Willette et al. 1994b). The following three hypotheses have been developed from our phase I results: (1) predation by age 3+ pollock in offshore habitats was underestimated in 1994, (2) age 3+ pollock that target juvenile salmon in nearshore habitats account for the majority of the predation losses and these predators were not sampled adequately in 1994, (3) other nearshore fish predators not sampled in 1994 account for the majority of the predation losses, and (4) high condition of the late release group resulted in differential mortality between early and late releases after early June.

Several factors may have resulted in underestimation of juvenile salmon consumption by pelagic age 3+ pollock. Pollock biomass may have been underestimated due to vessel avoidance, occurrence of pollock in the surface layer (0-5m) that was not surveyed, and occurrence of pollock below 125 m depth that was not surveyed. These questions are being addressed by project (96320N). In addition, pollock food consumption may have been underestimated if the fish are glut feeding in the surface layer then migrating to depth to rest. This project conducted studies in FY96 to determine the feasibility of sonic tagging pollock as a means of evaluating their vertical migratory behavior. Sonic telemetry has been used successfully to investigate the daily activity and movement patterns of juvenile Atlantic cod (Clark and Green 1990). During summer, these fish migrated between a warm surface layer to feed at night and a deep cold layer to rest during the day.

Much of our effort in FY96 focused on developing techniques for sampling predators in nearshore habitats that may not have been adequately sampled in previous years. This involved studies to determine the feasibility of using fixed-uplooking video cameras to estimate relative abundance and observe the behavior of juvenile salmon and their predators. This technology has been used successfully to estimate fish abundance and size (Irvine et al. 1991, DeMartini and Ellis 1995), identify fish species (DeMartini and Ellis 1995), and evaluate activity and feeding patterns (Collins et al. 1991). Night observations have been made using infrared lighting which cannot be detected by fish and invertebrates (Collins et al. 1991). Project 96320N examined the feasibility of using side-looking acoustics to estimate the relative abundance of predators in nearshore habitats. Variable mesh gillnets were used to obtain fish samples in nearshore habitats.

This project also collected samples to evaluate whether condition-dependent predation may lead to differential mortality of juveniles rearing in nearshore habitats. These samples are being analyzed by project 96320U. If condition-dependent predation occurs the presence of large numbers of enhanced salmon may adversely affect wild salmon during the early marine period. An inverse relationship between whole body energy content and fry density at three sites sampled in 1995 suggests that growth may be density-dependent (Paul and Willette 1996). All juvenile pink salmon released from PWS hatcheries will be otolith thermal marked in FY96 providing an essential tool for these investigations. This component of the pink salmon recruitment model will provide a useful tool to improve management of the Sound's wild and enhanced salmon stocks.

Objectives:

1. Refine estimates of juvenile salmon consumption by pelagic pollock.

2. Develop techniques for sampling coupled predators in the nearshore zone.

3. Collect samples needed to evaluate condition-dependent predation among wild and enhanced salmon.

Methods:

Objective 1:

A feasibility study was conducted to determine if the diel behaviour of pelagic pollock can be revealed by application of sonic tags. Two pollock were tagged and tracked for several days in July, 1996. The fish were caught with a hook and line, immediately placed in a holding tank, and observed for several minutes. A Vemco ™ V16 depth sensitive sonic tag was inserted into each fishes stomach via the esophagus, and each fish was observed for several minutes before release. An approximately 7 m vessel was used to track the fish. Depth and position readings were recorded periodically using the Vemco ™ V60 directional receiver. A global positioning system (GPS) was used to obtain position readings.

Objective 2:

Investigations of predator/prey coupling in the nearshore zone were initiated in FY96 as a feasibility study. Seven sites were sampled during three 9-day sampling trips in May and June (Figure 1, Table 1). Acoustic and net sampling were conducted every three hours from approximately 9 pm to 9 am each day. Project 96320N conducted acoustic surveys utilizing side-looking (420kHz) and downlooking echosounders (70kHz). Acoustic data was collected on one alongshore transect on each three hour cycle to estimate the abundance of predators and juvenile salmon in the nearshore zone. Acoustic data was also collected along five transects perpendicular to shore to relate nearshore and offshore predator abundances. An approximately 25 m trawl vessel sampled fish in offshore areas using a 40 m x 28 m mid-water wing trawl equipped with a net sounder. The cod end of the trawl was lined with 1.5 cm stretch-mesh web to retain small specimens. Each tow was made approximately 1 km offshore parallel to the shore in the upper 40 m of the water column. A purse seine vessel sampled fish in the upper 20 m of the water column in nearshore areas with bottom depths greater than 20 m. Each seiner fished a small-mesh purse seine (250 m x 30 m, 1.5 cm stretch mesh web) holding a hook with the seine open in the direction of the prevailing current for 20 minutes. In nearshore areas shallower than 20 m, variable mesh sinking and floating gill nets (150 m, 1.5 cm to 10 cm stretch mesh) were used to sample fish predators. These gear were deployed from an approximately 6 m aluminum skiff. Each gill net was attached to the beach and set perpendicular to shore. A hotel boat provided room and board for field sampling crews. All sample processing was conducted on board the hotel boat by a single processing crew.

Processing of fish samples from each net set occurred in two stages following procedures outlined by Livingston (1989) and Dwyer et al. (1987). If less than 300 fish were captured, all fish in the catch were enumerated by species. If a large number of fish were caught, species composition was estimated from a random sample of 300 individuals. Fish greater than 150 mm FL were processed differently than those less than 150 mm FL. Fish less than 150 mm FL were identified to the lowest possible taxonomic level. A sample of 30 individuals from each species was preserved in 10% buffered formaldehyde for later analysis of stomach contents under project 96163 (Forage Fish Influence on Recovery of Injured Species). The purpose of these studies is to examine diet overlap among forage fish.

For large fish (greater than 150 mm FL), a randomly selected sample (n=60) from each net set and each species was taken. The stomach was excised, placed in a cloth bag, and preserved in 10% buffered formaldehyde for later analysis of stomach contents. Fish showing evidence of regurgitation were not included in the sample. Fork length was measured to the nearest millimeter. Weight was measured to the nearest gram when conditions permitted. Sex and sexual maturity was recorded. Later in the laboratory, total stomach contents wet weight was measured to the nearest .01 gram. Invertebrate prey in the gut were generally identified to the family level. Fish in the gut were identified to the lowest possible taxonomic level, enumerated, and measured to the nearest millimeter. The proportion of total stomach contents in each taxonomic group was visually estimated. Stomach fullness was expressed as a proportion of fish body weight. In cases where distinct size classes occurred within species, stomach contents analysis was conducted for each size class as described above. Size related shifts in diet toward piscivory have been noted in several species of gadoid fishes, including Pacific cod (*Gadus macrocephalus*) (Livingston 1989), walleye pollock (*Theragra chalgogramma*) (Dwyer et al. 1987), Atlantic cod (*Gadus morhua*) (Daan 1973), Pacific whiting (*Merluccius productus*) (Livingston 1983), and silver hake (*Merluccius bilinearis*) (Langton 1982).

An analysis of variance was conducted to test for differences in the mean percent of predator diets comprised of juvenile salmon among three time periods in May and June. Data were arcsin square root transformed prior to conducting the test (Zar 1984). Several species of nearshore benthic fish (*Hemilepidotus hemilepidotus, Myxocephalus verrucosus, Hexagrammos decagrammus, Hexagrammos octogrammus, Blepsias bilobus*) were pooled in the analysis All specimens were included in the analysis to examine changes in diet for the population within each taxonomic group as a whole. An analysis of variance was conducted to test for changes in the natural-logarithm transformed mean catch per net set of juvenile salmon predators by date. Trawl data was expressed as natural-logarithm of catch per hour of tow. Analysis of variance was also conducted to test for differences in the mean proportion of the diet comprised of various taxonomic groups by date. Data were arcsin-square root transformed prior to conducting the test.

A study was conducted to determine the feasibility of using fixed-uplooking video cameras to estimate the abundance and feeding behavior of fry and predators in nearshore nursery habitats where side-scan acoustics are not feasible due to reflection from the bottom and sea surface. Two cameras were installed at locations where fry continuously reside due to current structures. The study sites were at Tipping point on Northwest Perry Island and at Fox Farm Harbor on the west end of Elrington Island. These sites differed in that Tipping Point is exposed in Perry Passage, while the Fox Farm Harbor site is located in a protected bay.

Underwater video cameras were held in an uplooking position approximately 2.5 m from the waters surface. This position was maintained by attaching the camera body to foam flotation. The foam flotation was in turn attached to a line running down through a pulley anchored to the bottom and back up to a fixed object on shore. Camera depth was adjusted by pulling in or letting out line as tides rose and fell. These adjustments were made every two hours when tapes were changed or more often when tides were changing rapidly. After the field season, all tapes were reviewed manually, potential predators enumerated, and the time in field of view recorded for each group of potential predators. The approximate density of predators (no. m^{-3}) was calculated from the product of abundance and time in view (no.· sec) divided by the product of the approximate volume of water in view and the total time the cameras were in operation (m^3· sec). The occurrence of juvenile salmon in the field of view was enumerated for each hour of the day over all observations.

Objective 3:

Analyses of condition-dependent predation among wild and enhanced salmon was conducted at sites where sufficient numbers of juvenile salmon could be obtained from predator stomachs. All samples were taken from the stomachs of age 1-2 pollock, Pacific cod, tomcod or dolly varden trout. Processing of predator stomach samples was generally conducted as described in objective 2; however, any juvenile pink salmon with intact skin found in the stomachs were washed in freshwater and immediately frozen for later analysis of energetic content (Project 96320U). Each fry specimen was labelled to allow sample tracking in relation to the predator.

At each site, samples (n=20) of juvenile salmon were also obtained with a small mesh purse seine (10 m x 40 m, 2 mm mesh) deployed from an approximately 4 m skiff every three hours. All samples were frozen as soon as possible after collection. Several of these samples were pooled from each site for analysis of energetic content. In the laboratory, the otolith was extracted from each juvenile pink salmon, length and wet weight measured, and the whole body and head placed in a 20 ml vial and frozen for later analysis of energetic content. For samples not analyzed for energetic content, the otolith was extracted and length, wet weight and dry weight measured Otolith thermal marks will be used to identify the wild or hatchery-origin of these fish.

At each site, samples (n=20) of juvenile salmon were also for stomach contents analysis. All samples were preserved in 10% buffered formaldehyde solution. Later in the laboratory, length was measured to the nearest millimeter, wet weight to the nearest .01 g and stomach contents weight to the nearest milligram. The proportion of total stomach contents weight in three taxonomic groups (large calanoid copepod (>2.5 mm), small calanoid copepod (<2.5 mm), and 'other' prey) was visually estimated . At each site, CTD and zooplankton samples (20m vertical tow, 243 um mesh) were collected in association with each fry sample to evaluate environmental conditions at each site. Zooplankton samples were subsampled with a stimpel pipette and zooplankton enumerated into the following groups: large calanoid copepod (>2.5

mm), small calanoid copepod (<2.5 mm), and 'other' zooplankters.

Results:

Objective 1:

The first pollock was tagged on July 11 at 1715 hrs approximately 5 km from Cordova near Salmo Point. After release, the fish moved towards bottom where it remained until approximately 1845 hrs. With fading light, at 1945 hrs the pollock began a gradual ascent at the same time moving in an arc that took it closer to shore (Figure 2). By 2230 hrs the fish had moved very close to shore (less than 50 meters) and was now only 7 meters deep. Numerous small fish were observed jumping at the surface in the area of the tagged fish. The tagged fish moved in a westerly direction, remaining nearshore until approximately 0345 hrs on July 12. As light levels began to increase, the pollock began to descend, move away from shore and back towards the original capture point. Between 0420-0830 hrs the pollock had made vertical movements ranging its depth from 9.5 to 60 meters while moving east toward Nelson Bay. At one point, the sonic tag indicated a depth of 36 meters, while at the same time hydroacoustic equipment showed a group of targets at the same depth indicating that the tagged fish was moving with a group of other fish. By 1100 hrs on July 12, the tagged fish had slowly moved into Nelson Bay maintaining a depth of about 45 m. The fish appeared to be remaining within approximately 10 meters of bottom. Throughout July 13 the pollock moved sporadically about within Nelson Bay. Most of the time it remained within a few meters of the bottom. At 0100 hrs on July 14, the tagged fish made a short movement out to slightly deeper water. This was the last recorded movement.

The second pollock was tagged on July 18 at 1840 hrs approximately 5 km from Cordova near Salmo Point. The fish returned to the bottom after release. At about 2100 hrs, it moved up in the water column from 74 m to 16 m. By 0100 hrs it returned to the bottom and by 0400 hrs it stopped moving. It is not clear whether the tag was regurgitated or the fish died.

Objective 2:

Species composition and mean catch per net set of fishes in variable-mesh gillnets deployed in nearshore habitats were similar between 1995 and 1996 (Table 2). Various sculpins, gunnels, greenlings, and rockfish, as well as, Pacific cod, tomcod and pollock occurred commonly in the catches. Herring appeared to be more abundant in nearshore habitats in 1996 compared to 1995 (Table 2). Catches of age 3+ pollock in the mid-water trawl declined during a period of high tidal range (julian date 140) then increased again (Figure 3a). Mean catch per net set of herring, age 1-2 pollock and age-0 fishes in small-mesh purse seines increased from May to June (Figure 3).

The mean percent of the diet comprised of juvenile salmon was greatest for dolly varden trout followed by age 1-2 tomcod, Pacific cod and pollock (Table 3). The mean percent of the diet comprised of juvenile salmon increased significantly for herring (P=.043) and benthic fishes (P=.057) in early June (Table 3). During early May, large calanoid copepods comprised approximately 30% and less than 20% of the diets of age 3+ and age 1-2 pollock, respectively (Figure 4). The mean percent of the diet comprised of large calanoid copepods ranged from 20-60% for herring during this same time period (Figure 4). Euphausiids and amphipods comprised the majority of the diets of age 3+ pollock during late May and early June (Figure 4). Consumption of fish increased among age 1-2 pollock in early June (Figure 4b).

Video cameras were successfully operated in nearshore habitats for approximately 59 hours at Tipping Point and 32 hours at Fox Farm Harbor. Approximately 343 potential predators were seen on three occasions mostly after 2300 hrs. Species identification was difficult due to backlighting, but most of the fish appeared to be herring or juvenile gadids. The approximate density of potential predators calculated from these observations was .0015 m^{-3}. The frequency of occurrence of juvenile salmon in the field of view was relatively low from 0500 hrs to 1200 hrs increasing until nightfall at approximately 2300 hrs (Figure 5).

Objective 3:

Sixty-three juvenile pink salmon were obtained in relatively intact condition from predator stomachs at 7 sites in northwest PWS. An additional 100 juvenile pink salmon were randomly selected from samples (n=20) taken with a small mesh purse seine at these sites. All samples were frozen and sent to Seward for analysis under project 96320U. No data is yet available from analyses of juvenile salmon energy content or origin using otolith thermal marks.

Total zooplankton biomass in nearshore habitats ranged from approximately 0.2-0.7 g m^{-3} (Figure 6). The abundance of large calanoid copepods declined rapidly in early May while abundances of 'other' zooplankters increased from May to June (Figure 6). Juvenile salmon increased in size from approximately 35 mm and 0.3 g in early May to approximately 57 mm and 1.5 g in early June (Figure 7). Juvenile salmon stomach fullness generally declined from early May to June (Figure 8a). The percent of the diet comprised of large calanoid copepods declined during May while consumption of 'other' zooplankters increased from May to June (Figure 8).

Discussion:

Sampling with fixed gear in nearshore habitats revealed an assemblage of fish species that may be important predators on juvenile salmon. The species composition of this assemblage was generally similar between 1995 and 1996 (Willette et al. 1996b). Fixed gear sampling in 1996 consisted of sinking and floating variable-mesh gillnets deployed from the shore in nearshore habitats. These gear appeared to be very efficient for capturing potential predators in shallow nearshore habitats.

In general, consumption of juvenile salmon in nearshore habitats appeared to be greater in 1996 compared with 1995. As in previous years, dolly varden trout (*Salvelinus malma*) appeared to be an important predator on juvenile salmon in these areas (Willette et al. 1995b, 1996b). As in 1995 (Willette et al. 1996b), the percent of the diet comprised of juvenile salmon was also relatively high for age 1-2 Pacific cod (*Gadus macrocephalus*), Pacific tomcod (*Microgadus proximus*) and pollock (Table 3). However, age 3+ pollock, herring, and adult pink salmon appeared to be important predators on juvenile salmon in 1994 (Willette et al. 1995b). Bakshtanskiy (1964) concluded that juvenile pollack (*Pollachius virens*) and cod (*Melanogrammus morhua morhua*) were important predators on juvenile pink and chum salmon in the White Sea. He observed that juvenile pink and chum salmon were at times driven from nearshore nursery habitats by large schools of juvenile pollack and cod. Consumption of juvenile salmon by nearshore benthic fish and herring appeared to increase in early June (Table 3). We observed schools of herring targeting on juvenile salmon during night surveys of some study sites in early June. Bakshtanskiy (1964, 1965) concluded that predation by herring largely determined survival of juvenile pink and chum salmon in the Barents Sea and White Sea. Predation by herring and pollock on juvenile salmon has also been observed in Alaska (Thorsteinson 1962, Armstrong and Winslow 1968).

Mean catch per net set was relatively low for age 3+ pollock sampled in the upper 50 m of the water column in 1996 compared with the previous two years. In early May, the abundance of large calanoid copepods in vertical net tows was relatively high, yet the percent of pollock diets comprised of large calanoid copepods was only about 30% (Figure 4). In 1994, consumption of large copepods and pollock catches in the 0-50 m layer declined during June (Willette et al. 1995b). The decline in consumption of large copepods in June coincided with a decline in the biomass of late-stage *Neocalanus spp.* in the upper 50 m of the water column (Cooney 1995). It appears that age 3+ pollock filter feed on large calanoid copepods (Yoshida 1994). Shifts between particulate and filter feeding modes are likely related to the relative profitability of each strategy, which is largely determined by prey size and density (Crowder 1985). Pollock likely filter feed in relatively high density layers of large calanoid copepods. Perhaps the density of copepods in these layers was largely below the threshold at which filter feeding becomes profitable for age 3+ pollock. Further, analyses of these data are needed to explore the possible causes for these observations.

Mean catch per net set of herring and age 1-2 pollock tended to increase from May to June in 1996. Rogers et al. (1986) noted a substantial seasonal increase in fish species diversity and density in Prince William Sound. In winter, fish distributions shifted further offshore and deeper in the water column (Rogers et al. 1986). Seasonal migrations of fish into deeper water in winter and shallow water in summer are well known (Trout 1957, Alverson 1960, Jean 1964, Heeseen 1983). These seasonal shifts in distribution may be related to temperature, light or food abundance (Laevastu and Hela 1970). Seasonal changes in the vertical distribution and activity patterns of cod have been related to seasonal stratification of the water column (Clark and Green 1990). In the present study, a more detailed analysis of fish distribution and water column structure is needed.

Feasibility studies on sonic tagging of age 3+ pollock suggest that this technique may be used effectively for behavioral studies. However, few conclusions should be drawn about pollock behavior from this one experiment because of questions about tag effect. In the present study, tags were inserted into the fishes stomach. This method of tagging may have caused mortality or tag regurgitation. In FY97, net pen studies will be conducted prior to the field season to evaluate mortality and behavioral effects associated with placement of the tag in the stomach, external attachment of the tag and surgical placement in the body cavity. Results from this work should enable us to minimize mortality and behavioral effects of tagging in future field studies.

Feasibility studies on the use of underwater video cameras to estimate relative abundance of juvenile salmon and their predators provided mixed results. The technique provided useful information about diel changes in the relative abundance of juvenile salmon in nearshore habitats. Video observations clearly indicated that juvenile salmon moved inshore at night (Figure 5). Results from shoreline surveys conducted every three hours throughout the night indicated the same behavior. It seems likely that this behavior is related to avoidance of predators in offshore waters. Fixed-uplooking video cameras may not be a practical method for estimating the relative abundance of potential predators. In the present study, potential predators were within the field of view of the cameras only .01% of the time. In addition, species were difficult to identify due to back lighting of targets. In FY97, we will examine the feasibility of towing underwater cameras along fixed transects to examine relative abundance of potential predators and predator behavior.

Conclusions:

1. Dolly varden trout, age 1-2 pollock, Pacific cod, and tomcod appeared to be important predators on juvenile salmon in nearshore habitats in 1996.

2. Abundance of age 3+ pollock in the upper 50 m of the water column was relatively low in 1996 compared with the previous two years, and large calanoid copepods were not the most important component of the diet of age 3+ pollock during the spring bloom period.

3. Sonic tagging of age 3+ pollock appears to be an effective method for studying the behavior of these fish, but further evaluation of tagging methods is required.

4. Juvenile pink salmon migrated inshore at night apparently to avoid predators in offshore waters of the passages.

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We would like to thank the staff of the Alaska Department of Fish and Game, Prince William Sound Science Center, and University of Alaska Fairbanks who endured difficult field conditions to obtain the samples needed for this study. The staff of the Prince William Sound Aquaculture Corporation was always very helpful when we needed logistical support in the western sound. This project would not have been possible without the charter vessel captains and crew who provided their equipment, assistance, and expertise.

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Table 1: Dates and sites where sampling was conducted in nearshore habitats in northwestern Prince William Sound. See figure 1 for locations of sampling areas.

Year	Area	Dates Sampled
1995	501	May 3, May 11, May 30
	502	May 17, June 5
	504	June 9
	505	June 11
	506	May 5, May 15, June 8
	509	June 13
	525	May 8, May 13, June 3
	526	May 9
1996	501	May 3, May 6, June 5
	502	May 4, May 7, May 24, June 1
	525	May 5, May 8, May 19, May 23, June 2, June 8
	504	May 25, June 6
	506	May 20, June 7
	586	May 21, June 3
	587	May 22, June 4

Table 2: Mean catch per net set for various fish taxonomic groups in nearshore habitats in western Prince William Sound during May and June .

Species	1995 n	1995 Mean	1995 SE	1996 n	1996 Mean	1996 SE
Sculpins, gunnels, etc.	165	1.4	0.06	86	1.6	0.11
Pacific cod, tomcod	123	1.8	0.15	122	3.4	0.35
Flatfish	16	1.1	0.10	8	1.0	0.00
Greenlings	247	1.9	0.08	155	2.6	0.17
Rockfish	147	3.4	0.42			0.83
Herring	23	6.4	3.52	130	87.8	36.90
Pollock	77	14.4	5.58	63	5.7	1.44
Adult Salmon	9	1.5	0.29	30	2.5	0.58
Sandlance, capelin	9	6.6	3.21	1	1.0	-
Dolly Varden	43	1.9	0.25	48	4.2	0.76
Squid	1	1.0	-	15	1.6	0.36

Table 3: Mean percent of diet comprised of juvenile salmon for several fish taxonomic groups during three time periods in northwest Prince William Sound, 1996. Benthic fishes include various species of sculpin and greenlings. Statistical test for changes in the mean diet percentage comprised of juvenile salmon among time periods. All specimens included in the analysis.

Date	Pacific Herring	Pacific Cod	Pacific Tomcod	Pollock (age 1-2)	Pollock (age 3+)	Dolly Varden	Benthic Fishes
5/3 - 5/9	.19	14.68	25.00	20.33	1.21	-	.39
5/19-5/26	.60	15.16	25.54	11.56	1.61	65.69	0
6/1 - 6/9	8.31	24.12	14.52	9.42	1.50	28.59	5.70
P-value	.043	.634	.638	.556	.937	.027	.057

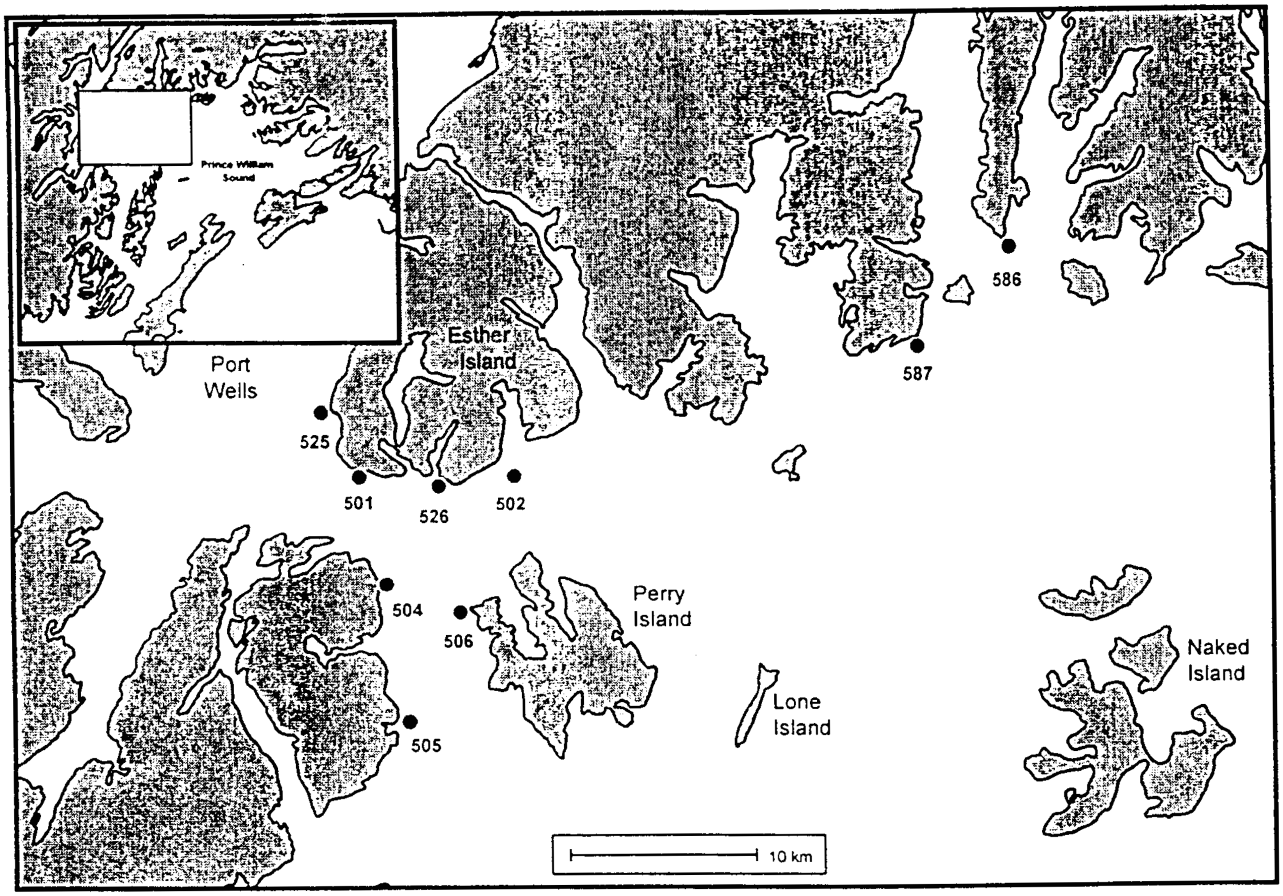

Figure 1: Study sites sampled in northwestern in Prince William Sound, 1996.

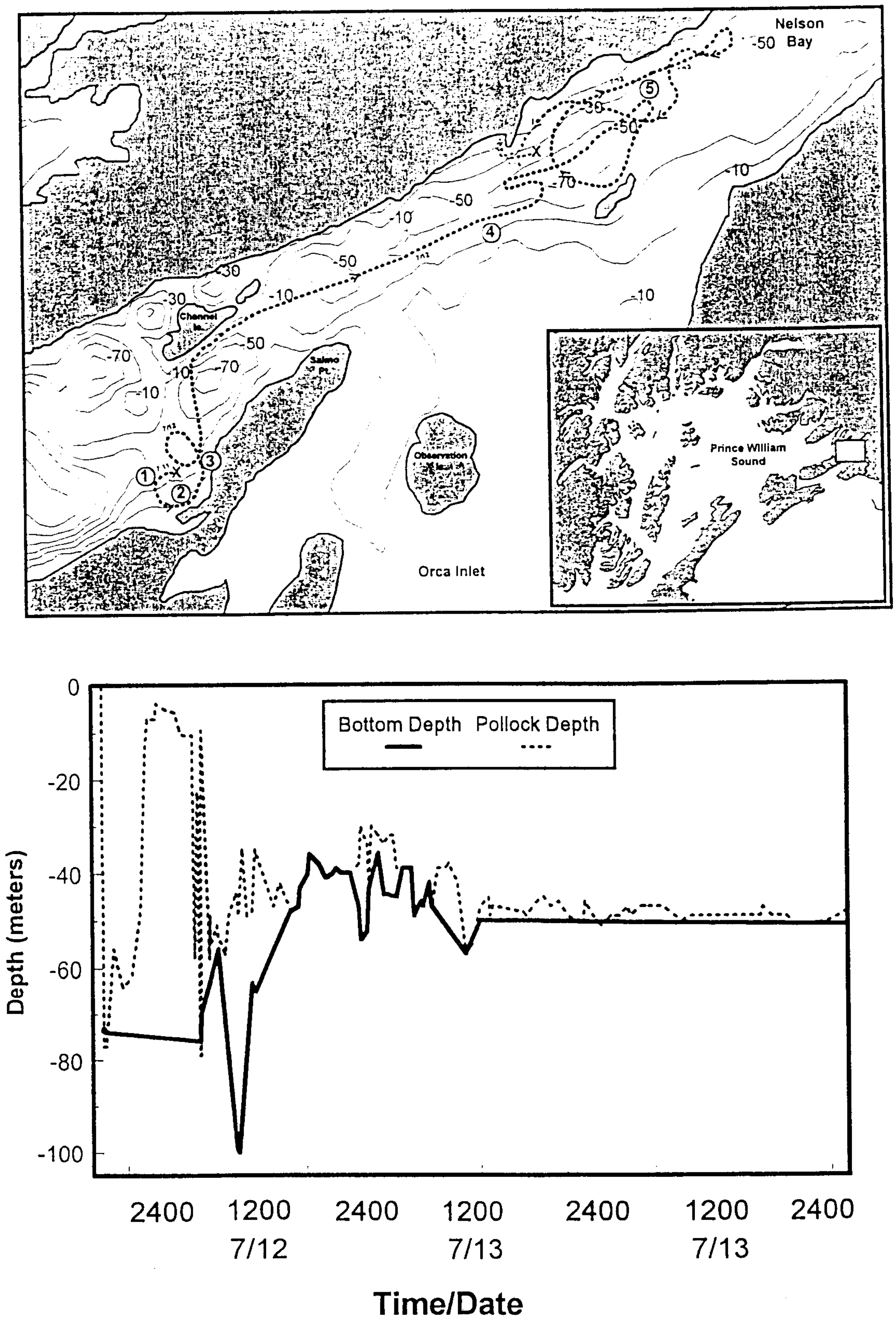

Figure 2: (a) Horizontal and (b) vertical movements of age 3+ walleye pollock sonic tagged in July, 1996.

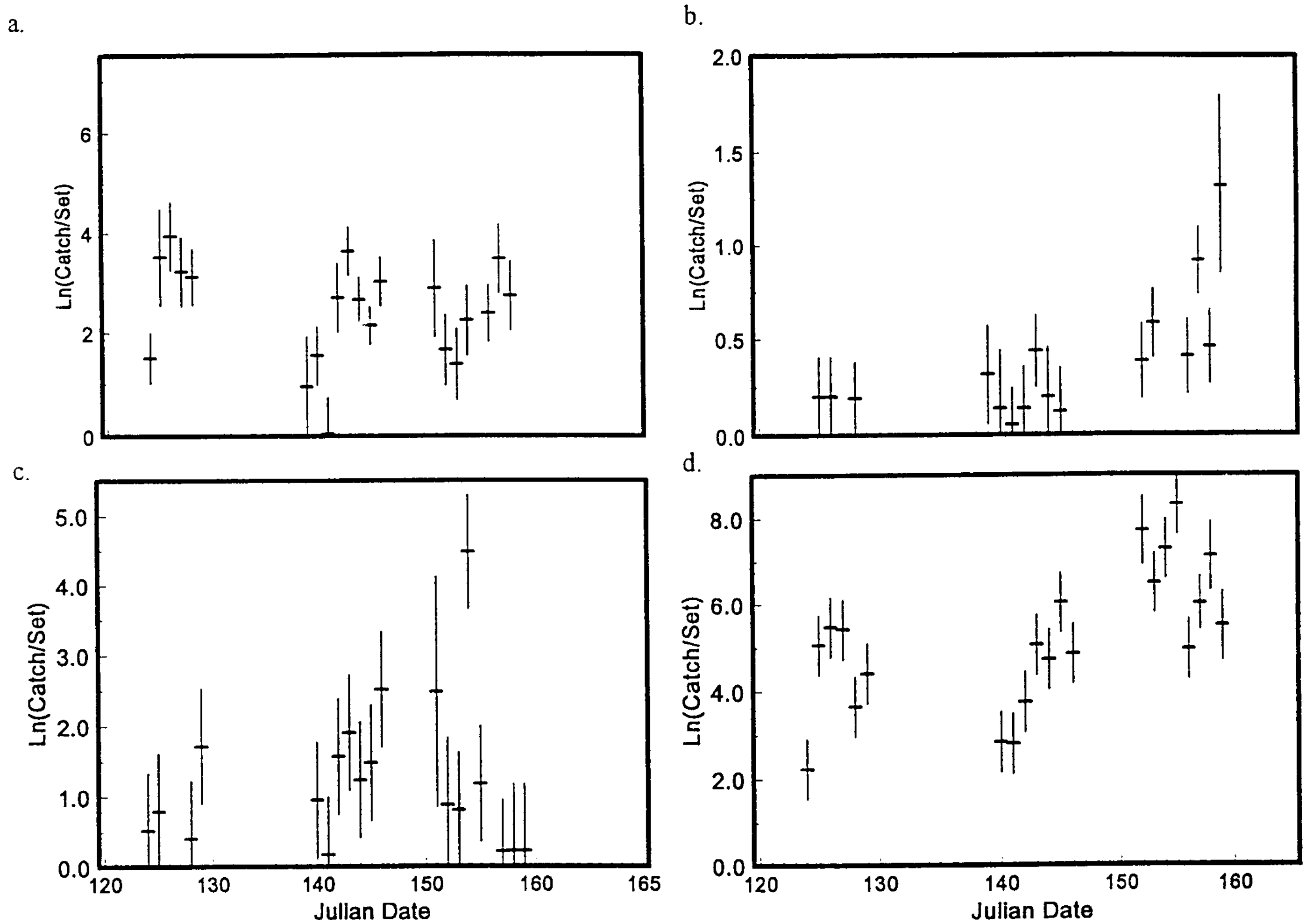

Figure 3: Mean catch per net set for (a) age 3+ pollock, (b) age 1-2 pollock, (c) herring and (d) all age-0 fishes in northwestern Prince William Sound, May-June 1996.

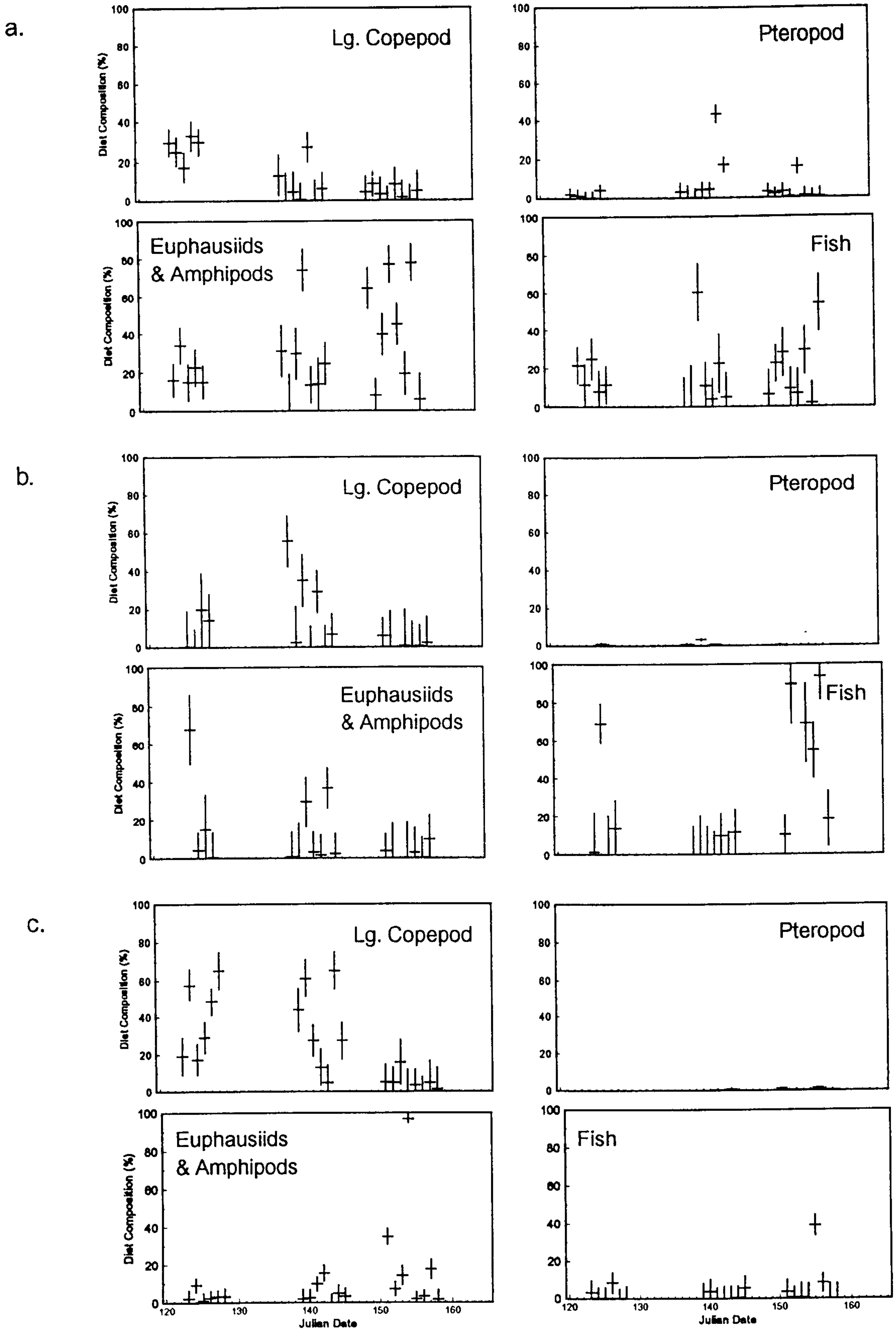

Figure 4: Diet composition of (a) age 3+ pollock, (b) age 1-2 pollock, (c) herring in northwestern Prince William Sound, May-June 1996.

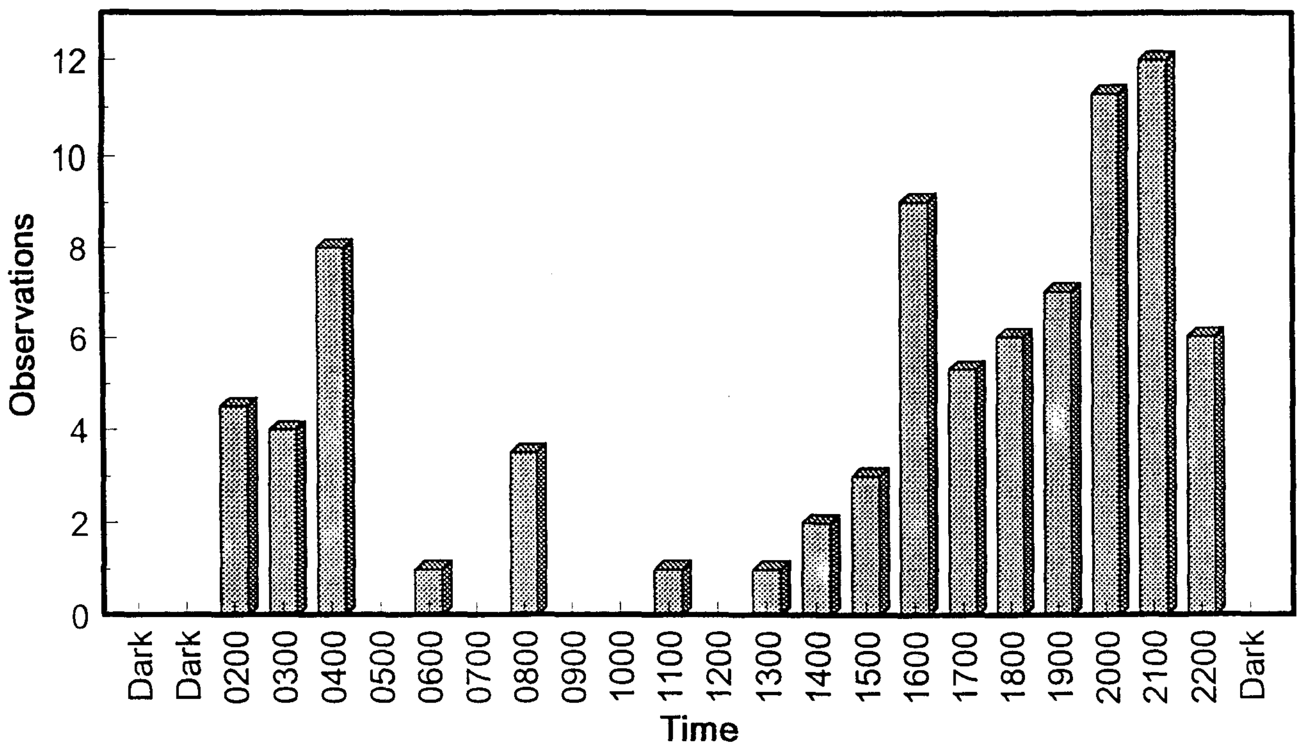

Figure 5: Estimates of relative abundance of juvenile salmon from fixed-uplooking video cameras in nearshore habitats of western in Prince William Sound, 1996.

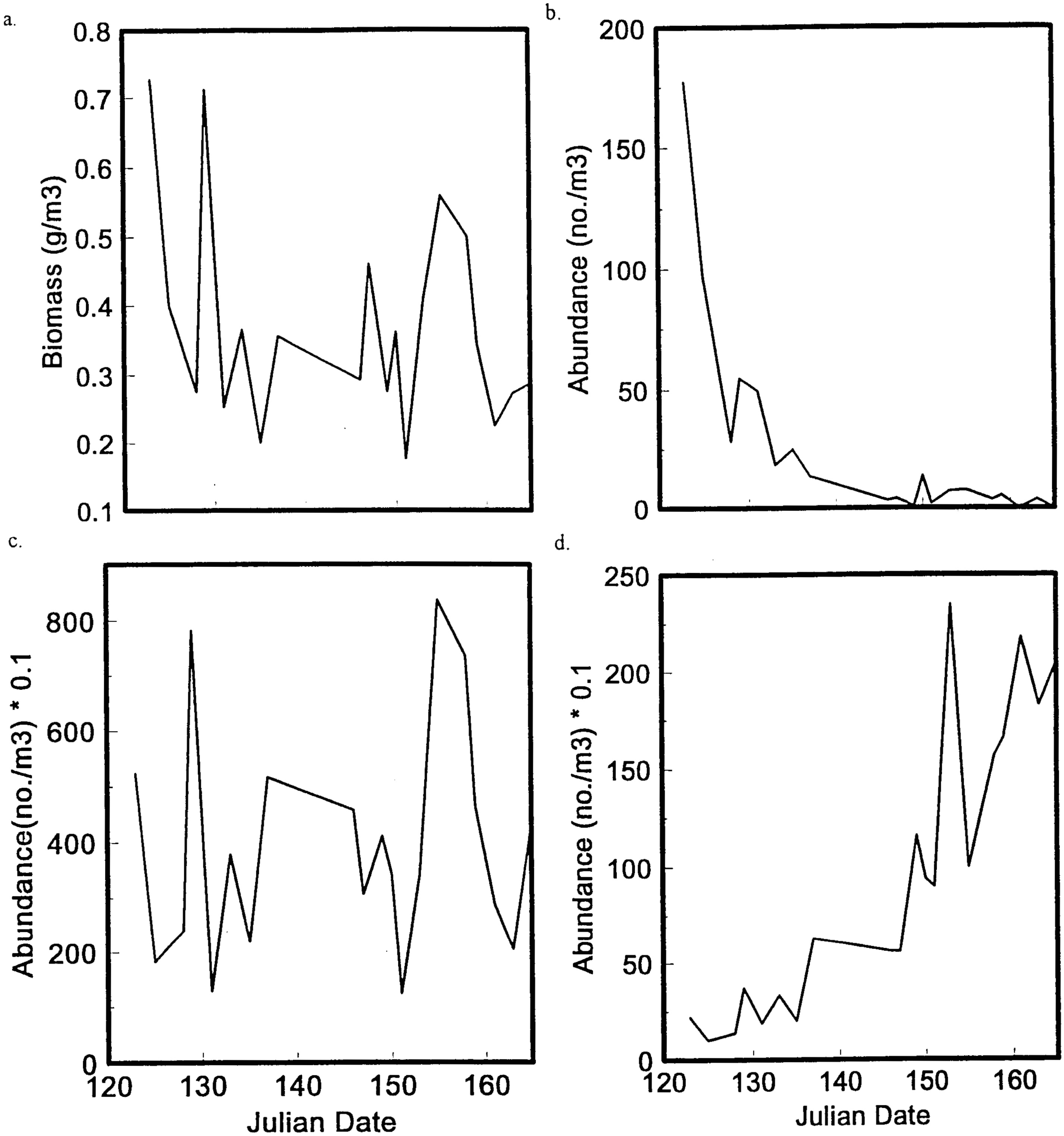

Figure 6: (a) Total zooplankton biomass and abundance (no./m3) of (b)large calanoid copepods, (c) small calanoid copepods, and (c) other zooplankters in nearshore habitats of northwestern Prince William Sound, May-June 1996.

a.

b.

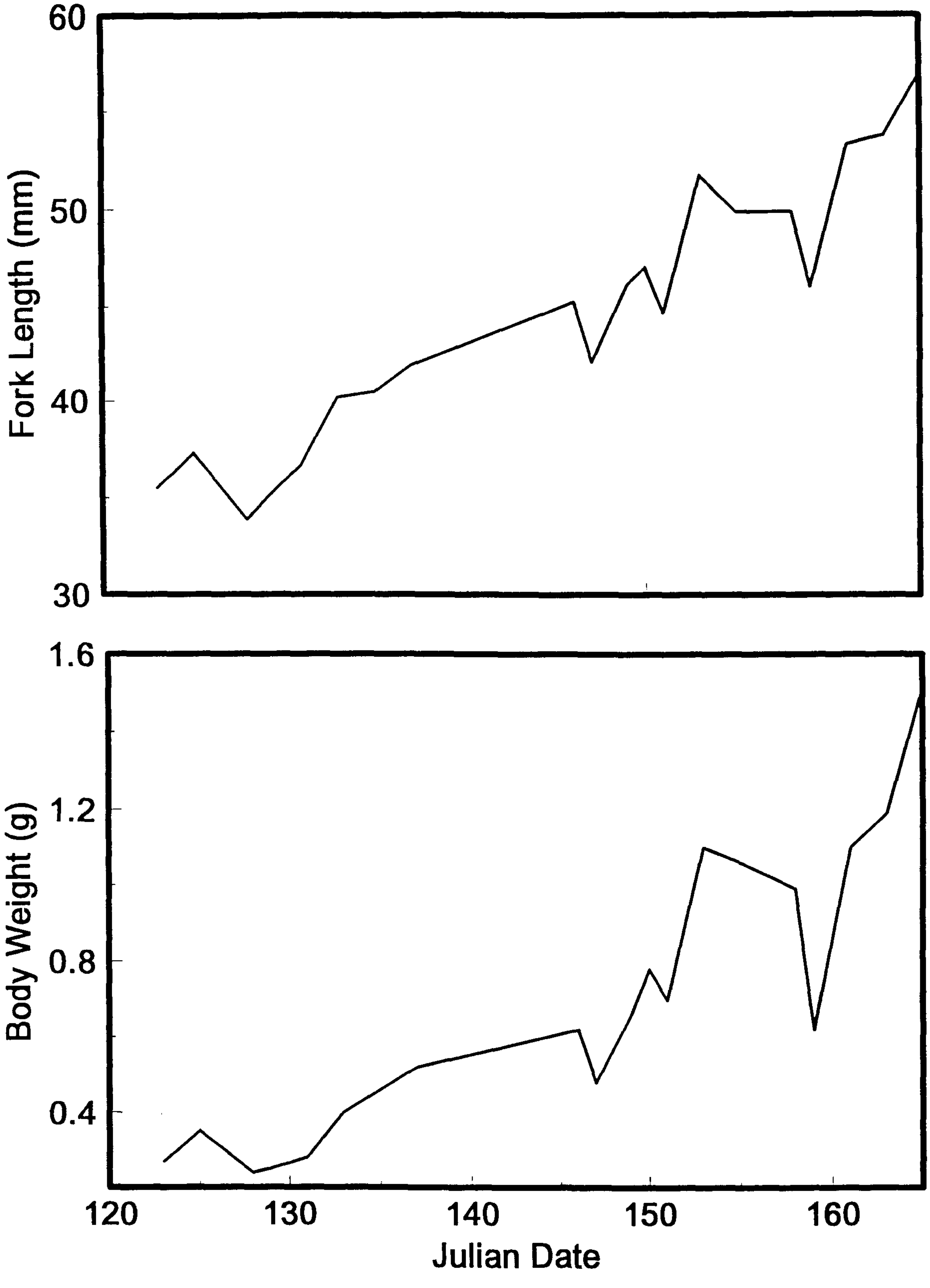

Figure 7: (a) Fork length and (b) body weight of juvenile pink salmon in nearshore habitats of northwestern Prince William Sound, May-June 1996.

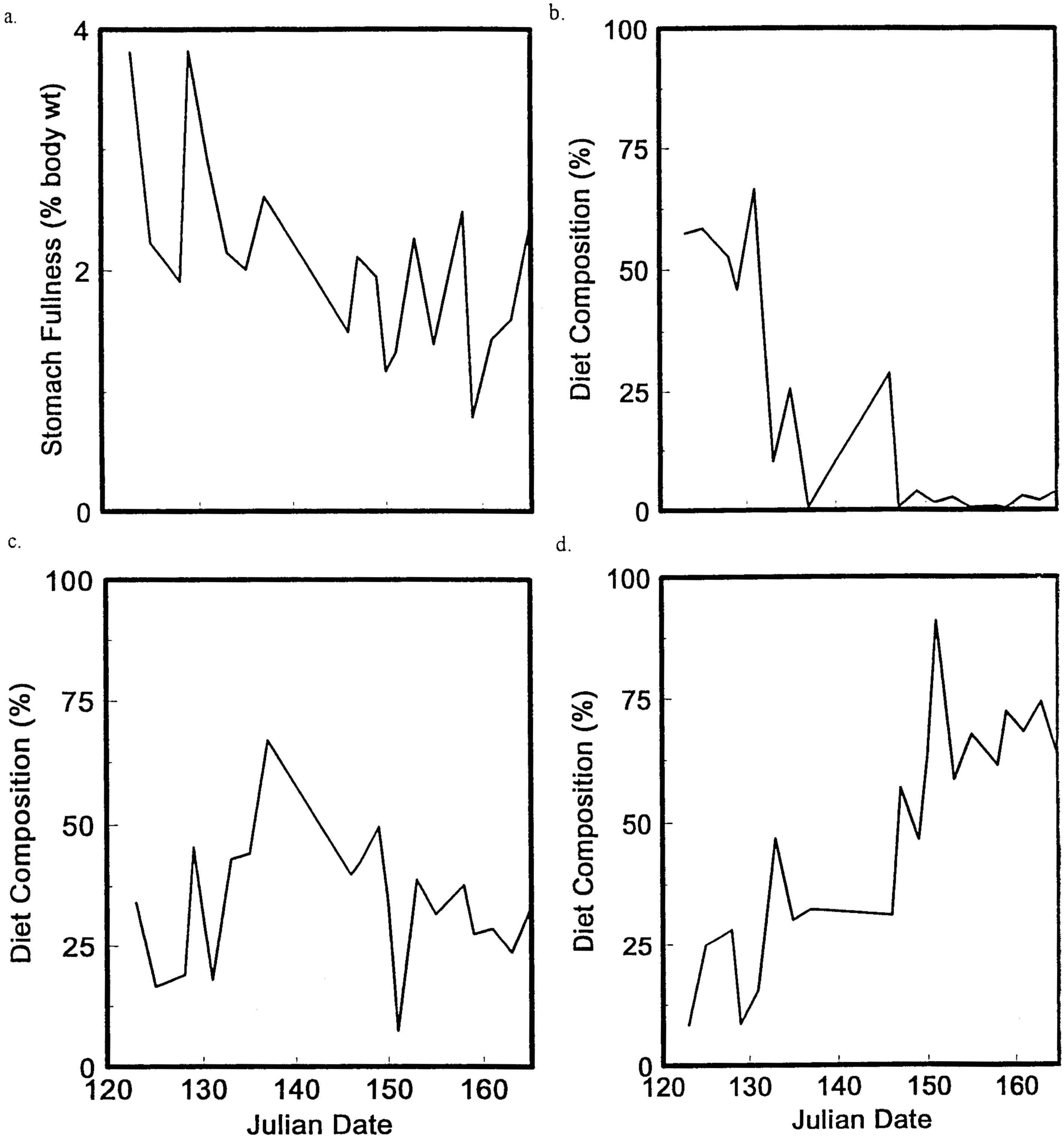

Figure 8: (a) Stomach fullness and the percent of total stomach contents weight comprised of (b) large calanoid copepods, (c) small calanoid copepods, and (d) other zooplankters for juvenile pink salmon in nearshore habitats of northwestern Prince William Sound, May-June 1996.