Aspects of the Life History and Ecology of the Pacific Pomfret *Brama japonica* During Winter Occupation of the Subtropical Frontal Zone

by

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I. ABSTRACT

One of the most widely distributed and abundant nektonic animals in the epipelagic North Pacific Ocean is the Pacific pomfret *Brama japonica*. We present various ecological and life history aspects of *B. japonica* based on 148 larval and juvenile specimens collected with a midwater trawl at 8 locations north of the Hawaiian Islands near the Subtropical Frontal Zone (STFZ). Most *B. japonica* were caught within the mixed layer in water temperatures of 17.5°-19.8°C; their distribution was limited to the south by the 21°C isotherm. Satellite data depicting the location of the STFZ, in conjunction with catch data, indicate that larval and juvenile *B. japonica* were typically distributed to the north of the Subtropical Front. Ages and growth rates of 32 larvae and juveniles were determined through analysis of otolith microstructures: Estimated ages were 1-2 months, and estimated growth rate was 0.353 mm d^{-1} for 11-24 mm standard length fish and hatching dates based on back-calculated age estimates were 2-30 January 1991. An examination of the feeding habits of pomfrets caught by driftnet near the STFZ revealed that most of the stomachs were empty; hyperiid amphipods along with other unidentified crustaceans were predominant in the stomachs that contained prey.

II. INTRODUCTION

Pacific pomfret *Brama japonica* are widely distributed in oceanic waters across the North Pacific approximately between 25° and 50°N latitude (Shimazaki and Nakamura 1981). As a predominant component of the incidental bycatch of the high seas squid driftnet fishery (second only to the target species in total biomass; INPFC 1991), *B. japonica* are considered to be among fishes with low economic value and are generally discarded when caught. Historically, *B. japonica* have drawn attention as an underutilized but promising fishery resource (Hitz and French 1965; Barnett and Teeny 1981).

Brama japonica, like the flying squid *Ommastrephes bartrami* and other species of the North Pacific Transition Zone (NPTZ), migrate northward during summer months to feed along the Subarctic Frontal Zone (SAFZ). During the fall, *B. japonica* undergo a rapid southward migration towards the Subtropical Frontal Zone (STFZ), where spawning is hypothesized to occur during winter through early spring (Shimazaki and Nakamura 1981; Yoon and Shimazaki 1981) (Fig. 1).

Most knowledge pertaining to the life history and ecology of *B. japonica* has been based upon catch data and samples collected with driftnets during the summer feeding period near the Subarctic Boundary (Machidori and Nakamura 1971; Shimazaki and Nakamura 1981; Wada and Murata 1985; Shimazaki 1989). Limited information is available regarding the distribution, ecology, and life history of *B. japonica* during their winter and spring occupation of the STFZ. In this paper, we focus on the biology of *B. japonica* occupying the STFZ during winter. Preliminary results are presented on the ageing and distribution of the larvae and juveniles and the feeding ecology of the adults.

III. MATERIALS AND METHODS

1. Larval and Juvenile Collection

During 25 February-21 March 1991, 40 tows with a modified pelagic Cobb trawl were conducted aboard the NOAA ship *Townsend Cromwell* in waters around the Hawaiian Archipelago (Fig. 1).

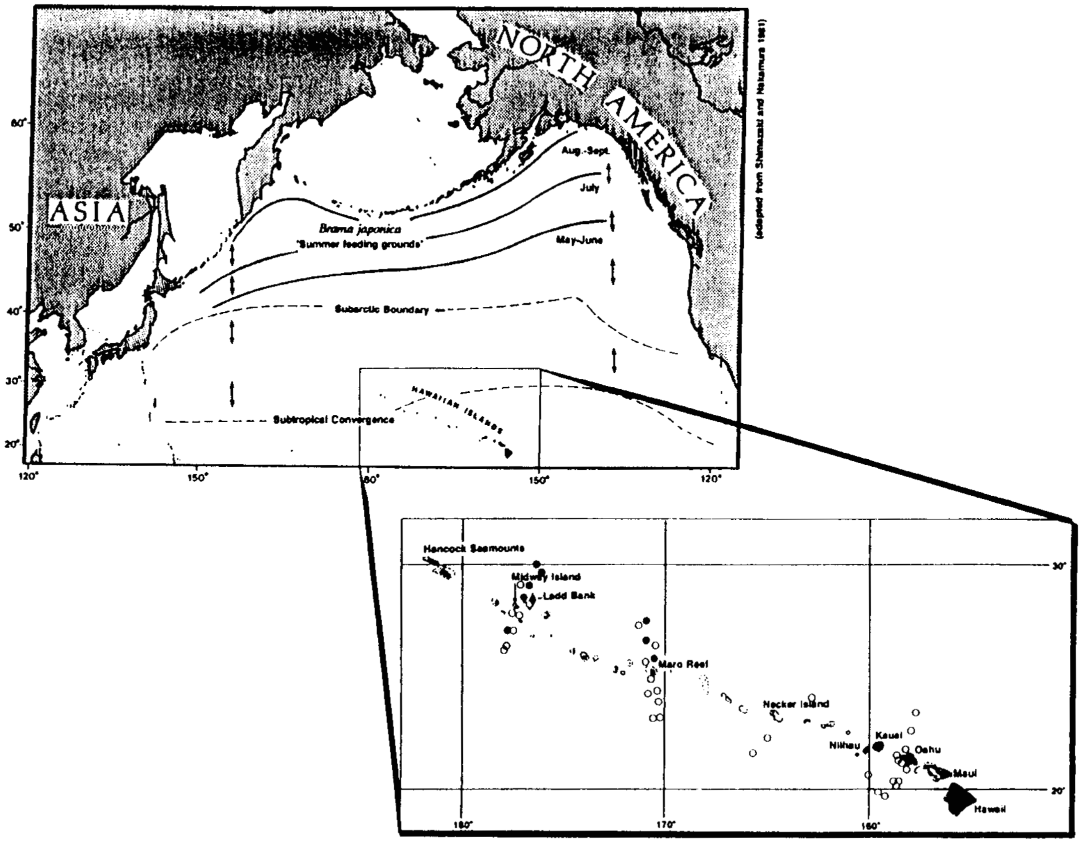

Fig. 1. *Brama japonica* seasonal distribution and collection locations of early life stages. Solid circles indicate positive midwater trawl tows, winter 1991; open circles indicate negative midwater tows; solid diamond indicates the capture location of two large (64.6 and 66.4 mm standard length) juveniles at Ladd Bank, April 1980.

The trawl is a basic dual warp midwater net, with a square mouth opening of approximately 140 m^2 when fishing (Wyllie Eche-verria *et al.* 1990; Lenarz *et al.* 1991) and is equipped with a cod-end liner constructed of 3.2 mm (1/8 in) knotless nylon delta mesh. During daylight hours, oblique tows targeted waters from the surface to 80 m depth, whereas at night, a horizontal tow in the upper 20 m was made by submerging the net just below the surface. All samples were frozen upon collection and returned to the laboratory for processing where late-stage larval and juvenile *B. japonica* were sorted and identified.

2. Satellite Oceanographic Observations

Satellite data were analyzed to characterize the mesoscale patterns of water masses and fronts in relation to the distribution of larval and juvenile *B. japonica*. Sea surface temperature (SST) measurements from NOAA-11 Advanced Very High Resolution Radiometer (AVHRR) images were obtained from satellite passes archived at the University of Hawaii's satellite oceanography laboratory. The SST measurements were integrated over 1.0 km^2, the area resolved by a single pixel on an AVHRR image; the accuracy of the SSTs measured by the NOAA-11 AVHRR was ±0.2°C.

3. Larval and Juvenile Age and Growth

Otoliths from early stages of *B. japonica* caught in Cobb trawls 204 km north of Maro Reef on 5 March 1991 (Fig. 1) were used for age determination. *Brama japonica* sorted from the trawl samples were fixed in 95% ethanol. Standard lengths (SL) of larvae from a broad size range were measured to the nearest 0.1 mm with an ocular micrometer and stereomicroscope. Both sagittal otoliths were extracted and mounted on microscope slides in clear resin (Eukitt). Thin sections in the sagittal plane were prepared following procedures outlined in Boehlert and Yoklavich (1985). Microstructural examinations were made with a compound microscope with polarized transmitted light at magnifications from 600-1500x (Fig. 2A). A conspicuous core area (Fig. 2B) was surrounded with a dark band. The radius of the core was 11-14 μm ($\bar{x} =$ 12.7 μm, $n = 25$) and was postulated to be a hatching mark. Growth increments were composed of alternating light and dark bands and were counted from the perimeter of the core to the otolith edge. Increments were counted by one observer at two separate reading sessions and averaged for a mean increment value. A linear model was fitted to the length-at-age data to describe larval and juvenile growth.

4. Feeding Ecology

Stomachs were examined from 76 adult *B. japonica* captured by large mesh (180 mm) surface gillnet aboard the research vessel *Shin-riasu maru*. Forty-four of the stomachs were extracted and frozen at sea from fish captured in the general vicinity of 30°N latitude and 170°E longitude on 18-22 January 1991. The remaining 32 were taken from fish captured and frozen whole at about 30°N latitude and 150°W longitude on 10-15 February 1991; stomachs were extracted in the laboratory. All of the *B. japonica* were sampled from driftnet sets deployed during 1500 and 1600 h and retrieved between 0000 and 0600 h. Samples were 39.0-48.3 cm fork length (FL) ($\bar{L} = 44.7$, SD = 3.4).

Procedures for examining the stomachs were similar to those employed by Seki and Harrison (1989). Briefly, stomachs were first examined for the presence of food items; empty stomachs were noted and discarded. Food samples were sorted, counted, and identified to lowest practical taxon. Sorted prey items were blotted dry, and wet weights were measured to the nearest 0.1 g. Values of prey items were assessed by using percent of the index of relative importance (IRI) values, modified from Pinkas *et al.* (1971), which incorporates percentage by number (N), weight (W), and frequency of occurrence (F): IRI = %F(%N + %W).

IV. RESULTS AND DISCUSSION

1. Larval and Juvenile Distribution

Brama japonica at early ontogenetic stages, including eggs, larvae, and juveniles, have been reported from single localities in the central North Pacific by Mead (1972); Loeb (1979a, b); and Seki and Mundy (1991). Our collections of larvae and juveniles are from a broad sampling range, providing insight into the vertical and spatial distribution of early life stages of *B. japonica* and consequently helping delineate spawning grounds and seasons of the species.

A total of 148 larval and juvenile *B. japonica* (Fig. 3A), from 9.8 to 34.0 mm SL ($\bar{L} = 14.2$, SD = 3.2), were collected from 8 locations (Table 1). Although sampling was conducted north and south through much of the Hawaiian Archipelago, all but one of the *B. japonica* were collected from stations 28, 113, and 204 km north of the 183 m (100 fm) contour at Midway Islands and Maro Reef. The SSTs at these stations typically were 17.5°-19.8°C, with the mixed layer typically extending to about 100 m. No *B. japonica* were captured at any stations south of Maro Reef (ca. 25°30'N) where surface temperatures exceeded 21°C.

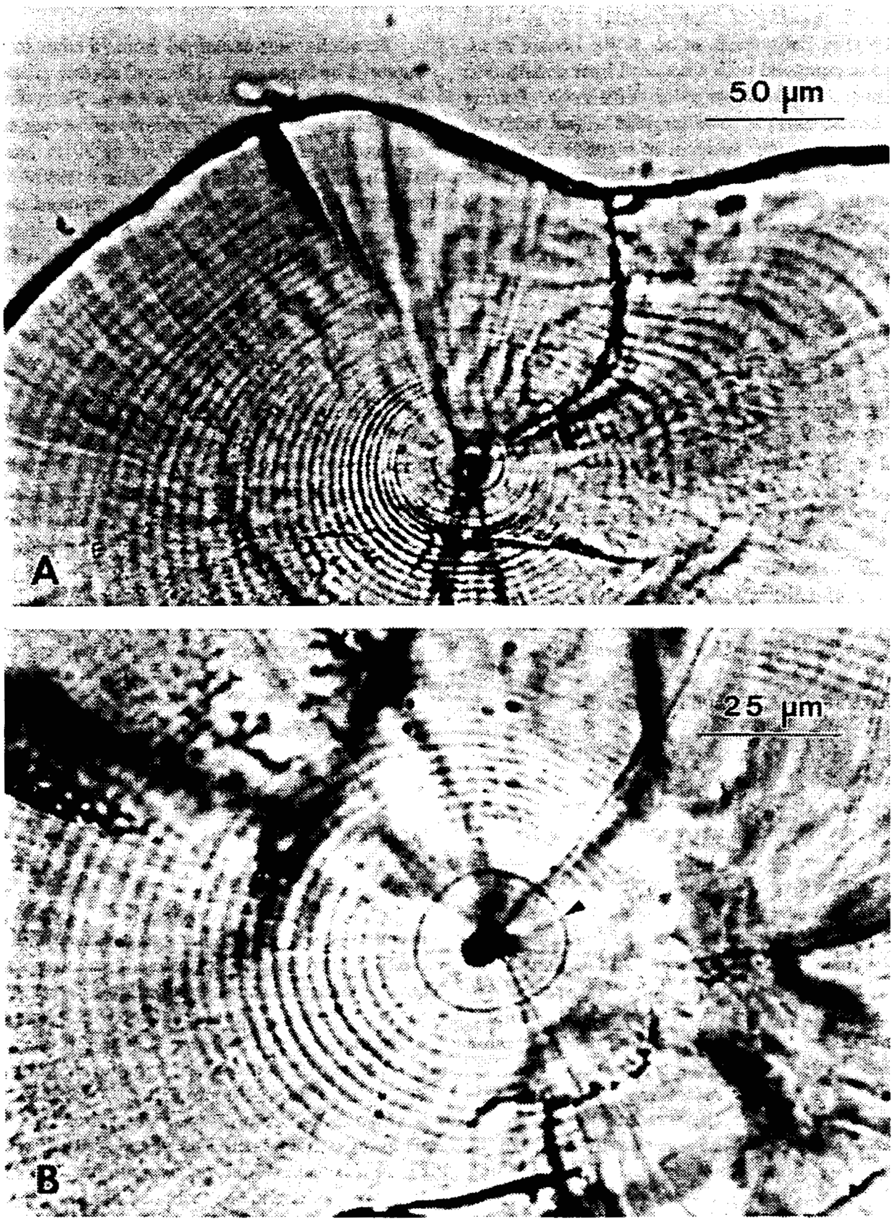

Fig. 2. Light micrographs of sagittal sections of otoliths from larval *Brama japonica*. (A) Growth increments from a 12.3 mm standard length larva. Duplicate increment counts were 40 and 41. (B) Central core area (arrow) was separated by a well-defined, dark band from the outer zone.

Table 1. Collection data from positive tows for large larvae and juvenile *Brama japonica* captured during March 1991 in the vicinity of the Hawaiian Archipelago (SL = standard length, SST = sea surface temperature, N = number of specimens).

		Location (start)				
Day	Time(h)	Lat.(°N)	Long.(°W)	N	SL(mm)	SST(°C)
4	1721-1930	25°50.9'	170°28.7'	11	10.6-11.8	19.8
5	0805-1009	27°27.8'	170°56.0'	48	10.8-34.0	17.7
6	1716-1912	30°03.2'	176°23.4'	12	11.8-22.0	17.5
7	0820-1006	28°32.2'	177°02.1'	24	9.8-16.5	18.4
8	1500-1712	27°04.1'	177°36.2'	1	13.1	21.3
9	1002-1158	29°12.0'	176°44.6'	49	10.4-21.0	18.0
9	2010-2214	29°42.0'	176°59.9'	2	12.3-12.5	18.0
11	1049-1245	26°44.2'	171°02.7'	1	11.2	18.2

This corroborates the reported southern distributional limit of *B. japonica* at the 21°C isotherm (Mead 1972).

Because of cloud contamination, most AVHRR images corresponding to the *B. japonica* capture dates (4-11 March 1991, Table 1) were unusable; however, a satellite pass on 3 March 1991 at 1500 h provided good coverage of the area where *B. japonica* were captured (Fig. 4). The difference in color in Figure 4 indicates a change in SST; clearly evident is the Subtropical Front between 26° and 28°N. The distribution of larval and juvenile *B. japonica* revealed that nearly all captures occurred in cold (17°-18°C) water to the north of the Subtropical Front. The AVHRR image from 3 March was likely representative of the mesoscale SST distributions, since shipboard SST measurements at capture locations of *B. japonica* corresponded well with SSTs derived from the AVHRR image.

Nearly all of the *B. japonica* were taken in oblique tows conducted during daylight hours; two individuals at one location were taken within 20 m of the surface in a night tow. However, since early stages of *B. japonica* have been taken in both day and night oblique tows near Southeast Hancock Seamount (29°47'N, 179°03'E) (Seki and Mundy 1991), the near absence of *B. japonica* in the night tows was likely an artifact of the surface sampling (0-20 m) rather than differences due to diel presence or absence in the water column. Early stages of *B. japonica* reportedly are vertically distributed through most of the mixed layer, with no evidence of diel migration (Seki and Mundy 1991).

The size at which the juveniles begin migration north is not known. Two large juvenile *B. japonica* (64.6 and 66.4 mm SL; 77.3 and 78.4 mm FL; Fig. 3B) were collected in a fish trap within 95 m of the surface at Ladd Bank (28°30'N, 176°38'W; Fig. 1) on 24 April 1980. By comparison, Shimazaki *et al.* (1981) captured juvenile *B. japonica* as small as 160 mm FL in NPTZ waters near the Subarctic Boundary using nonselective surface gillnets (20 mesh sizes of 25-233 mm stretched mesh). Unfortunately, most knowledge of pomfret distribution and ecology in the NPTZ is based on fish captured with surface gillnets, and little information is available with regard to the vertical distribution of pomfrets below the 10 m fishing depth of the driftnets where smaller juveniles may occur.

2. Larval and Juvenile Age and Growth

Otoliths were examined from 32 *B. japonica* ranging from 10.8 to 24.1 mm SL. Mean increment counts ranged from 34.5 for the youngest larva to 62.0 for the oldest juvenile. Mean difference between increment counts was 2.16 increments. No validation experiment was conducted to determine the periodicity of increment deposition; increments were assumed to be deposited on a daily basis, because daily increment deposition within postlarvae of related species, *Coryphaena hippurus* and *C. equiselis*, have been validated in the laboratory (Uchiyama *et al.* 1986).

Estimated length-at-age data (Fig. 5) were described as follows:

$$SL_t = -1.77 + 0.353t ,$$

where SL_t = standard length (mm) at age t. The coefficient of determination (r^2) was 0.70.

The growth model suggests that growth was 0.353 mm d^{-1} for fish of 11-24 mm SL. Growth rates

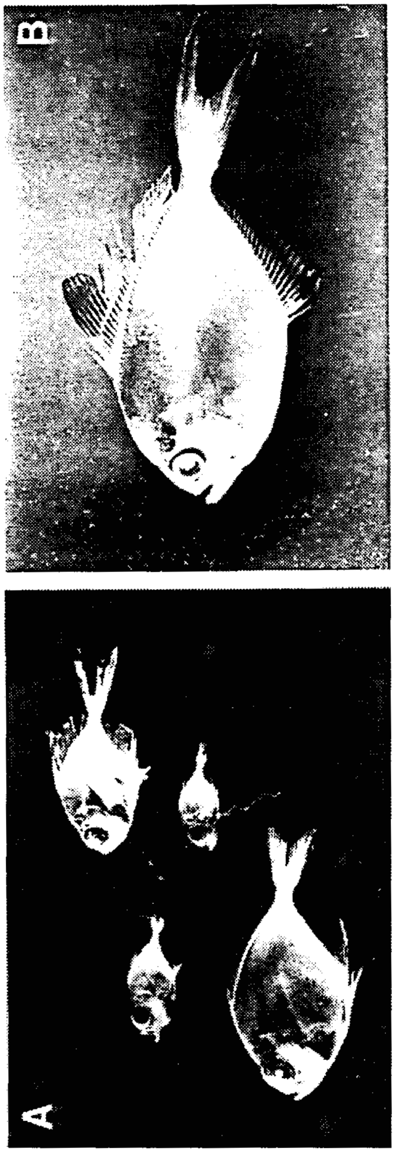

Fig. 3. Juvenile *Brama japonica*. (A) Juveniles of 15.1, 19.5, 26.0, and 38.6 mm standard length (SL) from prior collections at Southeast Hancock Seamount (29°47'N, 179°03'E; from Seki and Mundy 1991). (B) A 64.6 mm SL juvenile caught at Ladd Bank (28°30'N, 176°38'W).

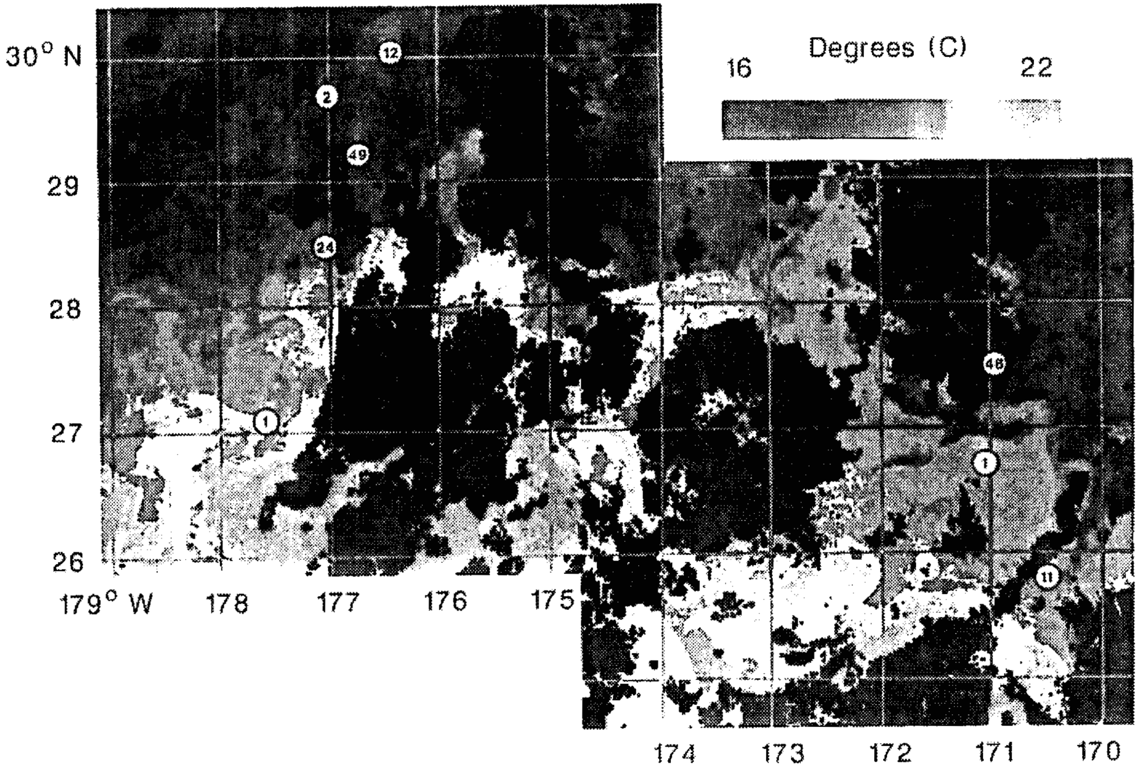

Fig. 4. NOAA 11 AVHRR image of sea surface temperature near the Northwestern Hawaiian Islands at 1500 h on 3 March 1991. Cold water is code in purple and blue and warm water in red; clouds appear black. Circles denote the locations where early stages of *Brama japonica* were captured; numbers indicate the number of individuals caught. (Satellite data provided by P. Flament, University of Hawaii, Department of Oceanography, Honolulu, HI 96822, U.S.A.)

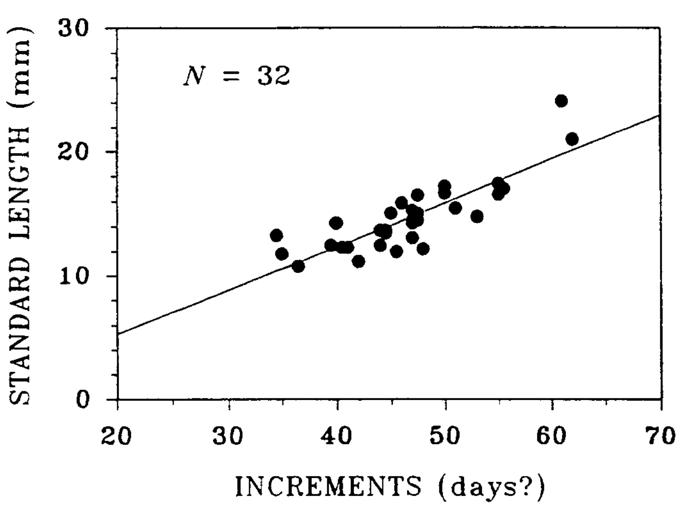

Fig. 5. **Relationship between standard length and number of growth increments in otoliths from 32 larval and juvenile *Brama japonica*.**

estimated using otolith microstructure from other perciform pelagic larvae and juveniles were 0.17 mm d^{-1} for 1.6-19 mm *Leiostomus xanthurus* (Warlen and Chester 1985), 0.17 mm d^{-1} for 2.5-6.0 mm *Trachurus symmetrics* (Hewitt *et al.* 1985), 0.33 mm d^{-1} for 3-11.2 mm *Thunnus maccoyii* (Jenkins and Davis 1990), and 1.02-1.07 mm d^{-1} for 12-48 mm *Coryphaena hippurus* and *C. equiselis* (Uchiyama *et al.* in prep.). While the comparison of growth in length is made difficult by the morphological diversity of larvae and the differences in environmental temperatures, the growth rate estimated for larval and juvenile *B. japonica* is within the range for related perciform species. The predicted fit of size at hatching was underestimated (-1.77 mm), as egg sizes in pomfrets range from 1.56 to 1.60 mm (Matarese *et al.* 1989) and larvae as small as 2.6 mm SL have been captured in the plankton (Seki and Mundy 1991). The size at hatching may have been underestimated either because of shrinkage of specimens in ethanol or the growth of early-stage larvae (preflexion) perhaps being slower than the modeled growth of larvae and juveniles.

Hatching date estimates, based on the ages of larvae and juveniles back calculated from the date of capture, ranged from 2 to 30 January 1991 when the first increment was assumed to be deposited at hatching. If the first increment was formed at a time after hatching (i.e., yolk-sac absorption, first feeding), then the actual hatching dates would precede the 2-30 January estimate. Hatching dates from our study correspond to those (November to May) of Shimazaki (1989), based on the back calculation of otolith increments from juveniles and adults and the period of reproduction (winter to early summer) predicted by Yoon and Shimazaki (1981).

3. Feeding Ecology

With regard to feeding ecology, only 14 (18.4%) of the 76 pomfret stomachs examined contained prey. No stomachs were replete from recent feeding, nor were any distended. Total weight of stomach contents ranged from 0.2 to 8.9 g ($\overline{W}$ = 3.5, SD = 3.1) and averaged 5.6 items (SD = 6.6). Unidentified crustaceans (%IRI = 47.8), hyperiid amphipods (%IRI = 19.3), and cephalopods (%IRI = 11.3) were the most important dietary components. Micronektonic fishes and pelagic tunicates represented the remainder of the identified stomach contents (Table 2). Debris items, such as plastic bag fragments and monofilament, also were found in the stomachs of three *B. japonica*, but were not considered prey (Table 2).

Little information is available on the feeding ecology of *B. japonica* during their southward winter migration. Qualitatively, Shimazaki and Nakamura (1981) reported that the diets of *B. japonica* caught in the subtropics during winter consisted of fish, squid, and other unidentified digested matter.

Table 2. Diet composition of 14 *Brama japonica* captured near the North Pacific Subtropical Frontal Zone, 18 January-16 February 1991 (IRI = index of relative importance).

Prey species	N	%N	Weight (g)	% Weight	Frequency	%F	IRI	%IRI
Crustacea	50	67.6	19.1	44.5	7	50.0	5605.0	47.8
Hyperiidae	33	44.6	7.3	17.0	4	28.6	1761.0	15.0
Platyscelidae	7	9.5	1.7	4.1	5	35.7	482.7	4.1
Phronimidae								
Phronima sedentaria	1	1.4	1.1	2.5*	1	7.1	27.5	0.2
Sergestidae	7	9.5	6.2	14.4	2	14.3	341.3	2.9
Unidentified crustacean remains	2	2.7	2.8	6.6	2	14.3	133.2	1.1
Cephalopoda	9	12.2	10.7	24.9	5	35.7	1324.5	11.3
Onychoteuthidae	4	5.4	7.1	16.6	1	7.1	157.2	1.3
Histioteuthidae	1	1.4	0.5	1.0	1	7.1	17.1	0.1
Octopoda	1	1.4	1.9	4.4	1	7.1	40.8	0.4
Unidentified teuthoid	3	4.1	1.2	2.8	3	21.4	147.8	1.3
Pisces	4	5.4	3.2	7.5	3	21.4	276.1	2.4
Stomiiformes	1	1.4	0.4	1.0	1	7.1	16.8	0.1
Gempylidae	1	1.4	2.2	5.2	1	7.1	46.4	0.4
Unidentified fishes	2	2.7	0.5	1.2	1	7.1	28.1	0.2
Tunicata	9	12.2	7.4	17.2	3	21.4	629.2	5.4
Salpidae	8	10.8	6.1	14.1	3	21.4	534.9	4.6
Pyrosomatidae	1	1.4	1.3	3.0	1	7.1	31.0	0.3
Unidentified remains	2	2.7	2.6	6.0	2	14.3	124.2	1.1
Plastic	3	----	5.0	----	3	21.4	----	----

*Includes "tunicate housing."

For *B. japonica* inhabiting the SAFZ waters during summer-fall, prior studies (Machidori and Nakamura 1971; Wada and Murata 1985; Kubodera and Shimazaki 1989; Shimazaki 1989) have reported that *B. japonica* feed on small pelagic fishes (sauries, sardines, myctophids, and juvenile mackerel) and small squids (gonatids and onychoteuthids). *Brama japonica* caught farther south during spring in the NPTZ feed on crustaceans and pteropods (Shimazaki and Nakamura 1981, Shimazaki 1989).

Shimazaki and Nakamura (1981) also reported high proportions of empty stomachs among *B. japonica* collected during winter (December-January) in the STFZ. The proportion of empty stomachs is comparatively much lower among *B. japonica* sampled near the Subarctic Boundary (Shimazaki and Nakamura 1981; Shimazaki 1989). Likewise, considerably fewer empty stomachs (46.2% were empty) have been found among pomfrets taken in the SAFZ during summer (Seki unpubl. data).

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