Title	Energy Transformations by a Blenny (Opisthocentrus ocellatus) Population of Usu Bay, Southern Hokkaido
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ance throughout the present study and for his permission to use hydrographic data including sea temperature and specific gravity measured at Usu Bay.

Materials and Methods

Area studies: Usu Bay (Fig. 1) located at the head of Uchiura Bay, along the coast of southern Hokkaido. It is about 140 m wide at the mouth and 600 m from the mouth to the head of the bay. The area of this bay is measured about $24.7 \times 10^4 m^2$ at mean tide level. An eelgrass bed, occupying about $4.2 \times 10^4 m^2$, is on a sand-mud flat in the middle of the bay. Mean water depth over the bed is 1.5–2 m and 0.5–1 m at high and low tide, respectively. The other eelgrass bed, occupying about $0.3 \times 10^4 m^2$, is located near the mouth of this bay. Sea temperature reaches its maximum (about 24°C) in late July, and its minimum (about 2°C) in late February. Specific gravity of surface water ranges from about 1.021 to 1.024, and is generally high in winter (Fig. 2).

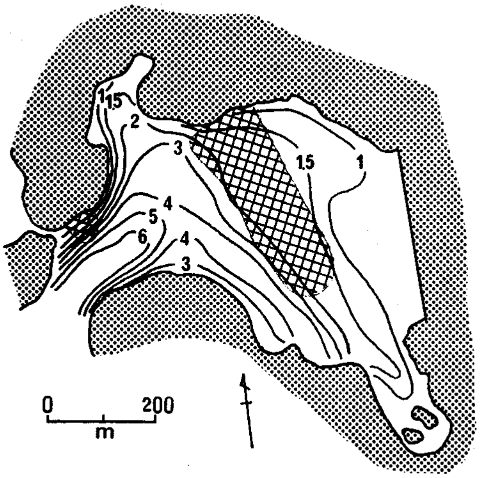

Fig. 1. Map of Usu Bay showing the location (indicated by meshy area) of the eelgrass beds at Usu Bay.

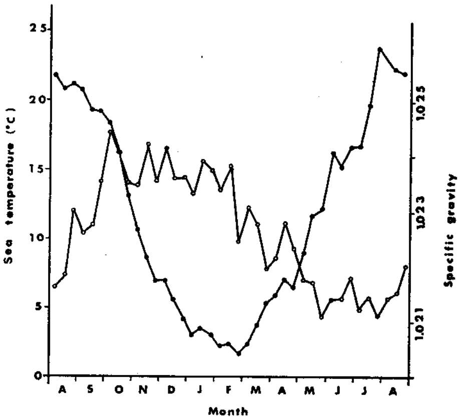

Fig. 2. Seasonal variations of surface sea temperature (solid circle) and specific gravity (open circle) in Usu Bay.

The eelgrass beds contain large numbers of juvenile and young fish, especially during spring to fall. The yearly abundance of fish in the eelgrass beds is shown in Figure 3. Twenty-four species of fish were found in this bay over the year, and they are divided into the following two categories according to their residing period in the eelgrass beds. The species of residents all year round; *Opisthocentrus ocellatus*, *Enedrias nebulosus* and *Pholidapus dybowskii*, and the members of seasonal residents (fishes which spend a definite season or a definite life stage); *Chaenogobius murorana*, *Sebastes schlegeli*, *Hexagrammos octogrammus*, *Myoxocephalus stelleri raninus*, *M. brandti* and *Liza haematocheila*, and all others. Of these species, it is obviously from Figure 3 that the blenny are the most abundant during the year.

Treatment and analysis of material: The present study is based on the bi-

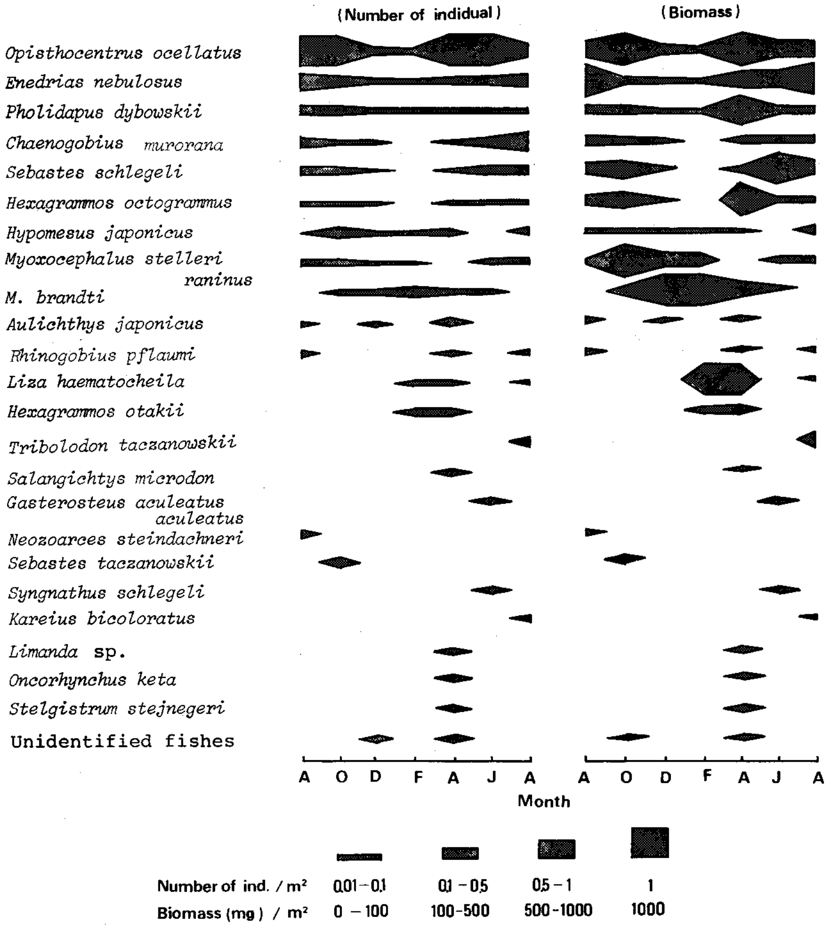

Fig. 3. Seasonal variations of fishes collected in the Usu Bay eelgrass beds. (Aug. 1976 to Aug. 1977).

monthly samples of the blenny taken from the eelgrass beds during from August 1976 to August 1977. The blenny in the eelgrass beds were sampled with a portable 17 m^2 purse seine, of 8 mm mesh nylon netting. A purse seine is designed to sample a known area of water by setting a net suspended over the surface prior to sampling. An average of five samples were taken, three at day and two at night, always at midtide.

Fish collected by this procedure were measured by their standard length, followed by the separation of gonadal tissue. After drying at 60°C for 3 days, dry weight of each tissue was weighed, and caloric contents were determined by means of a Nenken adiabatic bomb calorimeter and/or a Wet oxydation method derived from Karzinkin and Tarkovskaya[17]. Besides the samples for the above purpose, arbitrary samples of the blenny taken from the eelgrass beds were used for a description of the kinds and quantities of food found in the gut. The

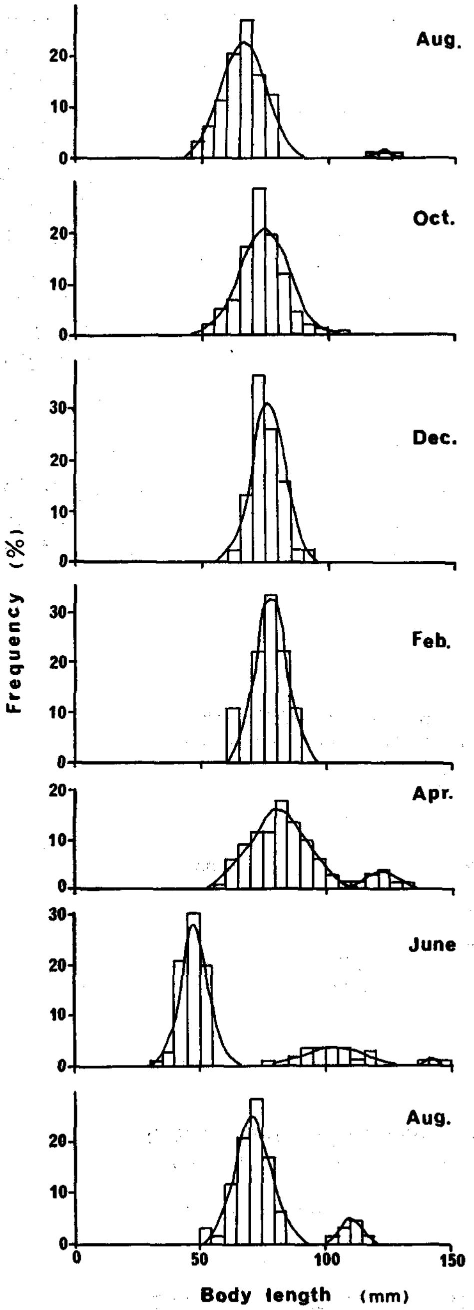

Fig. 4. Histogram showing the size frequency for the blenny population and several fitted normal curves calculated by the probability graph paper method.

composition of the gut contents were sorted according to the kinds of food ingested by the blenny. Dry weights were then obtained.

The feeding experiments were performed during April to October 1977 in aquaria, to which was applied a "recirculatory sea water system". The blenny which were brought into the laboratory aquaria became adapted to aquarium life and soon learned to recognize food when it was placed in the aquarium. Gammarid amphipods (mostly *Ampithoe* sp.) as food for the blenny were carefully handled, most of the water adhering on the body surface was removed by absorbent paper, then the wet weight weighed. The amount of food consumed was represented as the difference between the wet weight of gammarids at the beginning and ending of the experimental period. Faeces which settled on the bottom of the aquarium during the experimental period of every 24 hours, were siphoned out together with aquaria water, and filtered under suction through a filter paper whose dry weight had been weighed. The faeces weight was estimated as the difference between the dry weight of faeces with the filter paper and that of the filter paper alone.

The rates of oxygen consumption of the blenny were determined bimonthly over a wide range of fish size under the "open system". An oxycalorific equivalent of 4.83 cal ml^{-1} O_2[18] was used to convert oxygen consumption to energy units.

Results

Production rate

The size structure was estimated on the basis of body length distribution. The measurements of standard body length were divided into each group representing a range of 5 mm for the blenny. Then the frequency of each group was represented by percentage. The bimodal frequency distribution obtained was graphically analyzed by making use of a probability graph paper derived from Harding[19]. The frequency distribution of each group is represented in Figure 4 with several fitted normal curves which were calculated by such a procedure. It is possible to determine the growth rate of the mean body length of each of the size-groups and to estimate the size-group structure in percentage occupancy. Table 1 shows the results of the population size for the entire area of the bay, and the size-group structure based on the above percentage occupancy of each of the size-groups. It is generally agreed that the logarithm of an individual dry body weight (W) or of dry weight of gonad tissue (G) is linearly related to the logarithm of body length (L). These equations lead the dry weight for an individual body or for a gonad of mean length in each of the size-groups belonging to the population. The parameters of regression formulae are illustrated Table 2. The above equations were used to estimate the mean dry weight of individual body and of gonad tissue belonging to the various size-groups as a function of mean body length (Table 3). From the biomass of each size-group it is possible to estimate the product of the population size and the mean dry weight of body components of the individuals.

In general, the quantitative relations of metabolism of an animal population are represented as follows:

Table 1. *Population size (numbers per m^2) for Opisthocentrus living on the entire area of Usu Bay. Each roman number indicates size-group.*

Month	0	I	II	III
Aug.	—	1.09	—	0.03
Oct.	—	1.82	—	—
Dec.	—	0.44	—	—
Feb.	—	0.10	—	—
Apr.	—	1.36	0.17	—
June	0.94	0.29	0.02	—
Aug.	0.68	0.08	—	—

Table 2. *Body weight (mg) and gonad weight (mg) regression statistics at several body length (mm) for the blenny in the eelgrass beds.*

Month	$\log W = a \log L - b$		$\log G = a \log L - b$	
	a	b	a	b
Aug.	3.3694	−7.8041	16.2595	−74.4827
Oct.	3.0925	−6.7985	9.8531	−42.8991
Dec.	3.0588	−6.7681	8.3991	−36.6750
Feb.	2.2657	−3.4141	3.3455	−14.7638
Apr.	2.8616	−6.0400	2.3383	− 9.8364
June	3.3079	−7.6504	4.1167	−18.1942

Initial biomass + Consumption + Immigration = Egesta + Excreta + Respiration + Predation + Mortality + Yield + Emigration + Final biomass

Where, Consumption − (Egesta + Excreta + Respiration) = Growth

In the blenny population, the growth is divided into two parts; that is, body growth and gonad growth. The increase of the population is attributed to immigration and recruitment. The yield is an item without consideration. Consequently, the metabolic relation for the blenny population is replaced in the following equation:

Initial biomass + Body growth + Gonad growth + Immigration + Recruit = Mortality + Predation + Emigration + Gametes ejected + Final biomass

The magnitude for the individual growth increment is taken to be a positive value of the difference between the initial and final body weight multiplied by the arithmetical mean of the initial and final population size. If it is positive, the

Table 3. *Seasonal variations in the average dry weight (mg) and gonad weight (mg) per individual blenny. Roman numbers are the same as those shown in Table 1.*

Month	Body weight (mg)				Gonad weight (mg)			
	0	I	II	III	0	I	II	III
Aug.	—	557.1	—	4492.0	—	0.0	—	43.1
Oct.	—	681.5	—	—	—	0.6	—	—
Dec.	—	656.4	—	—	—	0.8	—	—
Feb.	—	633.4	—	—	—	0.8	—	—
Apr.	—	693.5	2233.7	—	—	1.6	4.1	—
June	170.9	2145.6	6339.8	—	0.0	2.4	9.2	—
Aug.	730.1	3483.7	—	—	0.0	7.3	—	—

Table 4. *Production structure for the blenny population. All data indicate dry weight (mg) per square meter. Each roman number is the same as those shown in Table 1.*

Duration	Items	0	I	II	III
Aug.–Oct.	Growth	—	181.9	—	—
	Immigration	—	452.3	—	—
	Emigration, Predation and Mortality	—	—	—	−136.1
Oct.–Dec.	Growth	—	−28.2	—	—
	Emigration, predation and Mortality	—	−924.0	—	—
Dec.–Feb.	Growth	—	−6.2	—	—
	Emigration, Predation and Mortality	—	−219.6	—	—
Feb.–Apr.	Growth	—	44.5	—	—
	Immigration	—	837.5	380.4	—
Apr.–June	Growth	—	1198.7	390.6	—
	Recruitment	160.6	—	—	—
	Emigration, Predation and Mortality	—	−1521.1	−644.0	—
June-Aug.	Growth	453.0	248.4	—	—
	Emigration, Predation and Mortality	−117.1	−592.1	−127.0	—

Table 5. *Caloric value (Kcal/g) for each size-group of the blenny population at different times of the year.*

Month		Size-group	Body	Gonad
1976	Aug.	I	5.39	6.64
		II	5.64	6.64
	Oct.	I	5.12	5.78
	Dec.	I	5.14	5.92
1977	Feb.	I	4.91	5.57
	Apr.	I	4.91	4.80
		II	4.62	4.80
	June	0	4.79	5.78
		I	5.39	5.78
		II	5.62	5.78
	Aug.	0	5.64	6.64
		I	5.91	6.64

Table 6. *Annual balance sheet for the blenny population living on the entire area of Usu Bay, from August 1976 to August 1977.*

Items	g/m^2/yr	Kcal/m^2/yr
CREDIT SIDE		
Initial biomass (Aug. 1976)	0.74	4.0
Growth	2.48	14.2
Recruitment	0.16	0.8
Immigration	1.67	8.2
DEBID SIDE		
Emigration, Predation and Mortality	4.28	22.8
Final biomass (Aug. 1977)	0.77	4.4

difference between the initial and final gonad weight multiplied by the arithmetrical mean of the initial and final population size corresponds to the gonad growth. If a negative value is obtained in the above computation, it is attributable to the magnitude for gametes ejected. If the difference between the initial and final population size mutiplied by the arithmetrical mean of the initial and final weight of body components is positive, it corresponds to the magnitude for immigrants and/or the newly born individuals. On the other hand, if it is negative, the above computation is taken to be the population loss attributed to mortality, emigration and predation.

The estimation of the population production of the blenny was made during a whole year, and the results were calculated as shown in Table 4. The production for the blenny population due to the growth increment occurs in the nine months from February through October. The increase of 0-size group between April and June was due to the recruitment members as the newly born individuals. From the bimonthly values for the calorific contents of each body component (Table 5) it was possible to provide the calorific contents of the same for every two-month period. The annual blance sheet of biological production for the blenny population is summarized in Table 6. The annual growth amounts to 14.2 Kcal m^{-2} $year^{-1}$ (or 2.48 g m^{-2} $year^{-1}$) and the recruitment of 0.8 Kcal m^{-2} $year^{-1}$ (or 0.16 g m^{-2} $year^{-1}$) contributes to the annual net production of 23.2 Kcal m^{-2} $year^{-1}$ (or 4.31 g m^{-2} $year^{-1}$). Since the loss of population which is attributed to emigration, predation and mortality, in this study, is not known separately, it is lumped together. The value of 22.8 Kcal m^{-2} $year^{-1}$ (or 4.28 g m^{-2} $year^{-1}$) corresponds to the above loss from the blenny population.

Energy flow of the blenny population

In general, it is well known that the logarithm of oxygen consumption, R, is linearly related to the logarithm of an individual dry weight, W. The exponential equation is $R=aW^b$, where a is a constant, and b is a regression coefficient. Figure 5 shows the oxygen consumption per unit time per animal plotted against dry weight on logarithmic scale. Although the regression coefficient showed no significant difference with season ($F_{(0.05)}=3.40>3.21=F_0$), there was clearly a seasonal change in the respiration rate over the whole range of animal sizes. When the constant a in the above regression formula was plotted to temperature (t), they fell approximately on a straight line. It is as follows: $a=0.0167\,t+0.2419$. So the value of expressing metabolic loss (R) as a function of temperature (t) and body weight (W) is obtained in the present study by combining the above two equations, thus

$$\log R=0.9789\log W+\log(0.0167\,t+0.2419)$$

This equation is used to estimate the respiration metabolism of the blenny population as a function of sea temperature (Fig. 2), dry body weight (Table 3) and population size (Table 1). The energy lost by metabolic activities for each two-month period was easily estimated from the indirect method of converting respiration rate into heat output by the application of an oxycalorific coefficient. There is 13.4 Kcal m^{-2} $year^{-1}$ for the blenny population on the eelgrass beds of Usu Bay.

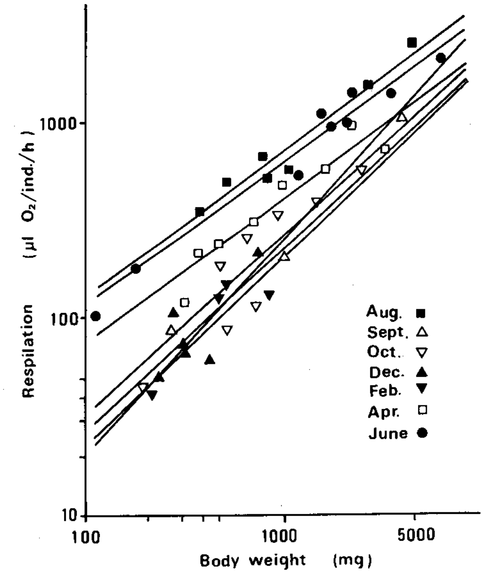

Fig. 5. Logarithmic plot of oxygen consumption against body weight of the blenny.

The composition of the stomach contents of the blenny collected from the eelgrass beds in Usu Bay is shown in Figure 6. This figure illustrates that the principal food of the blenny is small crustaceans which are living on the blades of

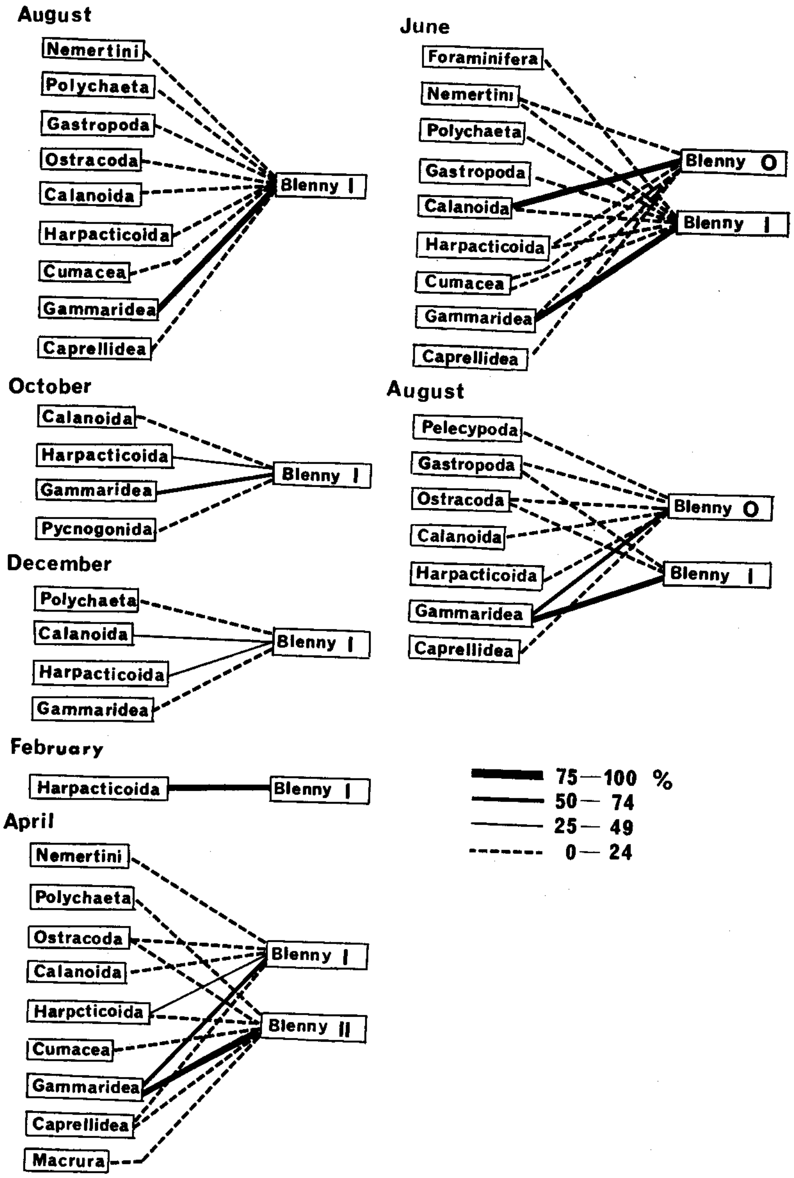

Fig. 6. Seasonal aspects of food chain in the Usu Bay eelgrass beds for the blenny population.

Zostera, such as gammarids, harpacticoids and calanoids. If the degree of preference of the blenny on the above categorized food items is proportional to the percentage occupancy of the stomach contents, it may be considered that gammarids (mostly *Ampithoe* sp.) have an important role in supplied nutriments for the blenny population. When gammarids were offered as diet, the total food consumed and faeces

Table 7. *Daily amount of food assimilated by different size of an individual blenny.*

Duration of experiment	Range of temperature (°C)	Range of body length (mm)	Caloric value of gammarids(cal/g)	Food consumed		Caloric value of faeces (cal/g)	Faeces excreted		Assimilation efficiency (%)
				(mg/day)	(cal/day)		(mg/day)	(cal/day)	
Apr. 24 – May 3	5.0– 8.9	122.2–137.8	3531	119.8	423.0	1560	37.1	57.9	86.3
		96.6–112.8	3531	52.6	185.7	2489	9.4	23.4	87.6
		87.7– 95.7	3531	31.9	112.6	2033	7.2	14.6	87.0
		68.8– 74.7	3531	11.7	41.3	2039	2.5	5.2	87.4
Aug. 3 – Aug. 10	21.3–23.0	93.7–99.9	3762	56.4	212.2	3979	6.2	24.7	88.4
		75.3–82.0	3762	15.0	56.4	4143	1.9	7.8	86.2
		53.8–63.3	3762	22.0	82.8	3117	2.7	8.4	89.9
Oct. 22 – Oct. 28	12.2–15.1	83.5–88.3	3619	31.2	112.9	2837	4.8	13.6	88.0
		66.3–73.5	3619	19.8	71.7	2845	3.9	11.1	84.5
		57.3–66.5	3619	14.8	53.6	3240	2.2	7.1	86.7

excreted by the blenny are summarized in Table 7. The assimilation efficiency, which, expressed as percentages of the caloric equivalent of the blenny, ranges between 84% and 89%, with an average value of 87.2%.

The energy consumed as food equals the sum of energy lost as faeces, energy used of the formation of new tissue, and energy used for metabolic activities which are lost the surrounding as heat. Therefore, it is possible to estimate the annual consumption of energy by the blenny population as a function of annual growth (Table 6), annual respiration (Fig. 5) and the assimilation efficiency of 87.2% mentioned above. The annual consumption of food taken for the blenny population amounts to 31.7 Kcal m^{-2}, and the annual ejection of faeces is estimated at 4.1 Kcal m^{-2} $year^{-1}$ by the application of the assimilation efficiency of 87.2% obtained from the feeding experiments.

Discussion

Diagram of annual energy flow facilitates the description of the fluxation and use of energy through a population. Figure 7 shows schematically the rate of energy flow through the blenny population of Usu Bay. In an annual balance sheet, the credit side of energy is the sum of the energy assimilated as nutriments, immigrants and recruitment members. These values in the blenny population are 27.6 Kcal m^{-2} $year^{-1}$, 8.2 Kcal m^{-2} $year^{-1}$ and 0.8 Kcal m^{-2} $year^{-1}$, respectively. On the other hand, the total amount of energy entered on the debit side by the population during a whole year is 36.2 Kcal m^{-2} $year^{-1}$ including metabolic activity (13.4 Kcal m^{-2} $year^{-1}$) and the sum of emigration, mortality, and predation (22.8 Kcal m^{-2} $year^{-1}$). For this reason, the magnitude of 0.4 Kcal m^{-2} $year^{-1}$ is equal to the actual energy stored into the population during a whole year.

The respiration/consumption (R/C) ratio of 0.42 for the blenny population, composing mostly 40 to 70 mm in standard body length, agrees closely with the values of 0.46 to 0.55 for the young pinfish (*Lagodon rhombiodes*) and pigfish (*Orthopristis chrysoptera*) population in the Phillips Island eelgrass bed[2]. The environmental factors, such as extremes in sea temperature, may impose limits on the fish which utilize the beds. This low R/C ratio for the fish population in the eelgrass beds indicates that even though the blenny itself are subjected to physical extremes, such as temperature, the resident fish population adapted to the extreme. One of the most important factors in comparing the magnitude of the energy flow into and out of a trophic level is the production consumption (P/C) ratio[20]. This ratio for the blenny population was 0.45 in Usu Bay. Backiel[21] found the average P/C ratio for the fish population to be 5.5%, and MacKinnon[15] gives a value of 17% for American plaice population. Slobodkin[20] suggested that the P/C ratio of aquatic systems should be 5–20%. On eelgrass fishes, however, Adams[2] found that the ratios of the young pigfish (*O. chrysoptera*) and the gag (*Mycteroperca microlepis*) were 0.34 and 0.41 in the eelgrass bed of Phillips Island, respectively. MacKinnon[15] reported the ratio of 0.34 for young American plaice (*Hippoglosoides platessoides*) population in North temperate waters. The value of the blenny population obtained by our study shows a slightly high level in comparison with these values. This relatively high P/C ratio of the blenny population suggested that the fishes are fairly efficient in the utilization of consumed energy. Therefore, the eelgrass bed food web may be characterized by a comparatively small number of energy pathways, and a high energy flow per pathway, as well as the input of a large amount of energy in the form of phytal animals. However, the possible sources of error influencing the measurement of this high ratio must also be considered. For instance, the resident fish may use the bed mainly for cover and yet feed elsewhere. Data on the food habits, however, have shown that fish in the eelgrass beds consumed food produced mainly within the bed.

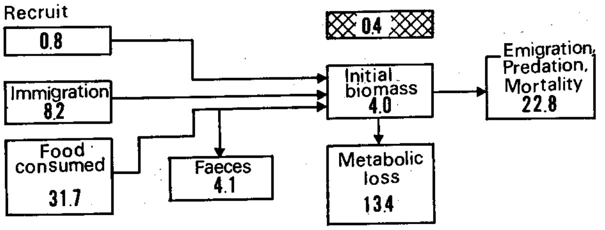

Fig. 7. Annual energy flow for the blenny population of Usu Bay. Rates are Kcal m^{-2} year^{-1}. Shadow area show a difference between initial and final biomass. Value for the initial biomass is Kcal m^{-2}.

Epiphytic fauna was important to only gammarid amphipods in the eelgrass beds of Usu Bay (Fig. 6). Blaber[22] and Whitfield[23] indicate a similar feeding pattern in fish communities of the South African estuarine systems. It is pointed out, however, that the dramatic seasonal fluctuation of standing crop of most phytal crustaceans generally corresponds with these of standing *Sargassum* and

Zostera crop[24,25]. The replacement of feeding on harpacticoids and/or calanoids for the blenny population during late fall and winter may be perhaps attributable to a marked decrement of standing gammarids crop in the eelgrass beds of Usu Bay. The inherent instability of seagrass and eelgrass beds reinforces the importance of flexibility in the diet of fishes which utilize these areas as nurseries. To clarify a seasonal fluctuation in the abundance which existed between various specific populations for phytal community and various fish populations for the eelgrass fish community would lead to an understanding of the eelgrass community structure and function, with data on biological production system and bioeconomics relationship of member population.

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