Reprinted from

JIBP SYNTHESIS

1975 Tokyo

Volume 10

PRODUCTIVITY OF COMMUNITIES IN JAPANESE INLAND WATERS

Edited by S. Mori and G. Yamamoto

Japanese Committee for the International Biological Program
UNIVERSITY OF TOKYO PRESS

PART 8

Productivity of the Yoshino River, Nara

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CONTENTS

8.1 Introduction

The Yoshino River team has been studying the communities of the Yoshino River for the purpose of discussing the productivity of that river.

The Yoshino River (Fig. 8–1) is situated in Nara Prefecture, Central Japan, about 70 km in length, with clear, soft water; it does not freeze over in winter. The area studied is the upper reaches as well as the tributaries of the river, where we find very rich aquatic insect fauna. No pollution, artificial dam or reservoir exists at present, although at least two dams will be constructed in near future.

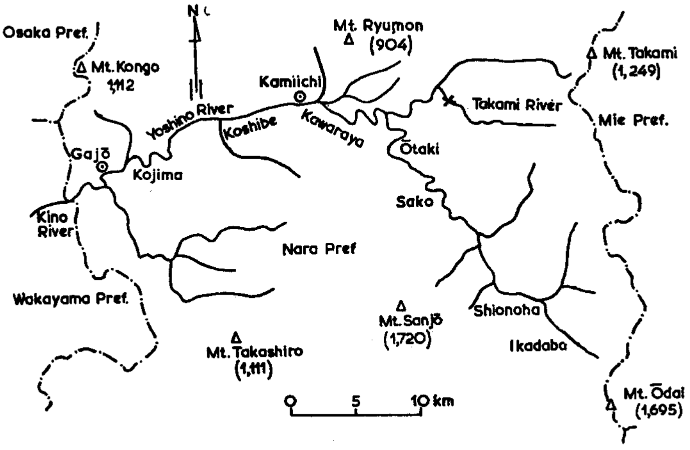

FIG. 8–1. Map of the Yoshino River. × indicates the main study site of Mizugase.

Fish, benthic animals, algae, etc. were studied in the area.

The main study site is the site Mizugase, at Takamigawa, a tributary of the Yoshino River. The productivity calculation was made for the communities at this site.

The members who participated to this Yoshino River study are the following:

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* Supported by the special project research "Studies on the dynamic status of biosphere" undertaken in the frame-work of the Ministry of Education of Japan. Contribution from Japan National Committee for International Biological Programme, PF Section.

8.2 Primary production

The primary production in rivers depends on the photosynthesis of algae. The productivity is usually expressed in terms of the amount of photosynthesis per day or per year, which is made by algal communities grown in a 1 m^2 river-bed. However, the algal communities in a 1 m^2 area vary not only in their constituent species but also in the standing crop at every place in the river. Therefore, it seems almost impossible to precisely estimate the value which represents the productivity at a certain river even in a short duration, unless the productivity in the total areas is measured. In a longer duration, factors which make the estimation more difficult, are changes in the circumstances in and around the river. The weather may differ from day to day; clear, cloudy or rainy etc. Temperature, light intensity and flow velocity change day by day. It may sometimes happen that algae on the surface of submerged stones would be stripped off by the influences of the flood. The conditions in and around the river are so dynamic and complicated, that the primary productivity of algae is continuously modified reflecting the alteration of the conditions.

How can be expressed "the primary productivity" in such an unstable river, is the basic problem. Firstly, we estimated the ability of photosynthesis and respiration of algae collected from the river at various temperatures and light intensities. The ability itself may fit one of the expressions of the primary productivity of algae grown in the river, though it does not reveal any more than the physiological activity of the algae. However, if the water temperature and light intensity were continuously recorded throughout a day or several days, one could plot graphs showing the quantity of the photosynthesis and respiration in each moment and one could express the primary productivity "per day" with the aid of this graph. Secondly, we made this graph and compared the value of the productivity thus obtained to that resulted from another experiment in which oxygen evolution or consumption of algae attached on the surface of a stone was continuously measured. We found that both values quite agree with each other. At this experimental level, the productivity could be expressed in terms of the oxygen evolution "of the algae in the river" but not of the oxygen evolution "of the river". For the latter, the distribution of algal standing crop or of algal chlorophyll in the river should be examined. Thirdly, we surveyed the distribution of chlorophyll-*a*, from which the average value of chlorophyll-*a* in unit area of the river would be obtained. Then the productivity of the unit area in the river may be expressed. Finally, we try to calculate the productivity of the river in a year, using the data thus far obtained.

8.2.1 Rate of photosynthesis and respiration of algae

1) Measurement with algae shaved from stones

The activity of photosynthesis and respiration was measured by an oxygen meter with an automatic recorder. Algae were shaved from stones and were centrifuged. The algal pellet was suspended in 1/100 mol phosphate buffer (pH 7.0) with 1% glucose and poured into a glass vessel of 5 ml inside volume, then an oxygen senser was set. During the periods of measurement, oxygen in the solution containing algae was continuously recorded.

Figure 8–2 shows the relationship between oxygen uptake (or evolution) and light intensities at different temperatures, which is derived from such experiments as described above on algae shaved on Jan. 25th in 1971. The same experiment was carried out on algae collected on Apr. 30th in 1969 and on Sep. 19th in 1969. In the latter two cases, algal samples were collected from many places in the river but the activity of photosynthesis and their respiration were similar to those seen in Fig. 8–2.

When oxygen uptake (or evolution) in 15,000 lux and in the dark at different temperatures are plotted, curves in Fig. 8–3 are obtained. In Figs. 8–2 and 8–3, the photosynthesis is expressed by the net production of oxygen, and not by the gross production. As Figs. 8–2 and 8–3 show that the volume of oxygen evolved in 15,000 lux is about 3 times of that consumed in the dark, the gross production in 15,000 lux by the algae are larger 4/3 times of the net production. If the darkness lasts for 12 hours and the sunshine of 15,000 lux for 12 hours, the amount of respiration in a day reaches 2/3 times of the amount of the net production. When light intensity becomes larger, oxygen evolved increases, but it is assumed from the declining tendency of the curves in Fig. 8–2 that the volume of oxygen in higher light intensities may be less than 2.5 ml an hour per 1 mg chlorophyll-*a* at 20°C.

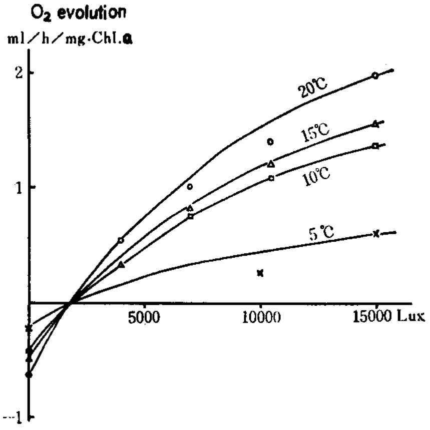

FIG. 8–2. O_2 uptake (or evolution) at various temperatures and light intensity by algae collected from the river.

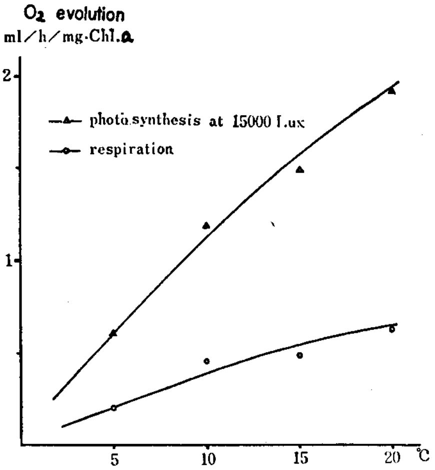

FIG. 8–3. Photosynthesis at 15,000 lux and respiration of algae collected from the river.

2) Measurement with algae attached on stones

The schema of the apparatus used for the measurement of the oxygen evolution from algae attached on a stone is shown in Fig. 8–4. A stone, on which algae was attached, was placed in a glass vessel. In the vessel, water flowed at a constant rate. The vessel itself was set in a larger glass vessel, into which water was poured from the surface of the river and from which water was always over flowing. The oxygen concentration of the water was measured at the entrance and at the exit. Water and air temperature, and light intensity were also measured. These values were continuously recorded on the paper of the recorder.

Figure 8–5 shows the result obtained by the experiment which was carried out from Sep. 27th in 1970. In this case, the algae containing 60 μg of chlorophyll-*a* grew on a stone surface. Water flowed through the vessel at the rate of 2.3 ml per minute. The oxygen concentration in the inlet water, which came from the surface of the river, was almost constant during the experimental period, while the oxygen concentration in the outlet water varied. From Fig. 8–5, it was calculated that 1.1 ml oxygen was evolved from the algae between 12 to 19

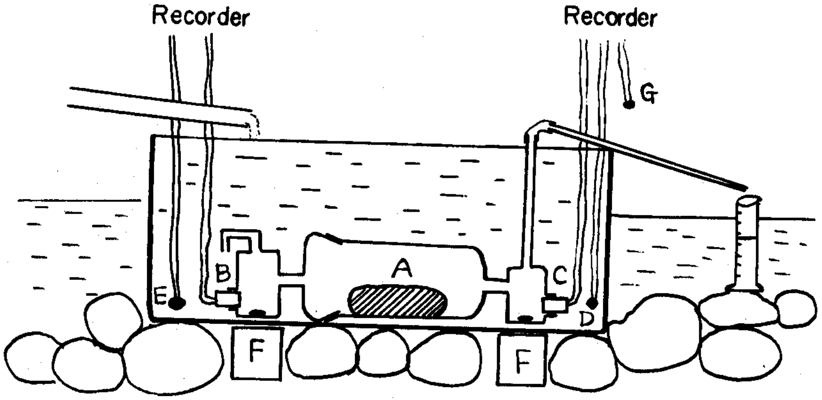

FIG. 8–4. Schema of the apparatus used for measurement of oxygen evolution from algae attached on a stone. A: Stone on which algae grow, B: Senser for oxygen in inlet water, C: Senser for oxygen in outlet water, D: Thermister for measurement of water temperature, E: Photocell, F: Magnetic stirrer, G: Thermister for air temperature.

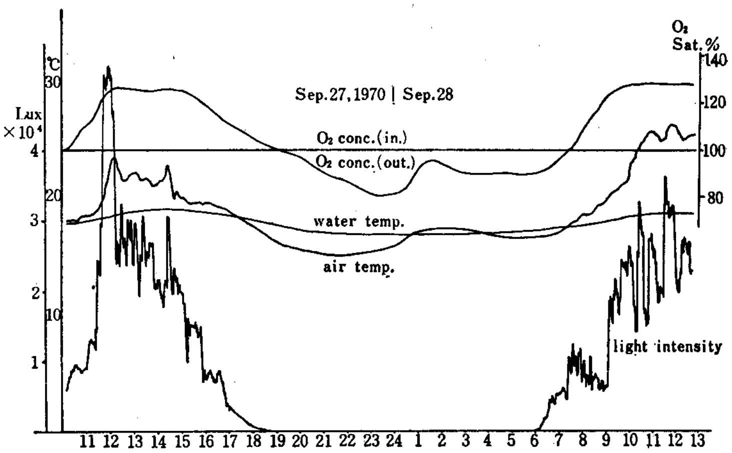

FIG. 8–5. Results of measurement with the apparatus shown in FIG. 8–4. (from Sep. 27th to Sep. 28th)

o'clock on the 27th day, that 1.1 ml oxygen was consumed between 19 o'clock on the 27th day to 7.5 o'clock on the 28th day, and that 0.9 ml oxygen was evolved between 7.5 o'clock to 12 o'clock on the 28th day. Totally, 0.9 ml oxygen was evolved by the algae between 24 hours. From these results, it was calculated that about 15 ml of oxygen was evolved from a mass of algae containing 1 mg of chlorophyll-*a*.

The same experiment was done from Oct. 6th and 7th in 1968. In this case, the average water temperature was 15°C, and the light intensity was similar to that of above experiment. The algae containing 51.6 μg of chlorophyll-*a* covering 12 cm^2 of a stone surface was placed in a vessel and 1 ml of water passed through the vessel every minute. In 24 hours, 1440 ml of water passed through the algae, and 2.5 ml of oxygen was evolved in light and 1.3 ml of oxygen was consumed in darkness. Totally, 1.2 ml of oxygen was evolved by the algae with 51.6 μg of chlorophyll-*a*, which corresponds to 23 ml of oxygen evolution from algae with 1 ml chlorophyll-*a*. If the algae evenly covered 1 m² area, 1,000 ml of oxygen would be evolved from there every day.

In winter, when the water temperature was very low, the same experiments were done, and one of the results obtained is shown in Fig. 8–6. The algae with 400 μg of chlorophyll-*a*, which was attached on the surface of a stone, were used. Water flowed through the algae at 6.5 ml per minute. The experiment was closed at 13 o'clock but the dotted lines in Fig. 8–6 were added under the assumption that they would have followed those figures if the experiment had been continued till 18 o'clock. From Fig. 8–6, it was calculated that 1.5 ml of oxygen was consumed from 18 o'clock on Jan. 24th to 9 o'clock on Jan. 25th in 1971 and that 2.4 ml of oxygen would be evolved from 9 o'clock to 18 o'clock. Within 24 hours after 18 o'clock on Jan. 24th, therefore, 0.9 ml of oxygen would be evolved. In the case of algae with 1 mg of chlorophyll-*a*, 2.3 ml of oxygen was calculated to be evolved every day. This value is about one sixth of the value obtained in experiments in September and October.

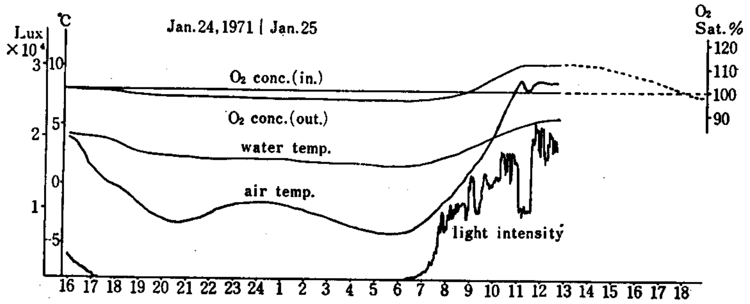

FIG. 8–6. Results of measurement with the apparatus shown in FIG. 8–4. (from Jan. 24th to Jan. 25th)

3) Comparison of values obtained by the two methods

When the water temperature and the light intensity in a day are continuously measured, the oxygen production per day by algae with a certain amount of chlorophyll-*a* can be calculated from Fig. 8–2 or conveniently from Fig. 8–3. For example, the volume of oxygen evolved per day in the case of Fig. 8–5 is calculated as follows. In these days, the sun shines for 12 hours between 6 to 18 o'clock, and the average light intensity within the term may be roughly regarded as 15,000 lux. The average water temperature within the term is 18°C. Fig. 8–3 indicates that 1.8 ml of oxygen would be produced per hour in 15,000 lux at 18°C by algae with 1 mg of chlorophyll-*a*. For 12 hours, 21.6 ml of oxygen would be liberated. As the average water temperature is 17°C at night, 0.6 ml of oxygen per hour would be consumed by the same algal mass. For 12 hours in the dark, 7.2 ml of oxygen consumption is calculated. Therefore, the net production of 14.4 ml of oxygen is performed per day by algae with 1 mg of chlorophyll-*a*. The value is quite in accordance with that obtained by the experiment using algae which was attached on the surface of a stone as described above.

As for the experiment done on cold winter days of Fig. 8–6, a similar calculation is possible. In those days, the duration, when algae are illuminated by about 15,000 lux, may be recognized as 8 hours and the average water temperature in the duration is 5°C. At night, the water temperature falls to 2°C, and it may continue for 13 hours when the algae cease the photosynthesis. It is calculated with the curves in Fig. 8–3 that the algae with 1 mg of chlorophyll-*a* may produce 0.6ml of oxygen per hour in light and consume 0.1 ml of oxygen in darkness, thus producing 4.8 ml of oxygen in the day and consuming 1.3 ml of oxygen at night. Totally, the net production of 3.5 ml of oxygen is calculated. In the experiment using algae attached on the stone, 2.3 ml of oxygen production was observed in the same day as mentioned above. Here again, two values which are derived from independent experiments and calculations agree well with each other.

8.2.2 Estimation of the standing crop

1) Standing crop on a small scale

Algal communities in rivers usually grow on the surface of submerged stones. Not all the stones are covered with algae. Under what conditions the stones allow algae to grow on them could not be precisely known. The conditions may differ from appearances of the rivers them-

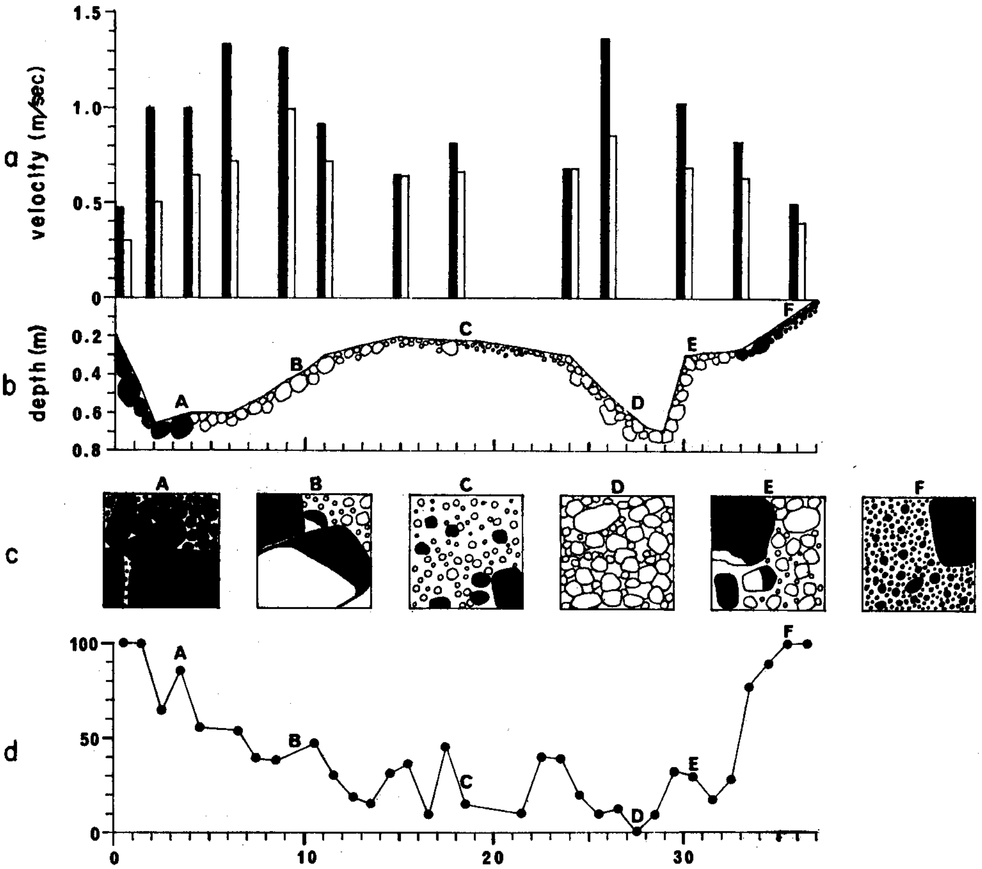

FIG. 8–7. Velocity of water flow (a), profile of river bed (b), stone arrangement of the river bed (c), and the rate of algal areas to the quadrate area (d) across the river. Blacked areas in b and c indicate the stones with well-grown algae.

selves. The large size of stones seems to be an important factor, because the unremoved standing is necessary for the algal growth. Near both river sides, where the river flow is somewhat slow, algae usually grow very much. However, the velocity of the river flow may not directly concern upon the algal growth, as heavy growing of algae are frequently found on stones in very rapid flows. In Fig. 8–7 b, a bottom profile of the river is shown, which is one of the stations of our investigation. Across the river, 37 quadrates of 250 cm^2, each of which is at a distance of 1m, were examined on the state of algal growth. Overlook views of the stone arrangements of these quadrates were sketched indicating on which stones algae grew. In Fig. 8–7 c, 6 quadrates A to F are shown, which correspond to those from A to F in Fig. 8–7 b. Blacked areas in the sketches indicate stones where algae grew well, and the ratio of blacked areas to a quadrate-area was calculated. Figure 8–7 d shows such ratio in each 37 quadrates across the river. From the graph it is known that 36 per cent of the river bed was covered with algae at this place. The maximum and minimum velocity of the river flow at each quadrate is shown in Fig. 8–7 a.

2) Standing crop on a large scale

The amount of chlorophyll-*a* of the river which represents the algal standing crop was surveyed along 630 m of river length. The results obtained on Sep. 27th (1970) and on Jan. 25 th (1971) are represented in the schema of Fig. 8–8. The survey was done as follows. The boundary of an area was limited, in which the state of algal growing and distribution was in some extent regular. For instance, an area was limited in which stone surfaces covered by algae was 35 per cent of the total area. Then the content of chlorophyll-*a* of the algae was measured. When a value 6 μg of chlorophyll-*a* per 1cm^2 was obtained, the area was recognized to contain 21 mg of chlorophyll-*a* per 1 m^2, which comes from the calculation of 60 mg/m^2 × 0.35 = 21 mg/m^2

The same observation and calculation extended from one area to the next and Fig. 8–8 was finally obtained. For several days before Sep. 27th, the river rose so much due to rain, that the algae on stones were considerably washed off. On Jan. 25th higher values of 1.5 to 2 times of those of Aug. 27th were measured. This indicates that algae can grow well even in cold winter, unless they suffer unfavorable influences by the rise of the river.

The average values of chlorophyll-*a* which are derived from many observations are summarized in Table 8–1.

TABLE 8–1. Average values of chlorophyll-*a* in the river bed.

	Chlorophyll-*a* (mg/m^2)	
Rapids	15–50	(25)*
Shoals	4–30	(15)
Pools	0–7	(5)
Stones with well-grown algae	40–70	(60)

* In parentheses, the representative values are shown.

8.2.3 Amount of plant leaves fallen into the river

A wire net was set across the river, and the amount of leaves caught by the net in a day was measured. One of the experiments was done on Nov. 20th and 21st in 1968. During 24

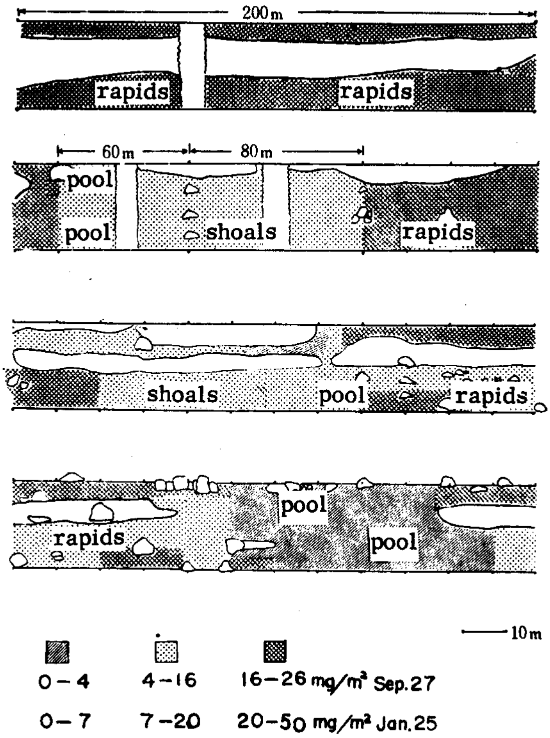

FIG. 8–8. State of algal growth along 630m of river length surveyed on Sep. 27th and Jan. 25th. Values obtained at the latter are in parentheses.

hours, leaves of 47g in dry weight was caught by the net. Among the leaves, 65.8 % were those from deciduous trees and 34.2 % from acerose trees. Leaves of Aceraceae were most dominant (24.7 %), then came leaves of Cryptomeria (24.2 %). The leaves would sink to the bottom of river pools or to the cavities between stones, where the water flow is slow. Most leaves which fell into a certain rapid would sink at the following pool, and some leaves would go to the next rapid. The leaves which were accumulated in the river bottom would be decomposed to detritus or microseston by bacteria and other organisms. The detritus or microseston with bacteria would flow out from the pools to the next rapids. If the river were stationary for a long period without any water rise, pools would continuously supply the microseston to the rapids, the amount of which would be comparable to that of the leaves fallen in the rapid ahead of the pool. These microseston may be important for the food of the net spinning insects. We set the wire net about 100 m below a pool, and 47g leaves were caught by the net in a day, which fell on about 1000 m² river surface; that is, 0.047g leaves per square meter in the day and 17.2 g per square meter in a year. The value 17.2 g per square meter may be evaluated too large, because the calculation was based on the data obtained in a autumn day, when the deciduous trees drop their leaves. If we assume the value of 10 g as the amount of leaves fallen into each square meter of the river surface in a year, and if 1g leaves correspond to 4 kcal, then the river would get the energy of 40 kcal per year from the outside of the river at each square meter of the river surface.

8.2.4 Estimation of the primary productivity in the river

As already described, the net oxygen production by algae with 1 mg of chlorophyll-*a* was 15 ml in a day on Aug. 27th and 2.3 ml in a day on Jan. 25th. From this values and those in Table 8–1, the net production of oxygen in those days is calculated as in Table 8–2.

TABLE 8–2. Oxygen production per day in a river bed.

	Chlorophyll-*a* (mg/m^2)	Primary production in a day (O_2 ml/m^2 river bed)	
		Aug. 27th	Jan. 25th
Rapids	25	375	57.5
Shoals	15	225	34.5
Pools	5	75	11.5
Stones with well-grown algae	60	900	138.0

To measure the oxygen evolution from algae attached on a stone for a long time is very difficult in our present experimental system. Therefore, the primary production per year must be calculated by the data given in Figs. 8–2 or 8–3 and in Table 8–3 dealing with the duration of sunshine and water temperature.

TABLE 8–3. Duration of sunshine and water temperature.

	Average value of duration of sunshine in each month (hours: minutes)	Water temperature in the middle of each month (°C)
Jan.	10:11	3.0
Feb.	10:58	5.0
Mar.	11:59	4.8
Apr.	13:02	12.4
May	13:57	15.0
Jun.	14:25	20.0
Jul.	14:11	20.6
Aug.	13:27	24.8
Sep.	12:29	24.2
Oct.	11:25	16.0
Nov.	10:25	11.2
Dec.	9:55	4.0

Under the assumption that the algal standing crop or the amount of chlorophyll-*a* remains unchanged throughout a year as in Table 8–1, that the algal ability for photosynthesis and respiration continues as in Fig. 8–1 or 8–2 throughout a year, and that the average light intensity in the duration of sunshine is 15,000 lux, the primary productivity in each month is calculated as in Table 8–4.

It is said that 688 kcal are utilized for the production of 6 mol of oxygen, that is, 5.1 kcal for 1*l* of oxygen. The net primary productivity in each square meter of rapids, shoals or pools

TABLE 8–4. Primary production of the river in each month.

	O_2 ml/mg chlor.-*a* per day	O_2 ml/mg chlor.-*a* per month	O_2 ml/m^2 river bed per month			
			Rapids	Shoals	Pools	Stones with well-grown algae
Jan.	2.0	62.0	1550	930	310	3720
Feb.	4.0	112.0	2800	1680	560	6720
Mar.	4.7	145.7	3642.5	2185.5	728.5	8742
Apr.	12.8	384.0	9600	5760	1920	23040
May	16.9	523.9	13097.5	7858.5	2619.5	31434
Jun.	21.9	657.0	16425	9855	3285	39420
Jul.	21.9	678.9	16972.5	10183.5	3394.5	40734
Aug.	24.6	762.6	19065	11439	3813	45756
Sep.	19.7	591.0	14775	8865	2955	35460
Oct.	12.0	372.0	9300	5580	1860	22320
Nov.	7.3	219.0	5325	3195	1065	12780
Dec.	2.7	83.7	2092.5	1255.5	418.5	5022
Total		4585.8	114645	68787	22929	275148

in the river can be estimated as 584.7, 350.8 or 116.9 kcal per year respectivelly, and algae grown on stones can produce 1403.2 kcal per year per square meter. In the area shown in Fig. 8–8, the rapids, shoals and pools occupy 56,28 and 16% of the total area respectively. The mean value, 444 kcal, as the net productivity per square meter in this area in a year is obtained by the calculation:

$$584.7 \text{ kcal} \times 0.56 + 350.8 \text{ kcal} \times 0.28 + 116.7 \text{ kcal} \times 0.16 = 444 \text{ kcal}$$

The amount of respiration is 2/3 times of the amount of net production as above described, so that 296 kcal is calculated for the value of the amount of respiration per square meter in a year.

8.3 Secondary production

8.3.1 Description of river and sites

The physical conditions of studied sites are shown in Table 8–5.

8.3.2 Standing crops and long term succession

Standing crop of benthic animals collected at approximately 1-month intervals from November 1969 to November 1970, in a riffle of the station Mizugase in the Takami River, one of the branches of the Yoshino River. Samples were taken by a 50 cm quadrat.

The standing crop of benthic animal communities is so rich, the wet weight being from 51g/m^2 to 155g/m^2 (Table 8–6). More than 99% of the aquatic insects consisted of the members of the following four orders: Ephemeroptera, Plecoptera, Trichoptera and Diptera. The dominant species is *Stenopsyche griseipennis*. Judging from the fact that the standing crop is rich and that the net-spinner's coefficient is from 61.9% to 93.0% (table 8–7), the present benthic animal communities are thought to be in the climax.

The aquatic insect communities of the whole Yoshino River are now almost at their climax

TABLE 8–5. Air temperature and mean water temperature for each sampling period from March 1967 to February 1968 (Anō and Ikadaba), November 1969 to October 1970 (Mizugase), March 1965 to February 1966 (Abashiri, Hokkaido) and accumulated water temperature for each station.

Station	Air temperature (°C)				Water temperature (°C)			
	Ano	Mizugase	Ikadaba	Abashiri	Ano	Mizugase	Ikadaba	Abashiri
Mar.	8.6		6.0	1.3	10.7		7.0	1.3
April	22.9		17.6	7.1	16.9		12.6	5.4
May	24.5		21.6	20.3	22.0		14.4	8.7
June	27.3		21.2	21.6	23.7		15.6	13.1
July	28.7		23.7	25.5	27.3		16.1	16.1
Aug.	31.2		31.6	25.9	27.1		21.3	18.3
Sep.	26.2		22.7	17.7	22.5		15.1	13.8
Oct.	22.5		21.9	13.4	16.2		12.8	9.5
Nov.	15.8	17.8	15.1	1.1	10.0	13.1	9.2	3.9
Dec.	7.5	4.2	6.0	–4.3	7.1	4.2	5.3	0.6
Jan.	6.8	0.9	8.9	–1.9	5.2	1.0	6.0	0.5
Feb.	8.8	7.9	2.1	–8.7	6.6	5.1	4.7	0.2
Mar.		5.1				4.9		
April		17.7				13.2		
May		21.6				15.4		
June		24.8				20.3		
July		28.6				22.0		
Aug.		30.1				24.9		
Sep.		25.1				20.8		
Oct.		19.5				16.6		
$\sum_{i=1}^{12}(\theta i\text{-}4)$ $\theta > 4$ (Accumulated water temperature)					147.3	116.5	92.1	56.9

TABLE 8–6. Benthic insects data in rapids of the River Takami-gawa at the station Mizugase from November 1969 to Novermber 1970. Four quadrat (50cm × 50 cm) samples from each month.

species	15 Nov.		14 Dec.		18 Jan.		15 Feb.		22 Mar.		26 Apr.		17 May		14 Jun.		12 Jul.		11 Aug.		15 Sep.		16 Oct.		12 Nov.	
	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)	No.	Wt. (mg/m²)
Ephemeroptera																										
Ephemera strigata	4	55	6	161			2	55	2	11	16	989									2	11	14	142	24	792
Ephemerella basalis			2	21			2	7	8	724	34	2,319	2	103	12	26										
Ephemerella trispina	76	252	60	340	81	763	39	602	24	354	31	854	14	757	5	1	8	8	36	88	71	223	79	237	49	168
Ephemerella rufa	511	177	402	173	421	191	362	271	358	694	274	968	232	702	643	448	183	141	132	522	37	74	607	183	622	597
Ephemerella nigra	48	156	79	451	78	603	104	1,172	74	1,551	18	491	22	892							71	19	43	113	58	186
Ephemerella yoshinoensis	88	88	140	246	161	272	169	310	145	304	82	264	226	1,504	188	1,474	62	457	198	214	104	98	102	38	84	128
Ephemerella spp.					8	18	6	33			42	41	28	53	191	247	68	179	102	236	168	634	41	57		
Baetis yamatoensis	91	49	283	116	329	164	819	564	871	2,248	290	1,096	710	618	466	424	313	473	280	932	339	671	768	1,064	521	390
Baetiella japonica					6	1	66	27	60	39	2	2	44	31	2	1			14	6	26	29	72	102		
Isonychia japonica	39	169	72	509	24	227	29	253	32	367	21	539	23	699	18	734	32	483	24	165	22	724	14	56	18	154
Epeorus latifolium	134	1,310	47	142	32	23	59	47	51	61	80	656	78	956	111	1,013	88	992	108	1,092	94	1,450	192	834	163	1,976
Epeorus uenoi	64	386	86	224	46	301	38	168	94	316	18	481	2	182	75	1,643	61	937	23	121	53	424	62	865	92	985
Epeorus ikanonis	68	229	41	178	47	492	21	476	19	912	9	819			247	141	192	84	126	92	79	137	91	233	67	226
Rhithrogena japonica	26	7	19	28	14	38	25	63	16	49	11	68	16	98	12	117	18	187	20	204	11	146	71	5	51	17
Plecoptera																										
Tadamus scriptus	64	135	211	1,596	104	1,920	94	2,419	57	5,964	15	1,504	17	1,989	6	997					13	1	16	5	131	192
Isoperla nipponica	43	7	51	55	52	58	49	63	28	87	13	281	14	745	5	372										
Paragnetina tinctipennis	23	671	17	628	22	1,048	23	1,334	15	1,112	21	1,941	7	1,592	46	3,694	23	1,988	25	2,351	16	862	22	728	7	1,003
Oyamia gibba	42	9,926	39	8,947	12	3,507	66	18,254	35	14,646	21	3,214	581	7,226	197	6,847	110	5,498	66	3,920	35	5,178	16	2,672	55	8,661
Perla tibialis	316	3,662	152	1,593	135	3,335	88	2,096	185	5,891	256	10,767	122	14,580	1	308	13	1	35	8	217	1,449	382	5,222	278	3,344
Trichoptera																										
Stenopsyche griseipennis	358	31,439	546	76,913	281	41,897	362	50,535	323	34,122	344	61,725	96	31,916	758	71,260	569	99,161	724	92,367	418	65,694	842	62,846	587	55,469
ditto, pupa									61	19,104	128	34,531	87	27,385	79	25,488	131	40,239	25	3,745	114	25,775	261	18,081	5	1,657
Hydropsyche ulmeri	343	2,212	1,781	8,497	424	2,725	914	8,296	569	5,738	76	947	232	4,435	879	9,154	211	2,790	2,568	7,150	993	8,651	964	5,378	1,021	9,109
ditto, pupa													13	165	27	388	2	23	3	31	15	208	5	69		
Rhyacophila nigrocephala			13	119	11	22	5	71	5	107	41	590	19	251	61	565	78	1,321	35	465	37	543	3	19	9	127
ditto, pupa													4	76	2	21							11	233		
Rhyacophila sp. *RG*			8	42	2	29	4	106	2	21	3	27	3	8	6	54	9	131	21	53						
Mystrophora inops	17	53			37	142	2	19	36	133					5	23									5	83
ditto, pupa					8	42			23	95					4	17										
Goera japonica					3	56	2	46			13	15														
ditto, pupa											17	253			8	224										
Coleoptera																										
Elmis sp. ED			1	1	5	2	2	1	2	1	13	5	2	2	2	1	2	1	3	2	5	4	4	3	2	1
Diptera																										
Antocha sp.	13	21	17	26	6	3	11	24	8	18	13	35	6	28	7	13	5	3	7	17	117	399	13	14	19	23
Spaniotoma spp.	467	169	409	256	506	451	673	601	695	619	664	347	215	48	462	103	137	31	382	85	686	152	418	93	439	159
Atherix ibis japonica			13	603	18	1,742	12	1,396											5	349	13	271	4	124	9	269
Total	2,835	51,173	4,495	101,865	2,883	60,052	4,048	89,309	3,798	95,288	2,556	125,769	2,815	97,041	4,525	125,798	2,315	155,128	4,962	114,215	3,776	113,828	5,119	99,416	4,315	86,716

TABLE 8–7. Data of benthic insects of the Takami River from November 1969 to November 1970. Four quadrat (50cm × 50cm) samples from each month.

Date	Dominant species	Individual number	Weight (mg)	Standing crop (mg)	Net-spinner's coefficient (weight basis)	Stenopsychidae coefficient (weight basis)
15 Nov.	*Stenopsyche griseipennis*	358	31,439	51,173	67.2	62.8
	Oyamia gibba	42	9,926			
14 Dec.	*Stenopsyche griseipennis*	546	76,913	101,865	84.3	75.5
	Hydropsyche ulmeri	1,781	8,497			
18 Jan.	*Stenopsyche griseipennis*	281	41,897	60,052	74.5	70.0
	Oyamia gibba	12	3,507			
15 Feb.	*Stenopsyche griseipennis*	362	50,535	89,309	65.9	56.9
	Oyamia gibba	66	18,254			
22 Mar.	*Stenopsyche griseipennis*	384	53,226	95,288	61.9	55.9
	Oyamia gibba	35	14,646			
26 Apr.	*Stenopsyche griseipennis*	472	96,256	125,769	77.3	76.5
	Perla tibialis	256	10,767			
17 May	*Stenopsyche griseipennis*	183	59,301	97,041	65.8	61.1
	Perla tibialis	122	14,580			
14 Jun.	*Stenopsyche griseipennis*	837	96,748	125,798	88.5	76.9
	Hydropsyche ulmeri	906	14,542			
12 Jul.	*Stenopsyche griseipennis*	700	139,400	155,128	91.7	89.9
	Oyamia gibba	110	5,498			
11 Aug.	*Stenopsyche griseipennis*	749	96,112	114,215	93.0	84.2
	Hydropsyche ulmeri	2,571	10,181			
15 Sep.	*Stenopsyche griseipennis*	532	91,469	113,838	88.1	80.4
	Hydropsyche ulmeri	1,008	8,859			
16 Oct.	*Stenopsyche griseipennis*	1,103	80,927	99,416	86.9	81.4
	Hydropsyche ulmeri	969	5,447			
12 Nov.	*Stenopsyche griseipennis*	1,092	57,126	86,716	76.4	65.9
	Hydropsyche ulmeri	1,021	9,109			

phase(Gose, 1968). After the "Isewan Typhoon" (September, 1959), the river bed was catastrophically disturbed and the benthic communities were destroyed completely. The river bed has recovered gradually during the lapse of 10 years and the communities as well. Diversity of species have increased, dominant species have changed with the lapse of time. The dominant forms changed from creeping form (Ephemeroptera, Plecoptera, etc.) to *Hydropsyche* and then to *Stenopsychidae* (Tsuda, 1962; Tsuda and Gose, 1964; Tsuda and Komatsu, 1964; Gose, 1968).

This river now has a *Stenopsychidae*-dominant community. Standing crop increased with sigmoid curve. Examples are given in Fig. 8–9 and 8–10.

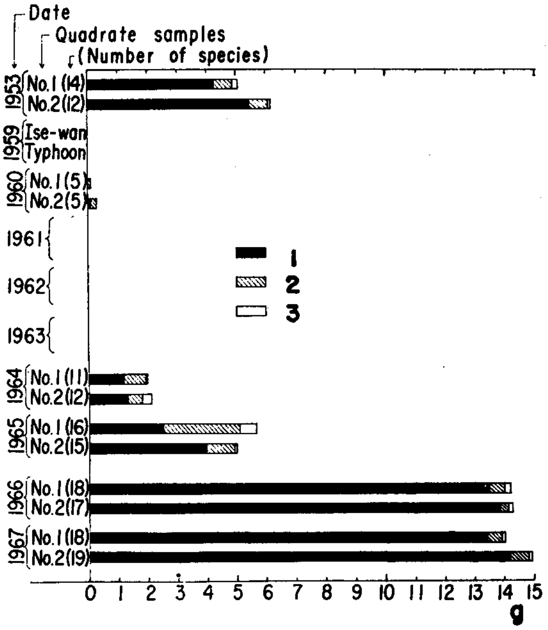

FIG. 8–9. Standing crop at the station Ikadaba [1953–1967; sum of two quadrat (50 × 50cm) samples] 1. net-spinning forms, 2. creeping forms, 3. others.

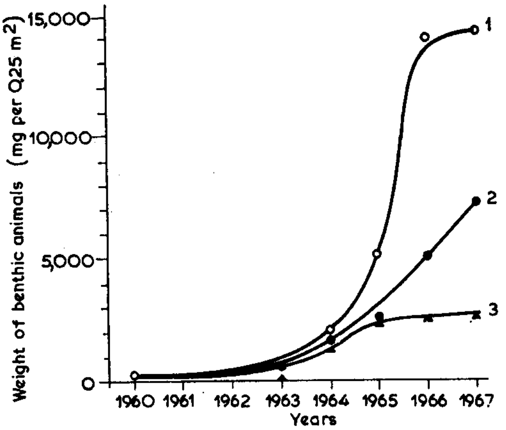

FIG. 8–10. Curves of increases of the standing crops after the Ise-wan Typhoon. 1. Ikadaba, 2. Kawaraya, 3. Ōtaki.

8.3.3 Life histories of benthic animals

Samples of Ephemeroptera, Plecoptera and Trichoptera was taken monthly from the stations of Ikadaba, Mizugase and Anō, the body length was measured, also instars were determined (Trichoptera). The life history diagrams of many insects will be shown in Figs. 8–11, 8–12 and 8–13 (Gose, 1970a, 1970b, 1970c, 1971).

At Ikadaba station, *Ephemera japonica* McLachlen, *Ephemerella trispina* Uéno, *Ephemerella yoshinoensis* Gose, *Ephemerella nigra* Uéno, *Ameletus costalis* Matsumura, *Epeorus uenoi* Matsumura, *Epeorus latifolium* Uéno, *Ecdyonurus kibunensis* Imanishi, *Ecdyonurus yoshidae* Takahashi, *Paraleptophlebia spinosa* Uéno (Ephemeroptera) and *Alloperla abdominalis* Okamoto (Plecoptera) have one generation per year, and *Stenopsyche griseipennis* McLachlan (Trichoptera) has 3 generations per two years.

At Mizugase station, *Paraleptophlebia spinosa* Uéno, *Ephemerella trispina* Uéno, *Ephemerella basalis* Imanishi, *Ephemerella yoshinoensis* Gose, *Ephemerella nigra* Uéno, *Ephemerella longicaudata* Uéno, *Ameletus montana* Imanishi, *Ameletus costalis* Matsumura, *Epeorus ikanonis* Takahashi, *Ecdyonurus yoshidae* Takahashi, *Rhithrogena japonica* Uéno (Ephemeroptera), *Nogiperla japonica* Okamoto, *Paragnetina tinctipennis* McLachlan, *Tadamus scriptus* Klapa-

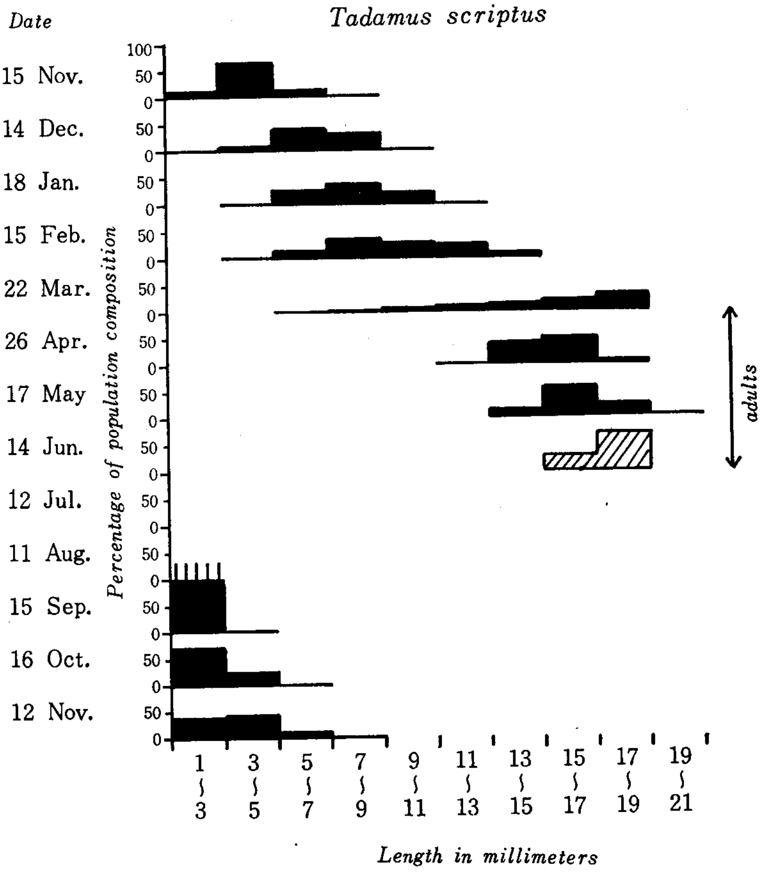

FIG. 8–11. The percentage size distribution in approximately monthly collection of *Tadamus scriptus* at the station of Mizugase. Histograms based on less than few specimens are cross hatched. The flight period of the adult is shown by a vertical line between arrowhead. The specimens in the 1–3 mm size group were not quantitatively collected, as they could not all be certainly distinguished from allied species, but their presence is shown by vertical lines.

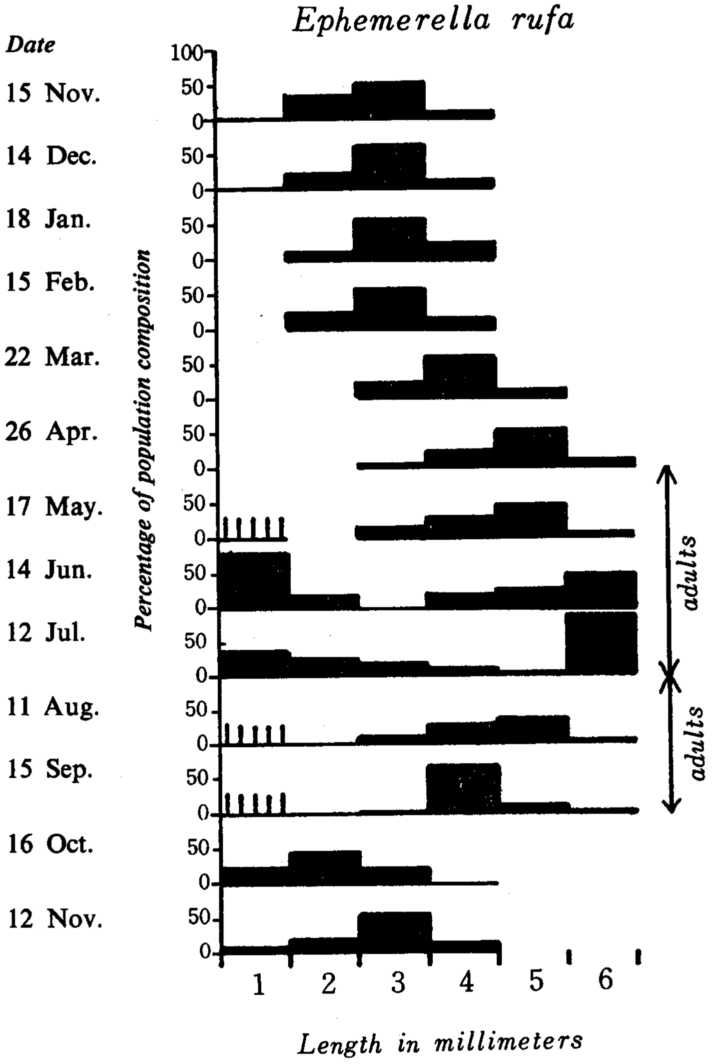

FIG. 8–12. The percentage size distributions in approximately monthly collections of *Ephemerella rufa* at the station of Mizugase. Histograms based on less than few specimens are cross hatched. The flight period of the adult is shown by a vertical line between arrowheads. The specimens in the 1–3 mm size group were not quantitatively collected, as they could not all be certainly distinguished from allied species, but their presence is shown by vertical lines.

lek, ***Perla tibialis*** Pictet, ***Oyamia gibba*** Klapalek, ***Isoperla nipponica*** Okamoto (Plecoptera) have one generation per year, and ***Paraleptophlebia chocorata*** Imanishi, ***Choroterpes trifurcata*** Uéno, ***Ephemerella rufa*** Imanishi, ***Bāetis yamatoensis*** Gose, ***Bāetiella japonica*** Imanishi, ***Epeorus Uenoi*** Matsumura, ***Epeorus latifolium*** Uéno (Ephemeroptera), ***Stenopsyche griseipenis*** McLachlen (Trichoptera) have two generations per year.

At Anō station with warmer water temperature than Ikadaba station, the ***Stenopsyche***

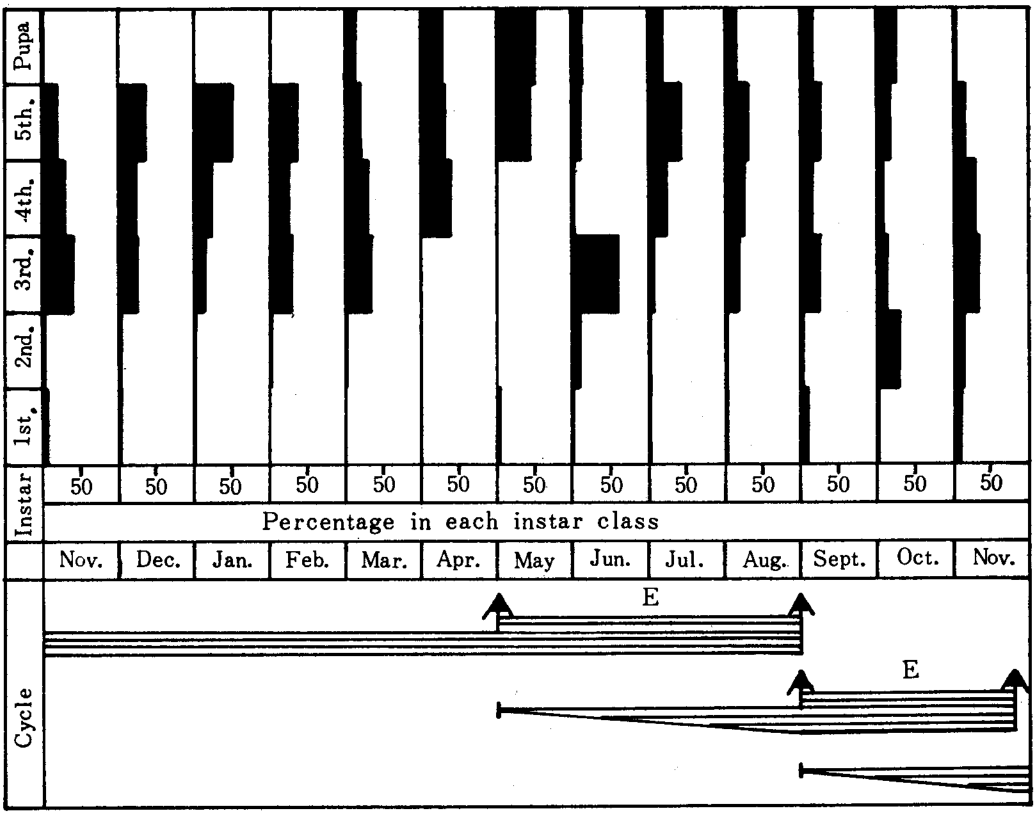

FIG. 8-13. The percentage size distributions in approximately monthly collection of *Stenopsyche griseipennis* at the station of Mizugase. Histograms based on less than few specimens are cross hatched. The flight period of the adult is shown by a vertical line between arrowheads. The specimens in the 1-3 mm size group were not quantitatively collected, as they could not all be certainly distinguished from allied species, but their presence is shown by vertical lines.

griseipennis has two generations per year. At Miyataki station a chironomid, *Spaniotoma* sp. A, has six generations in a year (Kitagawa, 1969).

The life history of *Stenopsyche griseipennis* was studied on the basis of the samples which were taken from the River Yoshino at the stations of Anō, Mizugase and Ikadaba, Nara Prefecture. The accumulated temperature of water temperature (Table 8–5) required by one generation of *Stenopsyche griseipennis* is 55 month–degree C, the minimum effective temperature being assumed to be 4°C. At about 4°C the larva of this species stops to eat. By the instar analysis it was determined that this species has two generations in a year at the stations of Anō and Mizugase, three generations in two years at Ikadaba, and only one generation in a year at Abashiri (Hokkaido). On the other hand the number of generations could be estimated on the basis of the accumulated temperature (Gose, 1970b).

8.3.4 Production rate

From the samples taken approximately in 1 month interval (Table 8–6), the production rate of each aquatic insect in a riffle of the station of Mizugase, Takamigawa was computed for each generation as follows, using the relationship proposed by Ricker (1946) and Allen (1949):

$$B = k\bar{P}$$

B = production rate in g per m² day, k = instantaneous rate of growth in g perg day; instantaneous growth rate for the 1-month period was calculated as the natural logarithm of the ratio of the maximum size at the end of the period to the maximum size at the beginning of the period; the result was divided by the number of days in the period to obtain k for one day $[k = (\mathrm{l}_n Wt_2 - \mathrm{l}_n Wt_1)/(t_2 \sim t_1)]$. $\bar{P}$ = means population density in g per m²; it was the geometric mean of population densities at the beginning (t_1) and end of the period (t_2)

$$P = \frac{P_2 - P_1}{\mathrm{l}_n P^2 - \mathrm{l}_n P_1}$$

Production in an approximate 1 month period was computed as the product of B and the number of days in the period.

The data of *Tadamus scriptus* Klapalek (Plecoptera), *Ephemerella rufa* Imanishi (Ephemeroptera) and *Stenopsyche griseipennis* McLachlan (Trichoptera) are shown in Tables 8–8, 8–9 and 8–10. Monthly changes of individual number per 1 m² are shown in Figs. 8–14, 8–17 and 8–20, and monthly changes of standing crop (weight) in Figs. 8–15, 8–18 and 8–21. Figures 8–16, 8–19 and 8–22 show the growth curve based on the largest individuals found in samples of each month. On the basis of Figs. 8–15 and 8–16, Figs. 8–18 and 8–19, Figs. 8–21 and 8–22 the production rates were calculated, which values are again shown in Tables 8–8, 8–9 and 8–10 (two columns at the right).

The annual production rate of *Tadamus scriptus* was found to be about 7.13g/m² at the riffle of the river. The yearly turnover-ratio is 4.7. The total estimates of production of *Ephemerella rufa* were about 1.25g/m² and 0.51g/m² for the winter and summer generations respectively, with an annual sum of 1.75g/m². The yearly turnover ratio is 5.7. The total estimates of pro-

TABLE 8–8. Production rate of *Tadamus scriptus* by the growth method from November 1969 to November 1970.

Period	Δt days	k g/g/day	$\bar{P}$ g/m²	Production rate (B) for day g/m²/day	Production rate (B) for period g/m²
Nov. 15–Dec. 14	29	0.0262	0.592	0.016	0.450
Dec. 14–Jan. 18	35	0.0242	1.780	0.043	1.508
Jan. 18–Feb. 15	27	0.0167	2.160	0.036	0.974
Feb. 15-Mar. 22	35	0.0261	3.921	0.182	3.582
Mar. 22–Apr. 26	35	0.0022	3.234	0.007	0.249
Apr. 26–May 17	26	0.0030	1.745	0.005	0.136
May 17–Jun. 14	28	0.0028	1.436	0.004	0.113
Jun. 14–Jul. 12	28	0.0028	0.144	0.001	0.011
Sep. 15–Oct. 16	31	0.1262	0.003	0.001	0.010
Oct. 16–Nov. 12	27	0.0623	0.051	0.003	0.086
Total annual production					7.129

Δt: time interval, k: instantaneous rate of growth, $\bar{P}$: population density.

TABLE 8–9. Production rate of *Ephemerella rufa* by the growth method from November 1969 to November 1970.

Period	Δt days	k g/g/day	$\bar{P}$ g/m²	Production rate (B) for day g/m²/day	Production rate (B) for period g/m²
Winter generation					
Nov. 15–Dec. 14	29	0.0077	0.171	0.001	0.038
Dec. 14–Jan. 18	35	0.0019	0.183	0.001	0.012
Jan. 18–Feb. 15	27	0.0025	0.230	0.001	0.016
Feb. 15–Mar.22	35	0.0083	0.447	0.004	0.130
Mar. 22–Apr. 26	35	0.0166	0.825	0.014	0.479
Apr. 26–May 17	26	0.0060	0.826	0.005	0.129
May 17–Jun. 14	28	0.0017	0.499	0.001	0.024
Jun. 14–Jul. 12	28	0.0017	0.113	0.001	0.005
Summer generation					
Jun. 14–Jul. 12	28	0.0741	0.087	0.006	0.180
Jul. 12–Aug.11	30	0.0320	0.274	0.009	0.263
Aug. 11–Sep. 15	35	0.0075	0.228	0.002	0.060
Sep. 15–Oct. 16	31	0.0075	0.017	0.001	0.004
Winter generation					
Sep. 15–Oct. 16	31	0.1063	0.035	0.004	0.114
Oct. 16–Nov.12	27	0.0320	0.345	0.011	0.298
Total annual production					1.752

Δt: time interval, k: instantaneous rate of growth, $\bar{P}$: population density.

TABLE 8–10. Production rate of *Stenopsyche griseipennis* by the growth method from November 1969 to November 1970.

Period	Δt days	k g/g/day	$\bar{P}$ g/m²	Production rate (B) for day g/m²/day	Production rate (B) for period g/m²
Winter generation					
Nov. 15–Dec. 14	29	0.0020	50.752	0.102	2.944
Dec. 14–Jan. 18	35	0.0011	57.687	0.064	2.221
Jan. 18–Feb. 15	27	0.0004	45.225	0.018	0.488
Feb. 15–Mar.22	35	0.0006	41.763	0.025	0.877
Mar. 22–Apr. 26	35	0.0014	46.548	0.065	2.281
Apr. 26–May 17	26	0.0077	45.165	0.347	9.042
May 17–Jun. 14	28	0.0072	46.362	0.334	9.347
Jun. 12–Jul. 12	28	0.0072	5.859	0.042	1.181
Summer generation					
May 17–Jun. 14	28	0.2131	0.719	0.153	4.289
Jun. 14–Jul. 12	28	0.0979	33.712	3.300	92.411
Jul. 12–Aug.11	30	0.0047	94.361	0.443	13.305
Aug. 11–Sep. 15	35	0.0027	78.243	0.211	7.394
Sep. 15–Oct. 16	31	0.0019	62.763	0.119	3.699
Oct. 16–Nov.12	27	0.0027	5.528	0.015	0.403
Winter generation					
Sep. 15–Oct. 16	31	0.0967	0.342	0.033	1.025
Oct. 16–Nov.12	27	0.1236	15.953	1.972	53.239
Total annual production					214.152

Δt: time interval, k: instantaneous rate of growth, $\bar{P}$: population density.

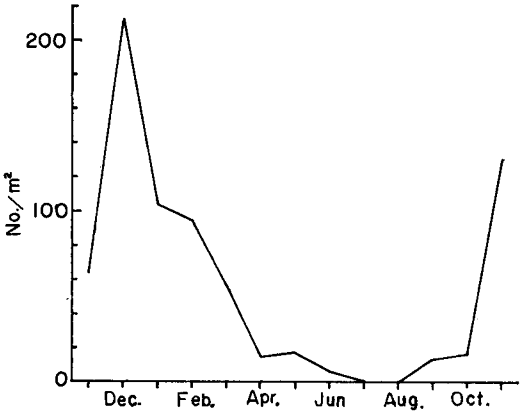

FIG. 8–14. Population density of *Tadamus scriptus* in a riffle, Mizugase.

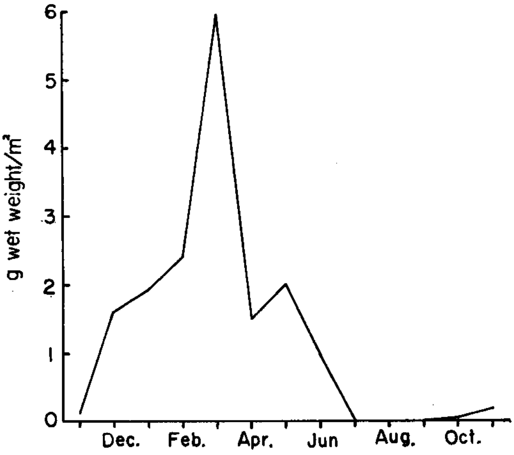

FIG. 8–15. Standing crop of *Tadamus scriptus* in a riffle, Mizugase.

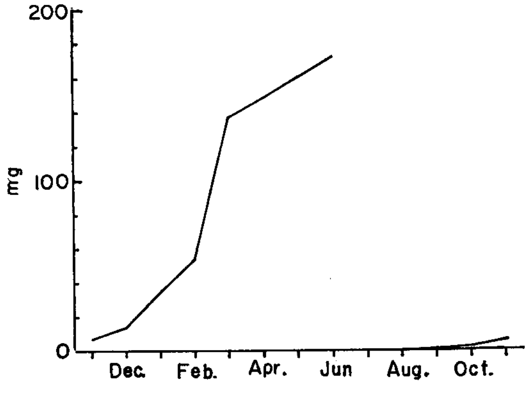

FIG. 8–16. Maximum weight of *Tadamus scriptus* from which the growth rates were calculated, Mizugase.

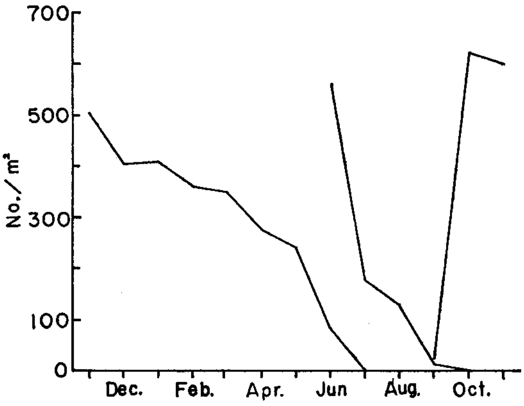

FIG. 8–17. Population density of *Ephemerella rufa* in a riffle, Mizugase.

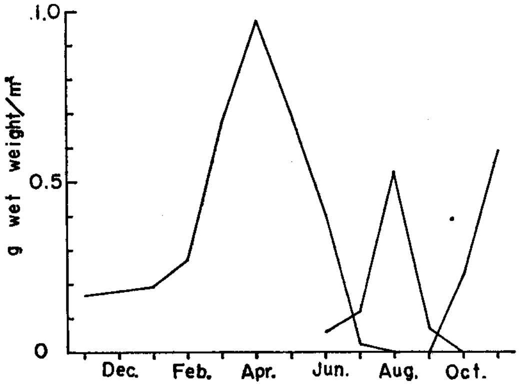

FIG. 8–18. Standing crop of *Ephemerella rufa* in a riffle, Mizugase.

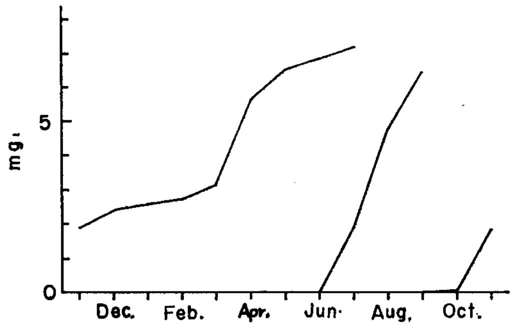

FIG. 8–19. Maximum weight of *Ephemerella rufa* from which the growth rates were calculated, Mizugase.

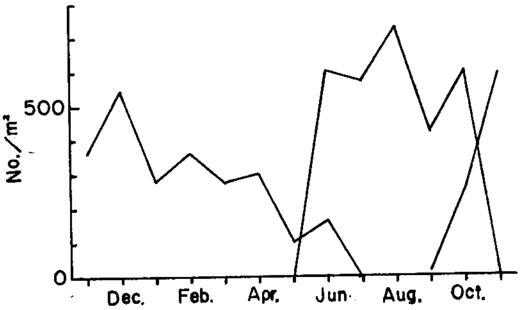

FIG. 8–20. Population density of *Stenopsyche griseipennis* in a riffle, Mizugase.

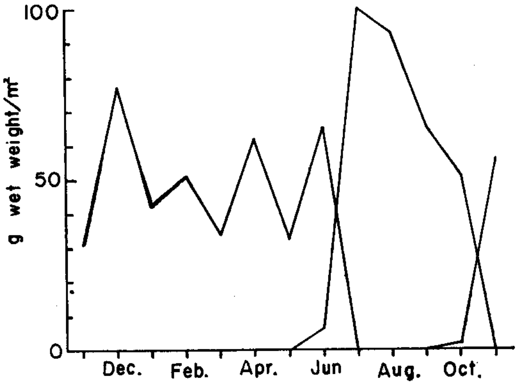

FIG. 8–21. Standing crop of *Stenopsyche griseipennis* in a riffle, Mizugase.

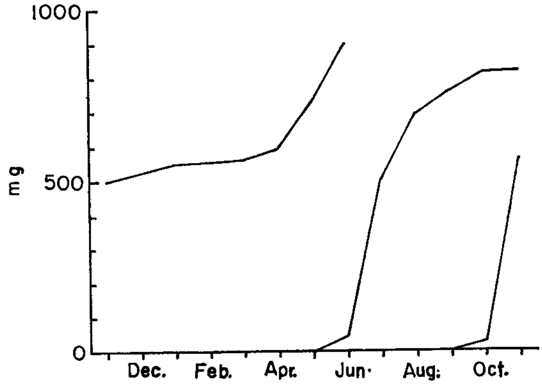

FIG. 8–22. Maximum weight of *Stenopsyche griseipennis* from which the growth rates were calculated, Mizugase.

duction of *Stenopsyche griseipennis* were about 83.65g/m^2 and 121.50g/m^2 for the winter and summer generations respectively, with an annual sum of 214.15g/m^2. The yearly turnover ratio is 5.4. The total estimates of the annual production of benthic animal communities was about 321g/m^2/yr. wet weight in a riffle of the station of Mizugase (Table 8–11). The produc-

TABLE 8–11. Mean annual standing biomass, annual production of the benthic insect community components in rapids of the River Takami-gawa at the station Mizugase from November 1969 to November 1970.

	Mean annual standing biomass g/m^2	Annual production g/m^2/year
Ephemeroptera		
Ephemera strigata	0.277	*0.665
Ephemerella basalis	0.533	**2.239
Ephemerella trispina	0.339	1.396
Ephemerella rufa	0.309	1.752
Ephemerella nigra	0.495	2.039
Ephemerella yoshinoensis	0.342	1.467
Ephemerella sp.	0.166	**0.963
Baetis yamatoensis	0.409	2.424
Baetillla thermicus	0.026	**0.161
Isonychia japonica	0.289	2.238
Epeorus latifolium	0.463	2.870
Epeorus uenoi	0.384	2.652
Epeorus ikanonis	0.306	1.255
Rhithrogena japonica	0.079	**0.324
Total (Ephemeroptera)		22.445
Plecoptera		
Tadamus scriptus	1.507	7.129
Isoperla nipponica	0.181	0.839
Paragnetina tinctipennis	1.069	4.008
Oyamia gibba	5.919	22.598
Perla tibialis	3.919	15.367
Total (Plecoptera)		49.942
Trichoptera		
Stenopsyche griseipennis	39.436	214.152
Hydropsyche ulmeri	4.337	**22.986
Rhyacophila nigrocephala	0.350	**1.435
Rhyacophila sp. RG	0.052	**0.213
Mystropora inops	0.076	**0.312
Goera japonica	0.039	**0.160
Total (Trichoptera)		239.258
Coleoptera		
Elmis sp. ED	0.002	***0.005
Diptera		
Antocha sp.	0.048	***0.504
Spaniotoma spp.	0.240	***4.192
Atherix ibis japonica	0.679	***4.754
Total (Diptera)		9.450
Total annual production		321.099

*,** Calculated from Gose's data.

*** Calculated from the data of Teal (1957), Jonasson and Kristiansen (1967), Kitagawa (1972), and Nagatomi (1958, 1961).

tion of Trichoptera was the largest of all, and especially that of *Stenopsyche griseipennis*, which was about 214/m²/yr wet weight, and it occupied the 66.7% of all the production. The total estimates of productions of Plecoptera, Ephemeroptera and Trichoptera were about 312g/m²/yr wet weight, and it occupied the 97.1% of all the production. The annual turnover ratio of every kind of species populations will be shown Table 8–12. The turnover ratio of Plecoptera is from 3.8 to 4.7. As to those of Ephemeroptera which have one generation per year, the turnover ratio is from 4.1 to 4.3, and those which have two generations show their ratio from 5.7 to 7.7. The turnover ratio of *Stenopsyche griseipennis* which belongs to Trichoptera is 5.4.

TABLE 8–12. Mean annual standing biomass, annual production, turnover ratio and number of generations of Plecoptera, Ephemeroptera and Trichoptera.

	(1) Mean annual standing biomass g/m²	(2) Annual production g/m²	(2) ÷ (1) Turnover ratio	Number of generation	Location remarks
Plecoptera					
Tadamus scriptus	1.51	7.13	4.7	1	Mizugase
Isoperla nipponica	0.18	0.84	4.7	1	Mizugase
Paragnetina tinctipennis	1.07	4.01	3.8	1	Mizugase
Oyamia gibba	5.92	22.60	3.8	1	Mizugase
Perla tibialis	3.92	15.37	3.9	1	Mizugase
Ephemeroptera					
Ephemerella yoshinoensis	0.34	1.47	4.3	1	Mizugase
Ephemerella trispina	0.34	1.40	4.1	1	Mizugase
Ephemerella rufa	0.31	1.75	5.7	2	Mizugase
Ephemerella nigra	0.50	2.04	4.1	1	Mizugase
Baetis yamatoensis	0.41	2.42	5.9	2	Mizugase
Isonychia japonica	0.29	2.24	7.7	2	Mizugase
Epeorus latifolium	0.46	2.87	6.2	2	Mizugase
Epeorus uenoi	0.38	2.65	7.0	2	Mizugase
Epeorus ikanonis	0.31	1.26	4.1	1	Mizugase
Ephemera strigata	1.8	4.3	2.4	1	*Anō
Trichoptera					
Stenopsyche griseipennis	23.76	149.96	6.3	2	Anō
Stenopsyche griseipennis	39.44	214.15	5.4	2	Mizugase
Stenopsyche griseipennis	4.19	16.70	4.0	1	Abashiri

* Anō (Gose, 1970).

8.3.5 Production, respiration, food consumption and excretion of benthic animals at the site of Mizugase of the River Takami-gawa

1) The standing crops at Mizugase in August are 114.2 g/m² in the hayase (swift rapid), 25.1 g/m² in the hirase (slow rapid) and 10.2 g/m² in the pool. And the ratio of the herbivorous insects and the carnivorous insects is assumed to be 8.2: 1.8. The net production of the herbivorous insects and the carnivorous insects in the hayase, the hirase and the pool were calculated from the above ratios (Table 8–13).

2) From the Table 8–13 and the ratio of areas of the hayase, the hirase and the pool at Mizugase, which is 2: 5: 3, the average production at the site is calculated as follows:

TABLE 8–13.

		Net production rate g/m^2
Herbivorous insects	Hayase	263.2
	Hirase	52.8
	Pool	22.4
Carnivorous insects	Hayase	52.8
	Hirase	12.1
	Pool	4.1

The herbivorous insects

$$\frac{263.2\ g/m^2 \times 2 + 52.8\ g/m^2 \times 5 + 22.4\ g/m^2 \times 3}{10} = 85.5 g/m^2$$

The carnivorous insects

$$\frac{57.8 g/m^2 \times 2 + 12.1 g/m^2 \times 5 + 4.2 g/m^2 \times 3}{10} = 18.4\ g/m^2$$

Calculated by the similar method, the respiration rate, the food consumption and the excretion rate are shown in the Table 8–14.

TABLE 8–14. Net production, respiration rate, food consumption and excretion rate of benthic animals at Mizugase between November 1969 and October 1970.

	Net production rate		Respiration rate	Food consumption rate		Excretion rate
	Wet weight g/m^2	Calory $kcal/m^2$	Calory $kcal/m^2$	Wet weight g/m^2	Calory $kcal/m^2$	Calory $kcal/m^2$
Herbivorous insects	85.5	77.9	96.1	5669.5	356.0	182.0
Carnivorous insects	18.4	16.8	24.3	50.4	45.9	4.8

Note: For the calculation of respiration rate and others the following diversion values were used:
Aquatic insects: 0.912 kcal/g in net weight (*Ephemera strigata*), from Mizuno (1971).
Attached algae: 0.0628 kcal /g in wet weight, from Gose (unpublished data).
Respiration rate of aquatic insects: By Watanabe (1970), Mizuno (1971).
Food consumption rate of aquatic insects: By Gose (1971) (Herbivorous), Mizuno and Tanaka (1969) (Carnivorous).
Excretion rate of aquatic insects: By Mizuno (1971).

8.4 Production of fishes and their food consumptions

8.4.1 Sites and methods

Two sites, Ōmata and Aritōshi, at the upper region of the river were chosen for the estimation of population densities and the measurement of sizes of fishes. The survey was carried out seasonally between October 1969 and September 1972.

At the site of Ōmata, the stream varies from 4 to 8 metres in width and is approximately 1.5 metres deep in the pool. The "Amago" (*Oncorhynchus rhodurus* f *macrostomus,* salmonoid fish), and the "Takahaya" (*Moroco steindachneri jouyi,* cyprinoid fish) are abundant at this site. Seven species of other fishes have been caught with fishing gears or observed with underwater equipment (see Table 8–15). The surveyed area, keeping a pool and a rapid, covers about 205 m² on the surface of the water.

TABLE 8–15. List of fishes caught or observed at surveyed areas.

Species	Ōmata	Aritōshi
Oncorhynchus rhodurus f *macrostomus* "Amago"	○	○
Plecoglossus altivelis "Ayu"	○	○
Tribolodon hakonensis "Ugui"	○	○
Moroco steindachneri jouyi "Takahaya"	○	○
Moroco steindachneri steindachneri "Aburahaya"		○
Zacco temmincki "Kawamutu"	○	○
Zacco platypus "Oikawa"		○
Pseudogobio esocinus "Kamatuka"		○
Liobagrus reini "Akaza"	○	○
Cobitis biwae "Shimadojō"	○	○
Anguilla japonica "Unagi"	○	○
Tukugobius flumineus "Kawayoshinobori"	○	○
Cottus hilgendorfi "Kazika"	○	○

At the site of Aritōshi, about 10 km down stream from the site of Ōmata, the width of the stream varies from 4 to 10 metres and the depth in the pool about 2 metres. Dominant fishes at this site are the "Ayu" (*Plecoglossus altivelis,* salmonoid fish), the "Ugui" (*Tribolodon hakonensis,* cyprinoid fish) and the "Takahaya". Nine other species of fishes have been caught or observed. The surveyed area covers about 467 m², keeping two pools and two rapids.

The net production rates of four species of fishes, the "Amago", the "Ayu", the "Takahaya" and the "Ugui" were estimated with the Riker's formula.

Food consumption rates of the "Takahaya" in different seasons were estimated *in situ* with the Morishita's formula in 1970.

8.4.2 Production and food consumption of the "Takahaya" *(Moroco steindachneri jouyi)*

1) Net production rate

Population densities of this fish in different seasons were estimated with the capture-recapture method. Fish were caught with the feeding trap, marked by clipping the tail fin and recaptured from 5 to 7 days after. Fish sizes were also measured by this procedure.

Fish were devided into different age groups with the Cassie's probability paper method, then, estimated their population densities with the Lincoln's method. Only the densities and the net production rates of the sub-adult and the adult fish were estimated since the trap is proved to be effective for individuals of more than two centimetres in body length (Maki, 1970).

Seasonal changes of the net production rate of this fish are shown in Fig. 8–23 (a) and (b). There are two seasons all the year round when the production rate of this fish is accelerated, that is, in early spring and between late summer and autumn. The former acceleration is based on fish aged two and three years, i.e. the adult one, on the other hand, the latter one is partly based on that of the one-year old fish, the sub-adult one, and partly on the two-year old fish.

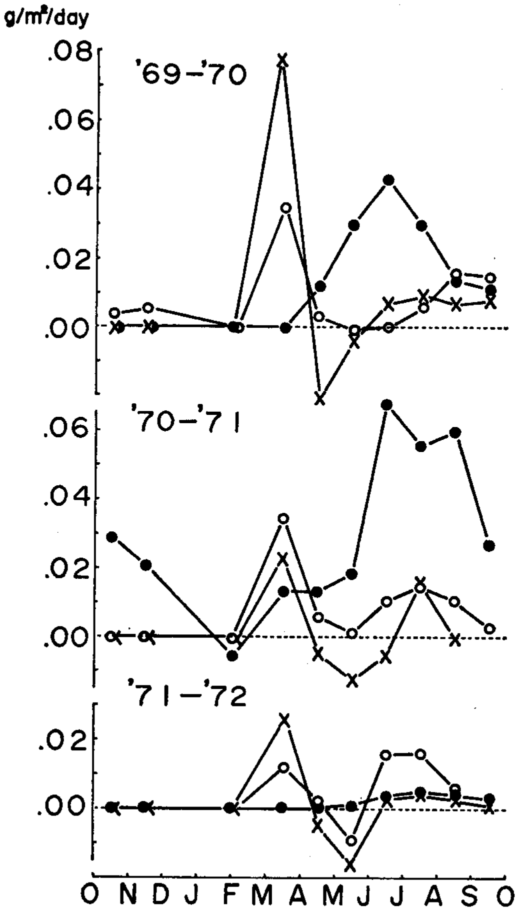

FIG. 8–23 (a). Seasonal changes of the net production rate of the "Takahaya" in three different years at the site Ōmata. Symbols, ●, ○ and × stand for the age 0–1-year old fish, the age 1–2-year old ones and the age 2–3-year old ones, respectively.

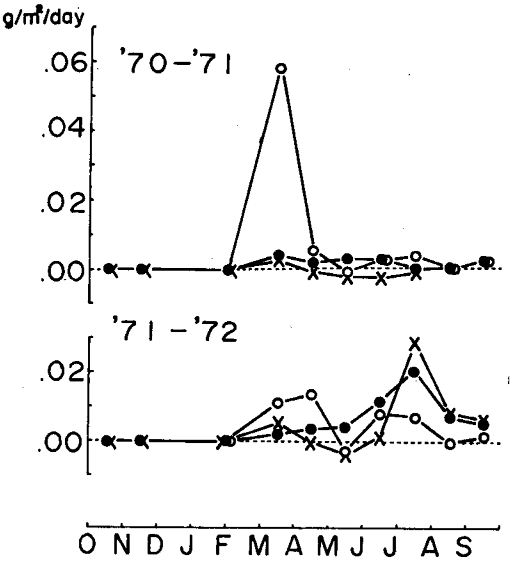

FIG. 8–23 (b). Seasonal changes of the net production rate of the "Takahaya" in the different years at the site of Aritōshi. Symbols in the figure stand for same as those in Fig. 8–23(a).

Net production rates at the site of Ōmata are 9.58g in wet weight/m^2/year between October 1969 and September 1970, 12.20 g/m^2/year during the same interval between 1970 and 1971 and 9.16 g/m^2/year between 1971 and 1972.

The values in the three different years above at the site of Aritōshi are 4.56g/m^2/year, 2.57 g/m^2/year and 3.42 g/m^2/year respectively.

2) Food consumption

Food consumption of the individuals in different seasons was estimated with the Morishita's formula (Morishita, 1968) as follows;

$$\text{Food consumption rate per day} = \sum_{i=1}^{n} C\tau i = \alpha\tau \sum_{i=1}^{n} v\tau i$$

where τ = time interval of the examination
v = food contents in the alimentary canal
α = instantaneous rate of decreasing of food contents after the fasting
C = food consumption at the interval

Daily changes of food contents and changes of them after the fasting condition of the fish were examined seasonally in the stream in 1970 (Kamata, 1973). Values of the individual in different seasons were converted into those of the population and then accumulated all the year round.

Food consumption rates of the population at two sites in different seasons between October 1971 and September 1972 are cited in the last column of Table 8–16 (a) and (b).

Food items of this fish in different ages and seasons in the River Yoshino are analysed by Mizuno et al. (1970). Based on their result, the above values were sub-divided into each food item. These values are also cited between the second and the fifth column in the tables.

TABLE 8–16 (a). Food consumption rates of the "Takahaya" in different seasons at the site Ōmata.

Seasons		Aquatic insects	Terrestrial insects	Attached algae	Terrestrial plants	Total
Age 0–1	year	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
	Oct.					
	Nov.					
	Dec.– Feb.					
	Mar.					
	Apr.					
	May	0.48	0.77	0.59	0.09	1.34
	June	1.26	0.08	0.05	0	1.38
	July	1.02	0	0.64	0.02	1.69
	Aug.	1.09	0.21	0.57	0	2.05
	Sept.	0.42	0	0.49	0.08	0.97
Total		4.27	1.06	2.33	0.20	7.42
Age 1–2	years					
	Oct.	1.82	0.10	2.87	0.18	4.96
	Nov.	0.62	0.03	0.83	0.18	1.64
	Dec.– Feb.	1.19	0.07	3.31	0.37	4.92
	Mar.	2.95	0.57	2.81	0.27	6.52
	Apr.	3.85	0.10	2.42	0.60	6.98
	May	1.44	0.09	3.78	0.23	5.54
	June	1.07	0.14	0.72	0.08	2.03
	July	2.18	0.19	0.38	0	2.74
	Aug.	1.52	0.11	1.74	0	3.38
	Sept.	1.09	0.16	0.77	0.19	2.22
Total		17.71	1.55	19.62	2.09	40.92
Age 2–3	years					
	Oct.	1.63	0.39	0.51	0.24	2.79
	Nov.	0.37	0.22	0.56	0.14	1.31
	Dec.– Feb.	0.76	0	1.78	1.41	3.93
	Mar.	3.81	0.14	1.12	0.16	5.20
	Apr.	3.50	0.09	2.20	0.55	6.34
	May	1.25	0.08	3.28	0.20	4.82
	June	1.15	0.15	0.78	0.08	2.18
	July	1.86	0.16	0.32	0	2.34
	Aug.	1.17	0.08	1.27	0	2.48
	Sept.	0.76	0.11	0.54	0	1.54
Total		16.25	1.41	12.36	2.78	32.94
Total		38.24	4.02	34.30	5.07	

Aquatic insects and attached algae are two important food organisms of this fish. At the site of Ōmata, the former is consumed 38.2g and the latter 34.3g in wet weight/m^2/year respectively. The former is consumed 24.5g/m^2/year and the latter 19.3g/m^2/year in the site of Aritōshi.

8.4.3 Production and food consumption of other fishes

The numbers of three other species of fishes at the two sites were counted seasonally with

TABLE 8–16 (b). Food consumption rates of the "Takahaya" in different seasons at the site Aritōshi.

Seasons	Aquatic insects	Terrestrial insects	Attached algae	Terrestrial plants	Total
Age 0–1 year	g/m²	g/m²	g/m²	g/m²	g/m²
Oct.	0.46	0.19	0.68	0.05	1.40
Nov.	0.12	0.19	0.41	0.02	0.74
Dec.– Feb.	0.26	0	1.12	0.87	2.23
Mar.	0.42	0.09	1.05	0.21	1.75
Apr.	1.92	0.05	0.38	0.05	2.41
May	2.74	1.05	3.36	0.53	7.63
June	9.30	0.56	0.39	0	10.17
July	9.25	0	5.82	0.22	15.35
Aug.	12.75	4.11	6.58	0	23.87
Sept.	3.40	0	3.93	0.65	7.86
Total	40.63	6.24	23.72	2.59	73.41
Age 1–2 years					
Oct.	2.39	0.14	3.77	0.24	6.52
Nov.	1.30	0.06	1.75	0.38	3.45
Dec.– Feb.	2.49	0.15	6.96	0.79	10.35
Mar.	6.22	1.21	5.92	0.56	13.73
Apr.	8.48	0.22	5.33	1.32	15.35
May	3.16	0.21	8.30	0.50	12.18
June	5.99	0.76	4.04	0.43	11.38
July	7.28	0.63	1.26	0	9.15
Aug.	2.95	0.20	3.37	0	6.56
Sept.	1.55	0.23	1.10	0.27	3.16
Total	41.80	3.79	41.79	4.49	91.83
Age 2–3 years					
Oct.	0.68	0.16	0.21	0.10	1.16
Nov.	0.17	0.10	0.26	0.07	0.61
Dec.– Feb.	0.36	0	0.83	0.66	1.84
Mar.	1.79	0.06	0.53	0.08	2.44
Apr.	1.69	0.04	1.06	0.26	3.07
May	0.48	0.03	1.25	0.08	1.84
June	0.85	0.11	0.58	0.06	1.62
July	1.42	0.12	0.25	0	1.79
Aug.	0.85	0.06	0.97	0	1.88
Sept.	0	0	0	0	0
Total	8.29	0.70	5.94	1.31	16.26
Total	90.71	10.73	71.45	8.38	

the under-water observation. Seasonal changes of these fish sizes were estimated from sample specimens caught in this stream. No examinations were made about their food consumption rates. They are taken from papers already reported or estimated from them.

1) The "Amago" *(Oncorhynchus rhodurus* f *macrostomus)*

Seasonal changes of the net production rate at the two sites between October 1971 and September 1972 are shown in Fig. 8–24. However, that of yearling fish between late autumn and the following May is not included in the figure.

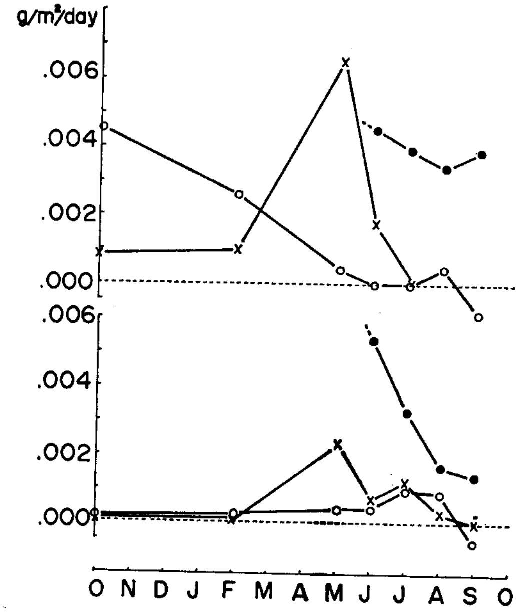

FIG. 8–24. Seasonal changes of the net production rate of the "Amago" at the site of Ōmata (upper) and at the site of Aritōshi (lower) between October 1971 and September 1972. Symbols in the figure stand for same as those in Fig. 8–23(a).

The net production rates at both sites take large values between April and September. Their values are 1.44 g in wet weight/m²/year at the site of Ōmata and 0.60g/m²/year at the site of Aritōshi respectively.

The food consumption rate of the individual per day was calculated from the data for the daily change of food contents in the alimentary canal reported by Mizuno (1972). Moreover, assuming that the fish takes food organisms at a constant rate between March and November, the food consumption rate of the population was converted from the above result.

This fish popultion, produced 1.44 g in wet weight/m²/year of the body at the site of Ōmata, have 7.85 g in wet weight of food organisms/m²/year. The 4.49 g/m²/year of food organisms are consumed at the site of Aritōshi.

The most important food organisms of this fish are aquatic insects and terrestrial insects fallen on the water surface are also eaten considerably (Mizuno, 1972).

2) The "Ayu" *(Plecoglossus altivelis)*

This fish is bred in this stream late in April and it inhabits there till early September. Changes of the net production rate in this interval at both sites are shown in Fig. 8–25.

The maximum rate of the net production is attained between June and July. Values at the site of Ōmata and the site of Aritōshi are 0.0133 g/m²/day and 0.046 g/m²/day in wet weight respectively. Net production rates per square metre per year are 0.992g in the former and 3.03g in the latter.

The food consumption rate of the individual is estimated by Kawanabe (1959). According to his result that this fish takes the food gaining the amount of 30 percent of its body weight per day, food consumption rates of the population at both sites were calculated.

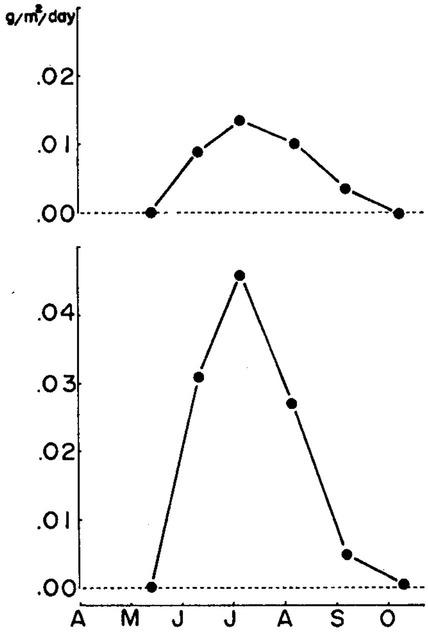

FIG. 8–25. Seasonal change of the net production rate of the "Ayu" at the site of Ōmata (upper) and at the site of Aritōshi (lower) between October and September 1972.

Their values at the site of Ōmata and the site of Aritōshi are 18.95 g and 70.62 g per square metre in the above interval.

3) The "Ugui" *(Tribolodon hakonensis)*

The net production rate of this fish was estimated only at the site of Aritōshi. Between May and August, the production rates of the sub-adult population, i.e. the one-year old and the two year-old fish, take large values, attaining to the maximum in July. On the other hand, those of the adult population, i.e. the three-year old and four-year old fish, take large values between June and September, and, at the spawnning season, that is, between April and May, they take negative values (see Fig. 8–26).

The net production rate of this fish is 2.98 g in wet weight /m^2/year.

The food consumption rate of this fish cannot be estimated.

8.4.4 Production of fishes and their food consumption at the upper region of the River Yoshino

Net production rates of four species of fishes and food consumption rates of three species of fishes, except the "Ugui" between October 1971 and September 1972 are cited in Table 8–17 (a) and (b). Values in the calory converted from the wet weight are also cited in the tables. Conversion rates from the wet weight into the calory are as follows;

"Amago": 0.93 kcal/g in wet weight, from Wallen et al. (1969)
"Ayu": 1.00 kcal/g in wet weight, from Suzuki (1973)

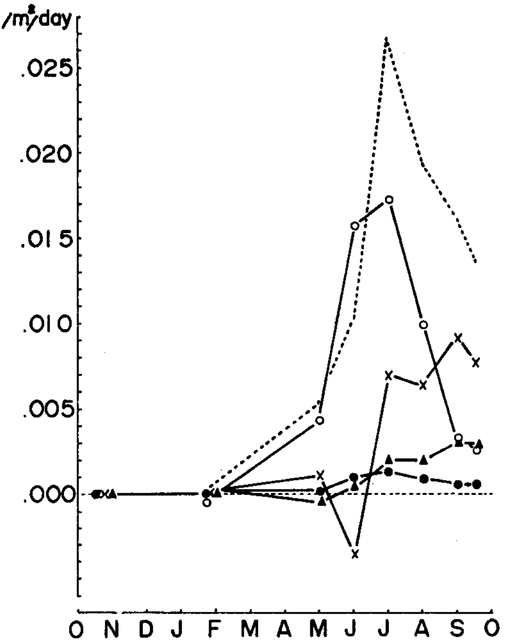

FIG. 8–26. Seasonal changes of the net production rate of the "Ugui" at the site Aritōshi between October in 1971 and September in 1972. Symbols in the figure stand for same as those in Fig. 8–23(a).

"Ugui" and "Takahaya": 0.97 kcal/g in wet weight, from Mizuno (1971). Substituted value for *Zacco platypus* (cyprinoid fish).

Aquatic insects and terrestrial insects: 0.912 kcal/g in wet weight, from Mizuno (1971). The value of the Mayfly *Ephemera strigata.*

Attached algae: 0.332 kcal/g in wet weight, from Kawanabe et al. (1960).

Terrestrial plant: 1.98 kcal/g in wet weight, from Mizuno (1971). The value of fallen leaves.

At the site of Ōmata the "Amago" takes 7.2 kcal of food organisms/m²/year and is produced 1.34 kcal/m/²year of its body. The value of the ratio of net production rate to food consumption rate (K_1) is 0.187. Food organisms of 4.10 kcal/m²/year are consumed and 0.561 kcal/m²/year of the body is produced at the site of Aritōshi. The value of K_1 takes 0.137.

Values of K_1 in the "Ayu" and the "Takahaya" are 0.158 and 0.128 at the site of Ōmata and 0.129 and 0.076 at the site of Aritōshi, respectively.

The total net production rates of these fishes take 11.23 kcal/m²/year at the site of Ōmata and 9.57 kcal/m²/year at the site of Aritōshi respectively. And, food consumption rates of these fishes are 82.85 kcal/m²/year at the former and 68.0 kcal/m²/year at the latter. No data are found of the food consumption rate of the "Ugui". It seems to consume approximately the same amount of food organisms, about 20 kcal/m²/year, as those of the "Ayu" since the net production rate of the former at the site of Aritōshi is about the same as that of the latter although the former is omnivorous. Then, the total food consumption rate at the site of Aritōshi takes about 87.99 kcal/m²/year.

TABLE 8–17 (a). Net production and food consumption rates of fishes at the site of Ōmata between October 1971 and September 1972.

Species	Age	Net poduction rate		Food consumption rate									K_1
				Aquatic insects		Terrestrial insect		Attached algae		Terrestrial plants		Total	
		Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Calory	
		g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	kcal/m^2	
Oncorhynchus													
rhodurus f	1	0.42		3.39 (included terrestrial insects)									
macrostomus	2	0.56		2.19 (included terrestrial insects)									
"Amago"	3	0.46		2.27 (included terrestrial insects)									
Total		1.44	1.34	7.85	7.16							7.16	0.187
Plecoglossus altivelis		0.99	0.99					18.95	6.29			6.29	0.158
"Ayu"													
Moroco													
steindachneri	1	0.52		4.27		1.06		2.33		0.20			
jouyi	2	8.17		17.71		1.55		19.62		2.09			
"Takahaya"	3	0.49		16.25		1.41		12.36		2.78			
Total		9.17	8.90	38.24	34.87	4.02	3.67	34.30	11.39	5.07	19.58	69.51	0.128
Total			11.23		42.03		3.67		17.68		19.58	82.95	

TABLE 8–17 (b). Net production and food consumption rates of fishes at the site of Aritōshi between October 1971 and September 1972.

Species	Age	Net production rate		Food consumption rate									K_1
				Aquatic insects		Terrestrial insects		Attached algae		Terrestrial plants		Total	
		Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Wet weight	Calory	Calory	
		g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	g/m^2	kcal/m^2	kcal/m^2	
Oncorhynchus													
rhodurus f	1	0.36		2.18 (included terrestrial insects)									
macrostomus	2	0.12		1.28 (included terrestrial insects)									
"Amago"	3	0.15		1.04 (included terrestrial insects)									
Total		0.60	0.56	4.49	4.10							4.10	0.137
Plecoglossus altivelis		3.03	3.03					70.62	23.45			23.45	0.129
"Ayu"													
	1	0.36											
Tribolodon	2	0.13											
hakonensis	3	1.42											
"Ugui"	4	0.76											
	5	0.32											
Total		2.98	2.89										
Moroco													
steindachneri	1	1.79		10.96		1.68		6.40		0.70			
jouyi	2	1.24		11.28		1.02		11.27		1.21			
"Takahaya"	3	0.15		2.24		0.19		1.60		0.35			
Total		3.18	3.09	24.47	22.32	2.96	2.64	19.28	6.40	2.26	9.08	40.44	0.076
Total			9.57		26.42		2.64		29.85		9.08	67.99	

It is suggested that about 80 kcal/m²/year of food organisms are consumed and about 10 kcal/m²/year of fish bodies are produced at the upper region of this river.

The consumption rate of aquatic insects and that of attached algae are 42.0 kcal/m²/year and 17.7 kcal/m²/year respectively at the site of Ōmata. On the other hand, the former take 26.4 kcal/m²/year and the latter 29.9 kcal/m²/year at the site of Aritōshi, 10 km down stream. Values of both food organisms at this site may take about 40 kcal/m²/year because the "Ugui" may take about 20 kcal/m²/year and it is omnivorous as mentioned before.

It is interesting that the farther upstream one goes the more aquatic insects are consumed although the consumption rates of the food organisms by fishes are about the same calories per square meter per year at both sites.

8.5 Trophic relationship

8.5.1 Trophic relationships

Trophic relationships of the ecosystem at the sites of Mizugase, Takami-gawa are represented diagrammatically in Fig. 8–27.

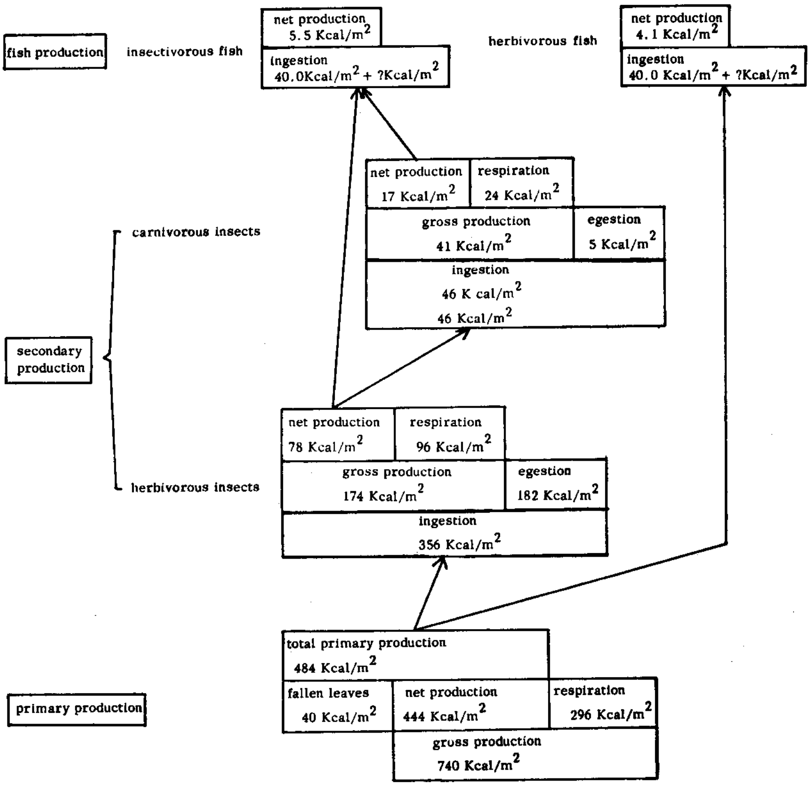

FIG. 8–27. Trophic relationships at the site of Mizugase, Takami-gawa (unit: kcal/m²/yr).

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