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PRODUCTION RATES OF AQUATIC INSECTS IN A TURBID RESERVOIR*

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Buckley Creek 3F is a turbid 13 ha reservoir in southeastern Nebraska. The quality of the environment was assessed in 1977 with an annual production estimate of the benthic insects.

Monthly bottom samples were taken using a 15 cm (6 in) Ekman dredge. To observe any correlation between production and other factors, chemical and physical parameters consisting of total alkalinity, hardness, pH, conductivity, salinity, temperature, dissolved oxygen, and suspended solids were monitored.

Total benthic production was 0.156 $g/m^2/yr$ (dry weight). Individual genera produced between 0.001 (*Chaobonus* sp.) and 0.057 $g/m^2/yr$ (*Hexagenia* sp.). Published studies show other waters to be two to 1,200 times more productive than Buckley on a total fauna comparison. Single species comparisons showed Buckley to be less productive by a similar magnitude.

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INTRODUCTION

Reservoirs are a major recreational resource in Nebraska. In a 1972 survey, it was estimated that Nebraska has more than 30,769 ha of water in small, artificial impoundments less than 405 ha each (Anonymous, 1973).

Although many reservoirs in the midwest are designed with recreational purposes in mind, a common problem of turbidity reduces their value. Fish production and, therefore, fishing success have been demonstrated to be lower in turbid water than in clear bodies of water (Alabaster, 1972). In a study of 12 ponds of varied natural turbidities, the average total weight of fish produced after the end of two growing seasons in clear ponds was approximately 1.7 times greater than in muddy ponds (Buck, 1956). One probable cause of low fish production is low food availability. Aquatic insects are an important food source for largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and other game fish (Gerking, 1962).

Production information is recognized as a valuable tool for aquatic biologists. Secondary production estimates of aquatic insect faunas have been lacking from the literature, and only recently have production rates been used in the evaluation of environmental conditions (Waters, 1977). Most production methods were developed for fisheries studies and require that each cohort be identified and followed through time. Complex life cycles and overlapping generations of many aquatic insects make cohort identification difficult.

Hynes (1961) introduced a new method of estimating productivity devised to eliminate the problem of cohort identification as well as provide estimates for the entire fauna. Errors in his original method were corrected by Hynes and Coleman (1968) and Hamilton (1969). The Hynes method in its final form gives results comparable to other methods (Hudson and Swanson, 1972; Neveu, 1973; Waters and Crawford, 1973; Cushman, Elwood, and Hildebrand, 1975). With the Hynes method it is now practical to calculate the production of entire benthic insect faunas.

The objective of this project was to determine yearly production rates of aquatic insects found in Buckley 3F Reservoir. A secondary objective was to compare Buckley's productivity to other bodies of water to assess the impact of the turbidity.

DESCRIPTION OF STUDY AREA

Buckley 3F is a 13 ha reservoir in Jefferson County, Nebraska, completed in November 1970. The reservoir is shallow (less than 4.5 m maximum depth) and very turbid. This impoundment and adjacent land is currently being developed

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for recreational uses. The reservoir was stocked with bluegill, largemouth bass, and channel catfish, *Ictalurus punctatus,* in 1971, and walleye, *Stizostedion vitreum,* and northern pike, *Esox lucius,* in 1975. A fishery survey conducted in 1977 found white perch, *Morone americana,* black bullhead, *Ictalurus melas,* gizzard shad, *Dorosoma cepedianum,* red shiner, *Notropis lutrensis,* and fathead minnow, *Pimephales promelas,* in addition to bluegill, largemouth bass, and channel catfish. Northern pike were not found.

Most of the reservoir is less than 2 m deep. Only near the dam where fill was removed is the water deeper. The original channel of Buckley Creek is located along the northern shore of the reservoir. Springs are present in the southeastern corner.

The substrate is almost universally silt and clay. Gravel is present only along the face of the dam and out to a depth of 1 m or less. Very little organic matter is evident in the substrate. In the deeper water (2–4 m), the substrate supports a fungus of the genus *Phycomycetes.* Only in the very shallow water (<1 m) near the shore, is there a slight build-up of decaying vegetation. This detritus is probably due to allochthonous input from terrestrial runoff since littoral vegetation is virtually absent.

Table I lists the mean physical and chemical information throughout the reservoir during the study. Of note are the relatively low conductivity values which ranged from 58 to 140 UMHOS/cm with a mean of 84 UMHOS/cm. This may be due in part to the nature of the inflow to the reservoir which is almost entirely due to rainwater runoff and reflects the condition of the adjacent lands.

The most distinguishing characteristic of the reservoir is its high turbidity. Secchi disc readings rarely, if ever, exceed 15 cm (Johnson, 1975). The suspended solid load ranged from 186 to 588 mg/l during the study (Table I); the highest values occurred during the summer months and near the bottom. Even during ice cover the solids do not settle out appreciably. Four factors contribute to this condition: (1) the silt-clay substrate, (2) the low dissolved solids of the water, (3) the shallowness of the reservoir, and (4) the openness of the surrounding area allowing little protection from the wind. With this high degree of mixing by the wind and the shallow depth, the silt-clay substrate is easily mixed throughout the water. Another consequence of the shallowness and degree of mixing is a relatively uniform temperature profile throughout the year. The reservoir rarely stratifies thermally. Oxygen is relatively uniform through all depths; however, a slight decrease appears near the bottom in the deeper water (3 to 4 m).

In general, the environment is a monotonous one. Aside from the small amount of allochthonous material near the shore, the benthos of Buckley Reservoir experiences the same conditions throughout the area.

METHODS

Monthly sampling was started in February 1977 and continued through January 1978. Three sample sites were selected in each 1 m depth interval. Since water deeper than 4 m was rarely found, four intervals were sampled, making a total of 12 sample sites which were in approximately the same locations each month. Dissolved oxygen, hardness, temperature, conductivity, salinity, pH, and alkalinity were measured in the field

TABLE I. Physical and chemical parameters of Buckley Creek Reservoir, Jefferson County, Nebraska.

Date	Oxygen (ppm)	Water Temp. °C	Conductivity (UMHOS)	Salinity (%)	Alkalinity (mg/l $CaCO_3$)	Hardness (mg/l $CaCO_3$)	pH	Suspended Solids (mg/l)
Feb. 10	10.2	3.0	---	---	---	---	---	---
March 19	10.5	5.0	---	---	78.5	68.4	8.4	283
May 13	7.6	20.0	---	---	119.7	136.8	6.7	317
June 1	5.6	21.0	---	---	59.9	59.9	8.3	403
June 25	6.2	24.5	126	0	59.9	59.9	8.0	528
July 23	6.1	28.0	140	0	88.5	78.5	7.9	588
Aug. 22	4.8	23.0	75	0	59.9	59.9	7.3	569
Sept. 25	6.4	19.0	65	0	68.4	51.3	7.1	489
Oct. 30	8.4	14.0	65	0	68.4	59.9	7.5	335
Nov. 20	10.6	6.0	59	0	51.3	51.3	7.5	273
Jan. 5	12.0	2.5	58	0	59.9	59.9	7.3	186
Average	8.0	15.1	84	0	71.4	68.5	---	397

on each sample date. Oxygen, conductivity, salinity, and temperature were determined using meters. Hardness, pH, and alkalinity were measured by using a Hach kit. Dissolved oxygen concentrations were checked in the laboratory by Winkler titration. Water samples were taken to the laboratory to be analyzed for suspended solids.

Bottom samples were taken each month using a 15.24 cm (6 in) Ekman dredge. Two samples were taken at each site for a total of 24 samples a month. In a similar study, it was shown that shallow water was more productive and diverse than deep water (Gerking, 1962). A higher percentage of the samples should be taken in the shallower, more densely populated habitats to increase the accuracy of the estimate. An analysis of variance of the March and May data showed no significant difference ($p>0.05$) in numbers, due to depth. Therefore, each depth was sampled equally throughout the program.

Samples were preserved in 10% formalin, taken to the laboratory and run through sieves to separate the organisms from silt and smaller debris. Sieve size is very important in the quantitative collection of benthos. Generally head capsule width determines if a sieve is quantitative (Jonasson, 1955). Other factors include body width and length. Large larvae may appear more numerous than small ones of the same instar in samples, indicating that growth within the stadium may also influence retention of larvae by the sieve (Shiozawa and Barnes, 1977). Jonasson (1955) showed a loss of 50% of *Chironomus anthracinus* having head capsule widths of 20% smaller than the sieve openings. The smallest sieve used in this study had a mesh size of 0.250 mm. Larvae with head capsule widths less than 0.250 mm are not quantitatively collected.

To facilitate sorting, material retained in the sieves was floated in a NaCl solution to separate organisms from excess detritus. A large number of samples must be taken to obtain an estimate having reliable accuracy. The tedious and time consuming "bug picking" chore often makes it impractical to collect enough samples to achieve the desired accuracy. Any reliable procedure which reduces sorting time, allowing additional samples to be processed, is beneficial. Considerable effort has been spent devising methods to reduce sorting time. Flotation techniques have been used in faunal analysis by a number of investigators with good success (Anderson, 1959; Kajak, Dusoge, and Prejs, 1968). Hand picking the "non-float" material in three random samples each month, determined that floating was 85.5% efficient for the total insect fauna. Dominant chironomids were extracted at an 83.9% efficiency. *Hexagenia, Stilobezzia, Caenis, Oecetis,* and *Chaoborus* were collected at 87.1, 95.4, 60.0, 62.5, and 100% efficiencies, respectively. With these values the aid of the flotation technique in the sorting process justified its use.

Larvae were hand picked from the remaining detritus under a dissecting microscope, sorted to the lowest taxonomic group feasible, and stored in 40% isopropyl alcohol. Chironomidae were further separated into groups according to external characteristics. Microscope slides of representative head capsules from each group were made for generic identification. Head capsules were cleared and mounted in a permanent mounting medium. Some small individuals were identified from simple wet-mount slides of uncleared head capsules. Identification was made primarily with the key by Mason (1973).

Production was estimated using the Hynes method as modified by Hamilton (1969). The most attractive feature of this method is that detailed knowledge of the species involved is not required for an estimate of the "right order of magnitude"; however, an increase in the accuracy of the estimate is possible when certain information is available on the individual species (Hynes and Coleman, 1968). In fact, to comply with the assumptions, life history information is required.

Originally, Hynes (1961) assumed that all species included in the estimate were univoltine. Hamilton (1969) demonstrated that annual production of species requiring less than a year to complete their life cycle is underestimated by a factor approximately equal to the number of generations per year, and in those species requiring more than a year for development is overestimated by a factor approximately equal to the number of years required to complete their development. Although Hynes and Coleman (1968) felt that bivoltine and hemivoltine species, to some extent, counteract each other, it was agreed that increased precision in the estimate would be achieved by handling each class of organism separately. It is therefore necessary to determine the voltinism of each species involved.

The ages of all specimens collected during this study were determined from head capsule width measurements as described by Kitching (1970). Organisms were measured to the nearest 0.025 mm in wet condition using an ocular micrometer in a dissecting microscope. By observing the percentage of individuals in each age class through time, the voltinism of the species could be determined. This was done for all major genera in this study.

A second assumption, shown by Hamilton (1969) to be very important, is that all organisms in the group treated together must be capable of growing to the same maximum size. If a species with small individuals is included with one of large individuals, an overestimate will occur. This is a common problem when dealing with more than one species, since rarely do organisms of two species grow to identical sizes. Using the same data and single species calculations, Waters (1977) estimated production to be two-thirds that of Hamilton's estimate which combined values for ten species of various maximum sizes.

A third assumption, growth of the organism must be linear, means growth is progressive and the organism must spend equal time in each size class. In practice this assumption is rarely met. Hamilton (1969) demonstrated that irregular growth did not seriously influence the accuracy of the estimate of total annual production. Because of this requirement, the choice of the measurement used for the size classes is important. For convenience, lengths were used by Hynes (1961), Hynes and Colemen (1969), Hamilton (1969), and Fager (1968). A better measurement is head capsule width. Growth in length of insects is often non-linear. Even under constant conditions larvae often decrease in length after metamorphosing from one instar to the next (McCauley, 1974). Head capsule widths, on the other hand, show a continued, progressive increase with each molt. The size intervals then are the instars for each species, determined by head capsule measurements. A frequency distribution of the head capsule widths for each species reveals the size interval for each instar.

Head capsule width measurements give more life history information than do lengths. The voltinism of each species must be determined, and therefore instar determination is required. The recognition of insect instars is usually based upon the width of the head capsule. With just the one measurement, instars can be distinguished, voltinism determined, and the organisms separated into size classes. Voltinism for each major genus was determined by observing changes in age composition throughout the year.

Hynes (1961), in his original work, converted lengths to wet weight by assuming organisms are cylinders five times longer than broad with a specific gravity of 1.05. Direct weighing would yield more accurate results (Hamilton, 1969) and therefore was done in this study. All the specimens were placed in respective size classes, oven dried at 110 C. for at least 20 hr, placed in a desiccator for 2 hr and weighed to the nearest 0.1 mg. This process was repeated three times to assure no additional loss of weight. The production values are in terms of annual dry weight/m^2.

RESULTS AND DISCUSSION

The insect fauna of Buckley Creek Reservoir was low in diversity and standing crops. Only six families from three orders were regularly represented in the samples. The family Chironomidae was dominant, contributing six genera while the other five families contributed only one genus each (Table II). Other insects were collected, but on only very rare occasions. These included Collembola, Dytiscidae, and other chironomid larvae of *Chironomus* sp., *Paracladapelma* sp., and *Glyptotendipes* sp. A damselfly, *Argia* sp., was collected using an artificial substrate sampler placed along the shore during September. Table II shows mean densities and summarizes production calculations for each major taxon.

TABLE II. Annual production data of benthic aquatic insects from Buckley Creek 3F Reservoir, Jefferson County, Nebraska, February 1977 through January 1978.

Size Interval (mm)	#/m^2	Mean Wt. (mg)	Wt. at Loss (mg)	# Loss/m^2	Wt. Loss (mg)	Production g/m^2
			DIPTERA			
Chironomidae						
Parachironomus sp.						
0.076-0.125	38.8	0.0091				
			0.0145	-100.0	-1.450	-0.00435
0.126-0.225	138.8	0.0190				
			0.0399	120.0	4.788	0.01436
0.226-0.325	18.8	0.0600				
			0.0600	18.8	1.128	0.00338
Total	196.4					0.01339
Polypedilum sp.						
0.051-0.125	10.4	0.0309				
			0.0297	-31.4	-0.9326	-0.00373
0.126-0.200	41.8	0.0285				
			0.0743	31.7	2.3553	0.00942
0.201-0.325	10.1	0.1201				
			0.2739	8.6	2.3555	0.00942
0.326-0.400	1.5	0.4278				
			0.4278	1.5	0.6417	0.00257
Total	63.8					0.01768
Cryptochironomus sp.						
0.076-0.125	1.0	0.0100				
			0.0204	-1.4	-0.0286	-0.00017
0.126-0.225	2.4	0.0308				
			0.1335	-0.9	-0.1202	-0.00072
0.226-0.325	3.3	0.2361				
			0.2361	3.3	0.7791	0.00467
Total	6.7					0.00378
Procladius sp.						
0.076-0.250	68.3	0.0084				
			0.0108	41.6	0.44928	0.00360
0.251-0.350	26.7	0.0132				
			0.0245	16.9	0.41405	0.00332
0.351-0.500	9.8	0.0358				
			0.0812	7.0	0.56875	0.00456
0.501-0.650	2.8	0.1267				
			0.1267	2.8	0.35976	0.00284
Total	107.6					0.01432
Coelotanypus sp.						
0.101-0.200	12.2	0.0164				
			0.0202	-35.6	-0.7191	-0.00216
0.201-0.350	47.8	0.0240				
			0.0671	17.5	1.1743	0.00352
0.351-0.550	30.3	0.1101				
			0.1101	30.3	3.3360	0.01001
Total	90.4					0.01137

TABLE II. (Continued).

Size Interval (mm)	#/m^2	Mean Wt. (mg)	Wt. at Loss (mg)	# Loss/m^2	Wt. Loss (mg)	Production g/m^2
Ablabesmyia sp.						
0.101 - 0.200	3.4	0.0368	0.0489	0.3	0.0147	0.00012
0.201 - 0.400	3.1	0.0611	0.0806	1.0	0.0806	0.00064
0.401 - 0.700	2.1	0.1000	0.2063	0.6	0.1238	0.00099
0.701 - 1.025	1.5	0.3125	0.3125	1.5	0.4688	0.00376
Total	10.1					0.00551
Ceratopogonidae						
Stilobezzia sp.						
0.051-0.075	38.7	0.0026	0.0047	-45.0	-0.211	-0.00084
0.076-0.125	83.7	0.0068	0.0236	38.2	0.901	0.00361
0.126-0.200	45.5	0.0404	0.1111	43.7	4.855	0.01942
0.201-0.275	1.8	0.1818	0.1818	1.8	0.327	0.00131
Total	169.6					0.02349
Chaoboridae						
Chaoborus sp.						
Limnetic						
Limnetic						
0.451-0.550	2.3	0.1954	0.2352	1.8	0.4233	0.00085
0.551-0.650	0.5	0.2750	0.2750	0.5	0.1375	0.00028
Total	2.8					0.00113
EPHEMEROPTERA						
Ephemeridae						
Hexagenia sp.						
0.21-0.30	0.49	0.0050	0.0067	0.00	0.000	0.0000
0.31-0.40	0.40	0.0084	0.1010	-0.98	0.000	-0.0011
0.41-0.50	1.47	0.0926	0.0783	-0.81	0.000	-0.0007
0.51-0.60	2.28	0.0639	0.1431	1.14	0.163	0.0019
0.61-0.70	1.14	0.2222	0.1707	-0.65	0.111	0.0013
0.71-0.80	1.79	0.1191	0.2151	-0.98	-0.210	-0.0024
0.81-0.90	2.77	0.3111	0.3431	1.14	0.391	0.0045
0.91-1.00	1.63	0.3750	0.4084	-1.14	-0.466	-0.0054
1.01-1.10	2.77	0.4417	0.6167	2.12	1.307	0.0150

TABLE II. (Continued).

Size Interval (mm)	#/m^2	Mean Wt. (mg)	Wt. at Loss (mg)	# Loss/m^2	Wt. Loss (mg)	Production g/m^2
1.11-1.20	0.65	0.7917	0.7000	-0.49	-0.343	0.0039
1.21-1.30	1.14	0.6083	0.7575	0.32	0.242	0.0028
1.31-1.40	0.82	0.9067	1.0594	-0.16	-0.169	-0.0019
1.41-1.50	0.98	1.2120	1.3060	0.00	0.000	0.0000
1.51-1.60	0.98	1.4000	1.8130	0.00	0.000	0.0000
1.61-1.70	0.98	2.2250	2.2625	0.49	1.109	0.0127
1.71-1.80	0.49	2.3000	2.4915	-0.33	-0.822	-0.0094
1.81-1.90	0.82	2.6830	2.6830	0.82	2.200	0.0253
1.91-2.00	0.00	0.0000	3.7665	-0.65	-2.448	-0.0281
2.01-2.10	0.65	4.8500	4.8500	0.65	3.152	0.0362
2.11-2.20	0.00	0.0000	5.5000	-0.16	-0.880	-0.0101
2.21-2.30	0.16	6.1500	6.1500	0.16	0.984	0.0113
2.31-2.40	0.00	0.0000	6.9000	-0.16	-1.104	-0.0127
2.41-2.50	0.16	7.6500	7.6500	0.16	1.224	0.0141
Total	24.00					0.0571
Caenidae						
Caenis sp.						
0.21-0.30	0.16	0.0200	0.0305	-1.96	-0.0598	-0.00054
0.31-0.40	2.12	0.0410	0.0479	-0.16	-0.0077	-0.00007
0.41-0.50	2.28	0.0598	0.0641	0.82	-0.0526	-0.00040
0.51-0.60	3.10	0.0733	0.1300	2.28	0.2964	0.00267
0.61-0.70	0.82	0.1867	0.1788	-0.48	-0.0858	-0.00077
0.71-0.80	1.30	0.1708	0.2104	0.50	0.1052	0.00095
0.81-0.90	0.80	0.2500	0.4167	0.50	0.2084	0.00188
0.91-1.00	0.30	0.5833	0.7417	0.14	0.1038	0.00093
1.01-1.10	0.16	0.9000	0.9000	16.00	144.0000	0.00130
Total	11.30					0.00587
TRICHOPTERA						
Leptoceridae						
Oecetis sp.						
0.11-0.20	0.33	0.0050	0.0062	-1.46	-0.0090	-0.00007
0.21-0.30	1.79	0.0074	0.0420	-0.17	-0.0071	-0.00006

TABLE II. (Continued).

Size Interval (mm)	$\#/m^2$	Mean Wt. (mg)	Wt. at Loss (mg)	$\#$ Loss/m^2	Wt. Loss (mg)	Production g/m^2
0.31-0.40	1.96	0.0766	0.0383	1.96	0.0751	0.00060
0.41-0.50	0.00	0.0000	0.1000	-0.98	-0.0980	-0.00078
0.51-0.60	0.98	0.2000	0.3650	0.82	0.2993	0.00239
0.61-0.70	0.16	0.5300	0.5300	0.16	0.0848	0.00068
0.71-0.80	0.00	0.0000	0.4650	-0.16	-0.0744	-0.00059
0.81-0.90	0.16	0.4000	0.4000	0.16	0.0640	0.00051
Total	5.70					0.00267

Parachironomus **sp.**: This chironomid belongs to the Chironominae. It was the most abundant taxon. *Parachironomus* sp. had one emergence period lasting from May through July. No fourth instar individuals appeared from August through January and were also lacking in February. *Parachironomus* sp. overwintered in Buckley in the first, second, and third instars.

Species of *Parachironomus* may have one or two generations per year. Mundie (1957) found two generations per year in shallow water but only one in water deeper than 6 m. *P. tenuicaudatus* has one generation per year in Ontario, Canada, but at Urbana, Illinois, it was suspected to have two (Miller, 1941). It is apparent that voltinism is a function of species differences and is affected by various environmental conditions.

Polypedilum **sp.**: This species belongs to the Chironominae. It was easily recognized by its red body, small, round head, and compressed posterior prolegs. The small first lateral teeth of the labial plate with larger middle and second laterals confirmed the identification when head capsules were examined microscopically.

Fourth instar larvae were present during most of the year except from September through November. During no month did they appear in large numbers to indicate pre-emergence.

Polypedilum sp. is univoltine in Buckley with emergence from June through September. This is in contrast to findings of Mundie (1957) who observed that species of *Polypedilum* have two or three generations per year. Potter and Learner (1974) found *P. albicornis* emerged only from May through July in a shallow, eutrophic reservoir in South Wales.

Crytochironomus **sp.**: This member of the Chironominae was easily recognized by its pale red body and wide, light, middle tooth of the labial plate flanked by oblique laterals. Larvae occurred at an average density of only 6.7 individuals/m^2. Studies in Michigan (Curry, 1958) also found low densities of this genus which were explained by their carnivorous and territorial habits.

Largest instars were sampled in Buckley throughout the year. This tends to indicate either a multiple or continuous emergence pattern. Curry (1958) found species of *Cryptochironomus* to emerge at various times from April through October. Potter and Learner (1974) collected adults of *C. psittacinus* from a reservoir in South Wales in May and then again in August indicating bivoltinism. In the same study they collected adults of *C. supplicans* from May through September indicating continuous emergence which could also be bivoltinism. *Cryptochironomus* appears to be bivoltine in Buckley.

Procladius **sp.**: This member of the Tanypodinae is characterized by a very small and narrow body with long posterior prolegs extending at right angles from the body. The large, oval-shaped head looked out of proportion with the body. Identification characteristics of the head capsule for members of this genus is a lingua with five black teeth and paralabial combs present. Generally, members of the Tanypodinae are carnivorous. Boesel (1974) found members of *Procladius* feeding on small crustaceans, other chironomids, and some diatoms.

Procladius was relatively abundant in Buckley with a mean density of 107.6 individuals/m^2. Throughout the year a large percentage of the population sampled was made up of younger instar individuals. This could indicate that individuals in Buckley experience slow development and remain first and second instars for a long time. Individuals overwinter in all four instars, but predominantly instars one and two.

Procladius is bivoltine in Buckley Reservoir, with emergence in May through June and again in September. This agrees with other studies. Heuschele (1969) observed two emergence periods of *Procladius bellus,* one in May and one in August in a shallow flood plain lake in Minnesota. The same study found that most overwintered in the third instar. Mundie (1957) found *P. choreus* and *P. crassinervis* to be bivoltine, but the second emergence was reduced. This also appears to be true in Buckley where larger populations were observed in early summer than the fall.

Coelotanypus **sp.**: This species was easily recognized by its large, oblong head, large posterior prolegs, and straight, plump body. The distinguishing characteristic of the head capsule of *Coelotanypus* is a lingua with seven light teeth and no paralabial combs. Also belonging to the Tanypodinae, *Coelotanypus* and *Procladius* have similar ecological requirements (Hilsenhoff and Narf, 1968; Boesel, 1974). Both genera have been found in the same area, although *Coelotanypus* is generally less abundant (Hilsenhoff and Narf, 1968). In Buckley they are found at similar densities. Roback (1969) found both to feed on similar food, although *Coelotanypus* also feeds on oligochaetes. The abundant supply of oligochaetes in Buckley probably allows *Coelotanypus* to occur in numbers similar to *Procladius.*

Coelotanypus is univoltine with emergence from May through June. A large percentage of the population is in the fourth instar stage in May and June, 83% and 99%, with a rapid decline in late June and July, 38% and 17%. Younger individuals begin to appear in larger numbers in June, July, and August. *Coelotanypus* overwinters in all instars but predominantly the latter two. In northeastern states Boesel (1974) collected *Coelotanypus scapularis* adults from June through August, but mostly in July.

Ablabesmyia sp.: This member of the Tanypodinae occurred in very small numbers at Buckley Reservoir (10.9/m^2). *Ablabesmyia* appears very similar to *Coelotanypus* externally. However, it has longer posterior prolegs with distinctive dark claws and a pair of long, straight anterior prolegs extending approximately one-fourth of the length of the head. The head capsule is characterized as having five pointed, dark, lingua teeth with the middle three having light tips and the maxillary palp having more than one basal segment. *Ablabesmyia* is predatory on such things as rotiferans, microcrustaceans, and other chironomids (Roback, 1969).

Ablabesmyia sp. has two emergence periods per year, one in May and June, the other in late August and September. There is a gradual progression through instars in the late fall with the population overwintering predominantly in the first and second instars.

Stilobezzia sp.: This ceratopogonid was collected at a density of 169.6 individuals/m^2, making it the second most abundant species. Members of *Stilobezzia* are found throughout most of North America in lentic and littoral habitats where they are primarily predators (Merritt and Cummins, 1978).

Stilobezzia sp. is univoltine in Buckley Reservoir. Large numbers of instar three were collected in May with the appearance of instar four in May and June. Total numbers drastically reduced from May to June, indicating an emergence at this time. Total numbers remained small during June through August, possibly indicating a long resting period in the inaccessible egg stage. Gradually early instars began to appear in August and September with a change in age composition towards the older instars in October and November. The larvae overwinter in all four instars, but predominantly instar two.

Chaoborus sp.: This species was collected at a density of only 2.8 individuals/m^2. Only third and fourth instar larvae were collected. Hilsenhoff and Narf (1968) found that the first two instars are limnetic and the third and fourth may also be limnetic during the daylight hours. Therefore, bottom samples may underestimate actual densities. *Chaoborus* demonstrates univoltinism here since third and fourth instar individuals were collected primarily during the fall. Hilsenhoff and Narf (1968) found *Chaoborus albatus, C. flavicans,* and *C. puntipennis* all to have one generation per year in Wisconsin lakes.

Hexagenia sp.: The burrowing mayfly, *Hexagenia* sp., was the most abundant ephemeropteran collected during the study. A total of 147 individuals was collected, giving an average density of 24.0 individuals/m^2. Because of the large number of molts characteristic of the ephemeropterans and the small number of individuals collected, it was impossible to detect the different instar divisions with a length frequency distribution. Head capsule widths ranged from 0.2 to 2.4 mm with individuals found in almost all 0.1 mm intervals between. The organisms were grouped into 0.1 mm intervals for the production estimate, and although this grouping is not an instar distinction, it should include all size classes passed through by each developing individual.

Most ages were present throughout the year, indicating continuous reproduction, unequal development, or multi-year life cycles. The presence of young and old larvae in a collection often indicates a two-year life cycle (Heuschele, 1969). *Hexagenia* requires two years to complete its life cycle (Merritt and Cummins, 1978).

Caenis sp.: Another ephemeropteran found in Buckley Reservoir was *Caenis* sp. (Caenidae). It is recognized by a pair of large, quadrate second abdominal gills and was usually found only at depths less than 1 m in allochthonous debris. Sixty-nine individuals showed a mean density of 11.3 individuals/m^2. Like the burrowing mayflies, individual instars were not detected and 0.1 mm size intervals were used in the production estimate.

Aside from one specimen collected in March, all larvae were found from August to January. It is possible that this group emerges in late winter and the eggs go through a long resting stage. A gradual breaking of diapause might explain the wide distribution of sizes at a given time. Similarly, Hynes (1970) reported that long egg diapause is exhibited by *Baetis rhodani,* a member of a genus closely related to *Caenis.* Because of the absence of individuals during part of the year, *Caenis* appears to have only one generation per year.

Oecetis sp.: This species (Leptoceridae) was the only trichopteran collected during the study. Only 33 individuals were found giving a mean density of 5.7 individuals/m^2, and most were found only at depths less than 1 m. Leptocerid larvae are omnivorous feeders (Wiggins, 1977). Again, instar distinction was not obtained, but 0.1 mm intervals of head capsule widths were used in the production estimate. The emergence period was in early summer. Absence of individuals during May and June was assumed to be during their egg stage while smaller individuals began to appear again in September and October.

Interest has developed in the ratio of production to standing stock, also known as the P/B or turnover ratio. Although there is a number of ways to calculate the P/B ratio, probably the most useful ecologically is figured on an annual basis by dividing annual production by the mean annual standing stock (Waters, 1977). The annual P/B ratio depends primarily on voltinism; however, it is usually constant for groups of animals with the same voltinism. The turnover values calculated for each species are summarized in Table III along with the summary of annual production values, densities, and voltinism.

Turnover or P/B values are consistent with those obtained in other studies. Annual P/B values ranged from 1.9 to 8.3 for the univoltine species, and 4.4 to 8.8 for the bivoltine species (Table III). The only species requiring more than one year to complete its life cycle was *Hexagenia* sp. with a P/B value of 3.0. Mann (1967) pointed out that annual P/B values would be about ten for multi-voltine species, five for univoltine, and two for species with 2-yr life cycles.

Benthic insect production in Buckley Reservoir is low compared with published production estimates. Few attempts have been made to estimate production of entire faunas. Waters (1977) reviewed production studies and found a range from 200 g/m^2/yr for all benthos in the Speed River in Ontario to a low of 0.37 g/m^2/yr for the herbivore–detritivore population in Lake Krivoe in the U.S.S.R. Hall and Hyatt (1974) estimated annual production for all benthos to be 15.2 g/m^2 in Marion Lake, British Columbia. Total fauna annual production estimates recorded in the literature range from 8.4 g/m^2 (Gerking, 1962) to 50.7 g/m^2 (Johnson and Brinkhurst, 1971). The estimate of 0.156 g/m^2/yr for aquatic insects obtained in the Buckley study was between 0.19X and 0.0003X published values.

Single species estimates appear with greater frequency in the literature. Waters (1977) listed 66 species estimates of which 25 were chironomids. The Buckley species ranged from 0.057 g/m^2 (*Hexagenia* sp.) to as low as 0.001 g/m^2 (*Chaoborus* sp.). Other studies compare as follows: *Glyptotendipes barbipes* in a waste lagoon in Oregon (Kimerle and Anderson, 1971), 161.6 g/m^2 and 40.5 g/m^2 production for *Glypotendipes* sp. in a shallow, eutrophic lake in eastern Scotland (Maitland and Hudspith, 1974).

TABLE III. Composition of benthos in Buckley Reservoir showing density, production, P/B value, and voltinism for each genus.

Genus	Mean Density Indiv./m^2	Production g/m^2	P/B Annual	Voltinism
Diptera				
Chironomidae				
Parachironomus	196.4	0.013	3.2	Univoltine
Polypedilum	63.8	0.018	5.2	Univoltine
Cryptochironomus	6.7	0.004	4.4	Bivoltine
Procladius	107.6	0.014	8.8	Bivoltine
Coelotanypus	90.4	0.011	2.4	Univoltine
Ablabesmyia	10.1	0.006	5.5	Bivoltine
Ceratopogonidae				
Stilobezzia	169.6	0.023	8.3	Univoltine
Chaoboridae				
Chaoborus	2.8	0.001	1.9	Univoltine
Ephemeroptera				
Ephemeridae				
Hexagenia	24.0	0.057	3.0	Hemivoltine
Caenidae				
Caenis	11.3	0.006	4.4	Univoltine
Trichoptera				
Leptoceridae				
Oecetis	5.7	0.003	5.2	Univoltine
Total	688.3	0.156		

Jonasson (1972) estimated annual production of *Procladius pectinatus* in Lake Esrom, Denmark, to be 0.52 g/m^2. This compares to 0.014 g/m^2 production of the Buckley species of *Procladius*. Potter and Learner (1974) estimated productivity of *Procladius rufovittatus* at 2.01 g/m^2, and *P. choreus,* a bivoltine species, at 3.41 g/m^2 in a shallow, eutrophic reservoir in South Wales. In the same study, Potter and Learner estimated production of *Parachironomus tener* to be only 0.11 g/m^2. This estimate is approximately 8X higher than the species of *Parachironomus* from Buckley.

Comita (1972) estimated production of *Chaoborus punctipennis* in Severson Lake, Minnesota, to be 0.012 g/m^2/yr, while Jonasson (1972) found *Chaoborus flavicans* to be 2.92 g/m^2/yr in Lake Esrom in Denmark. The value obtained by Comita is interesting when it is compared to the production value of *Chaoborus* in Buckley (0.001 g/m^2). It must be remembered, however, that all stages of the *Chaoborus* life cycle were not quantitatively sampled and therefore the figure is an underestimate.

Few published estimates of aquatic insect productivity in Nebraska are found. Two studies on both the northern and southern borders are recognized. Hudson and Swanson (1972) estimated the combined production of *Hexagenia limbata* and *H. bilineata* to be 1.5 g/m^2 in the Lewis and Clark Reservoir, which is the northern border of Nebraska. In Tuttle Creek Reservoir, Kansas, a large, turbid impoundment less than 160 km south and east of the Buckley Reservoir, Horst and Marzolf (1975) estimated production of *Hexagenia limbata* to be 0.12 g/m^2. This figure is approximately twice that of the Buckley species, while Hudson and Swanson's (1972) estimate is approximately 25 times higher.

Single species comparisons with other studies showed Buckley's productivity to be from 0.5X to 0.0003X that of other bodies of water, depending on species and environments compared. Total fauna estimates were lower by a similar magnitude. Why is productivity so low in Buckley Reservoir? Production is defined as the rate of tissue elaboration, regardless of whether it survives to the end of a given time period (Ivlev, 1945). Stated mathematically: Production = $G\bar{B}$, where G equals the instantaneous growth rate for the time period, and $\bar{B}$ equals the mean standing stock. Both components of production are low in Buckley.

Annual mean density for all insects was 688.3 individuals/m^2. Chironomids comprised 475 individuals/m^2. Potter and Learner (1974) found a mean population of chironomid larvae of 28,803 individuals/m^2 in their study of a shallow, eutrophic reservoir, more than 60X the density at Buckley. Morgan (1972) estimated mean density of four major chironomids in the shallow, eutrophic Loch Leven to be 19,750 individuals/m^2. Merritt and Cummins (1978), suggested that chironomid densitities of 50,000/m^2 are not unusual and may be greatly exceeded. The potential of chironomid populations is not met in Buckley Reservoir.

Total number of species supported by the reservoir is small. Eleven common genera were collected with six other less common taxa. Assuming one species per genus, fewer than 20 species are present. Natural lakes, ponds, and streams often have 50 or more species of chironomids (Merritt and Cummins, 1978). Fewer numbers are found in habitats exhibiting extreme conditions or little diversity. Buckley Reservoir is a very monotonous environment, one contributing factor to the low diversity of species.

Growth and development are abnormally slow in this impoundment. This was initially observed by the small and general starved appearance of the larvae. A good example is *Procladius* with its large head yet slender abdomen, appearing out of proportion.

Table IV compares average weights of larvae in Buckley Reservoir to those in Eglwys Nunydd, a shallow, eutrophic reservoir in South Wales (Potter and Learner, 1974). First instar larvae of *Procladius* are 1.4 times heavier in Buckley than in Eglwys Nunydd. However, by the time of the second molt, they are only 0.7 times as heavy. Fourth instar larvae are 0.25 times as heavy. Both species are bivoltine. Comparison with *Parachironomus* sp. gives similar results. Both studies recognize only three instars. Both are remarkably similar when the first instars are compared. However, the Buckley species achieves a final weight of only 0.06 mg. compared to the 0.1108 mg of the Eglwys Nunydd species. The difference is more significant when it is realized that the South Wales species is bivoltine and the Buckley species is univoltine. Incomplete and sporadic development is indicated by the relatively small numbers of older larvae. Of the 1,204 *Parachironomous* specimens only 115 were instar four. Of the 391 *Polypedilum* larvae collected only 9 or 2.3% were instar four. Only 12 pupae were recovered during the entire sampling program. Although production of pupae and emerging adults was not measured in this study, it was probably an insignificant amount. In a normally developing population, most individuals progress at a similar rate. In Buckley almost all

TABLE IV. Comparison of average weights (mg) for instars of *Procladius* sp. and *Parachironomus* sp. in Buckley Creek Reservoir and Eglwys Nunydd Reservoir.

Instar	Buckley Weight	Eglwys Nunydd* Weight	Buckley to Eglwys Nunydd Ratio
		Procladius sp.	
1	0.0084	0.0057	1.47
2	0.0132	0.0189	0.70
3	0.0358	0.0794	0.45
4	0.1267	0.5424	0.23
		Parachironomus sp.	
1			
2	0.0091	0.0089	1.02
3	0.0198	0.0327	0.61
4	0.0600	0.1108	0.54

*From Potter and Learner (1974).

instars were present during the same time. Some larvae either failed to develop or grew at a slower rate than others.

Possible physical, chemical, and biological factors affecting abundance, growth, and development are suggested in the literature. Topping (1971) concluded that abundance of larvae of *Chironomus tentans* was positively correlated with conductivity, pH, amount of food, and dissolved oxygen in an investigation of saline lakes in central British Columbia. He also concluded that temperature, calcium carbonate, and bicarbonate concentrations did not affect abundance. Growth and development are affected by species, temperature, and food availability (Merrit and Cummins, 1978). Danks (1971) listed light intensity, dissolved oxygen, day length, and nutrition as possible factors promoting development, but cited temperature as the most important. The abundance of food, predators, parasites, and disease as well as other unknown factors also play a role in larval development and survival (Hilsenhoff, 1966). Fahy (1973) suggested that life cycle length depends on latitude; however, other environmental factors such as turbidity, light, food, and temperature also have an effect.

The distinguishing characteristic of Buckley Reservoir is the high suspended solid load (Table I), and thus very turbid water. This factor is suspected to be the primary cause for the condition of the benthic invertebrates in this impoundment. Turbidity directly reduces the depth of light penetration. The littoral area is reduced and a normally productive and diverse zone (Gerking, 1962) is missing from the habitat. Also, the euphotic zone is reduced to the upper few centimeters of the water, which reduces total food available. With a limited amount of solar energy, much of the food web of the system must begin with allochthonous materials washed into the water. Little organic buildup in the substratum was indicated by the relatively sterile bottom samples. In addition, light intensity has been demonstrated to stimulate development (Danks, 1971; Fahy, 1973). Without light, individuals may fail to develop normally.

Other factors contributing might include low conductivity of the water and fungus-induced mortality. Conductivity was low in Buckley with a yearly average of 84 UHMOS. Topping (1971) found a positive correlation between conductivity and abundance of the larvae of *Chironomus tentans.* Large amounts of fungi (*Phycomycetes*) were collected at 3-4 m depths. Hilsenhoff (1966) described sudden declines in larval populations of *Chironomus plumosus* caused by fungi. It is possible that fungi cause mortality and reduced populations in Buckley.

Dissolved oxygen does not appear to be limiting since mixing generally circulates it throughout the entire water column. Only during a number of consecutive calm summer days would oxygen concentration be a problem.

In summary, productivity estimates can be a valuable tool for the aquatic resource manager in developing resources to their maximum recreational potential. Turbidity is the major factor affecting the benthic community, a common condition of many small reservoirs. With the base line data obtained in this study, a follow-up project should be initiated on the same reservoir. The turbidity could be reduced by liming or other methods, and the annual productivity again calculated. A comparison of results would reveal the actual impact of turbidity. At the same time, fish populations should be monitored for total numbers and condition. In a separate study the fish populations were concluded to be low in numbers and in poor condition. Similar results were obtained by the Nebraska Game and Parks Commission (Johnson, 1975). With the reduction of turbidity, an increase in benthic production could, in turn, improve the fish production, the ultimate goal of fishery biologists. With positive results, other reservoirs now useless and unproductive could be converted into a valuable resource.

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