ACOUSTIC CENSUS OF LIMNETIC FISH IN A GLACIALLY TURBID LAKE

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INTRODUCTION

Stable, single-beam echosounders, echo-counting, and midwater trawling have been used routinely for over 15 years to census limnetic fish in sockeye salmon (Oncorhynchus nerka) nursery lakes of western North America [1,2,3,4]. Census techniques in British Columbia have been developed for assessments of juvenile sockeye populations in dozens of remote lakes. The focus in recent years has been to investigate the effects of lake fertilization on growth and survival of sockeye and other limnetic fish [3] through enumeration of sockeye smolts just prior to seaward migration and of adults returning from the sea to their nursery lakes of origin [4].

The lakes of the B. C. outer coast and their limnetic fish are generally ideal subjects for census by acoustic and trawl surveys (ATS). The lakes have steep shorelines and small littoral zones. The fish occupy an ice-free, limnetic zone for 8-10 months each year, disperse at night which permits acoustic census by echo-counting, and are highly vulnerable to capture by trawls. Thus, we have employed ATS to successfully census limnetic fish in up to 40 coastal lakes annually since 1977 [3,4,5]. About 10 % of our study lakes present special difficulties for ATS application. These include: lakes in which large invertebrates (Chaoborus spp.) mask acoustic signals from fish [5] and glacially turbid lakes in which fish occupy non-insonifiable surface strata (NISS) of the water column.

In this paper we report on the feasibility of adapting ATS techniques to census limnetic fish in the large and glacially-turbid, Owikeno Lake on the central B. C. coast (Fig. 1a).

Study Background:
Before 1960, the Owikeno Lake sockeye population supported a thriving commercial fishery at River's Inlet [6]. Stock declines after 1960 led to consideration of management and enhancement measures to promote stock recovery. These measures have been planned within an atmosphere of uncertainty about whether factors causing the decline affected sockeye production during fresh water or marine life history stages. For practical reasons, attempts to partition fresh water and marine production have focused on assessments of juvenile abundance in Owikeno Lake [7] and returns of adults to the commercial fishery.

There is a long history of attempts to index the lacustrine production of Owikeno sockeye. The relatively high turbidity and low temperatures maintained throughout the summer (compare Great Central versus Owikeno Lake conditions, Fig. 1c, d, f, and g) promote greater surface orientation by fish in Owikeno Lake relative to other, clear-water, coastal lakes (compare Fig. 2a and b). Consequently, Ruggles [7], Chernoff [8], and many others [9] used surface trawling between 1960 and 1977 to characterize species composition and growth

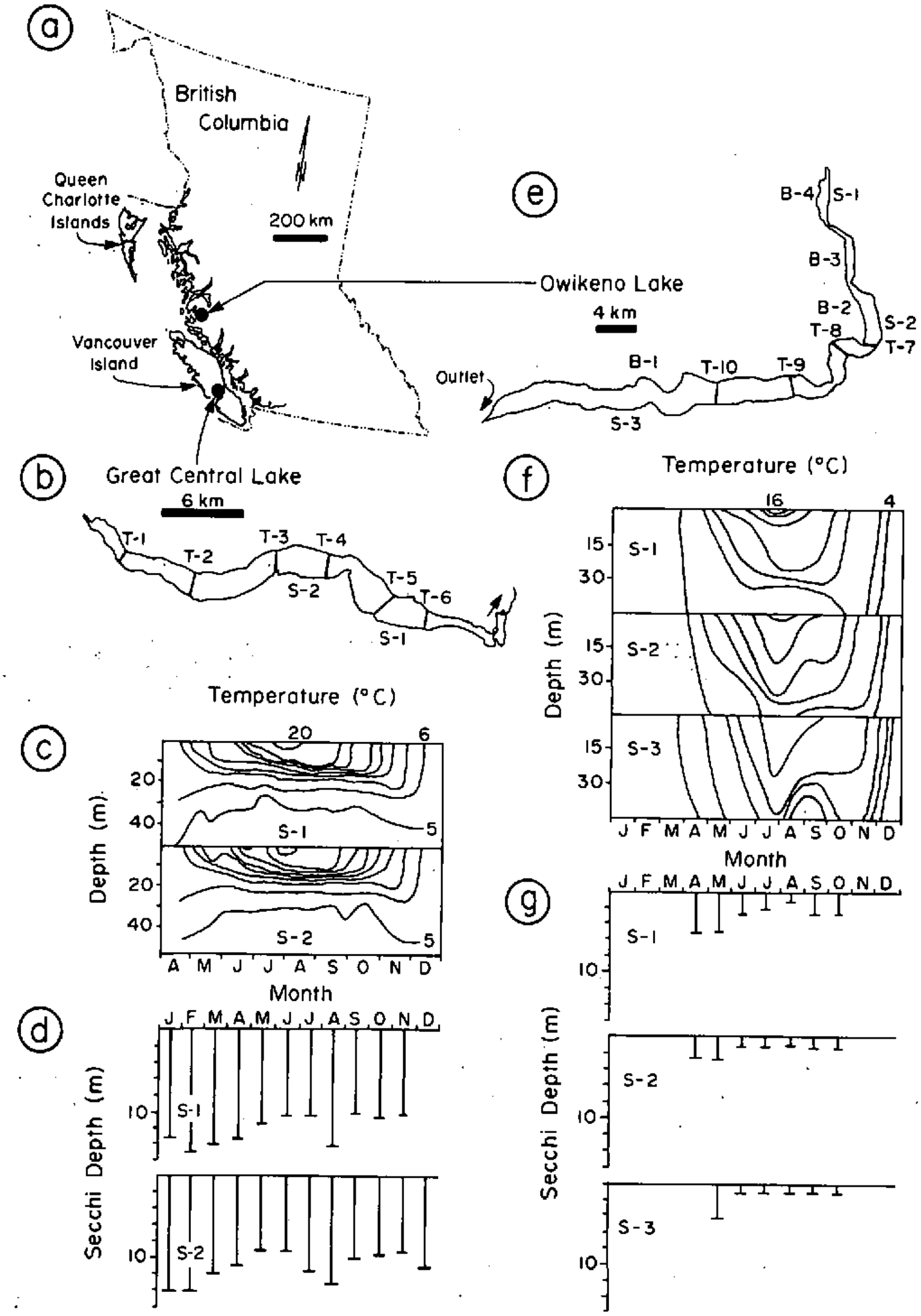

Figure 1. Geographic location and seasonal changes in temperature and water clarity (Secchi depth) in Great Central and Owikeno lakes on Canada's west coast. Temperature isotherms are in 2 degree increments. B1-B4 indicate basins, S1-S3 are limnological stations, and T1-T10 are acoustic and trawl transects.

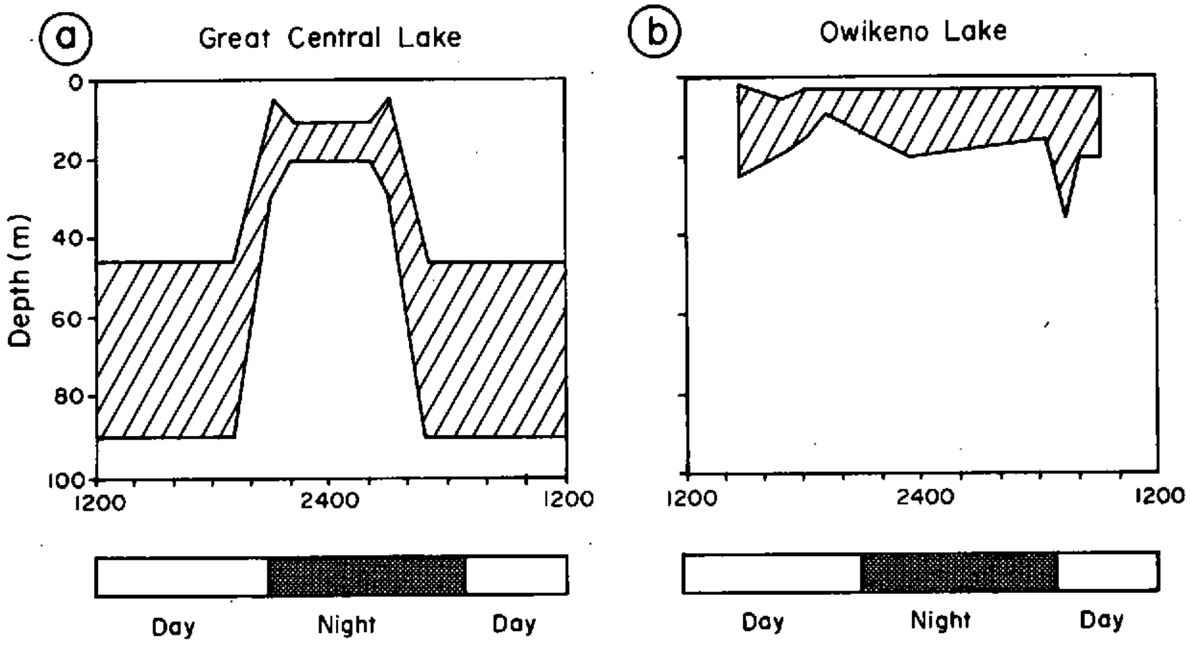

Figure 2. Diel variation in limnetic fish depth distribution in Great Central Lake (juvenile sockeye, Barraclough and Robinson 1971) and Owikeno Lake (juvenile sockeye and threespine stickleback, Levy 1989). The shaded area represents the depth range occupied by > 80% of limnetic fish.

of limnetic fish in Owikeno Lake.

However, annual trawl surveys were discontinued in 1978 because they did not provide a reliable index of interannual, abundance changes of limnetic fish due to low sampling power and high variability in trawl catch per unit effort among survey times, transects, dates, and years [8, Canada Department of Fisheries and Oceans, unpublished data].

Application of acoustic techniques alone to estimate Owikeno fish abundance has also produced mixed results. Simpson et al. [10] concluded that aggregation of Owikeno fish in the top 5 m of the water column at night precluded insonification of a large enough proportion of the population for reliable census. However, Levy [11] indicated that aggregation of fish in NISS was not a constant feature of Owikeno limnetic fish and he suggested that acoustic surveys could produce a reliable index of limnetic fish abundance (Levy, pers. comm.). We surveyed Owikeno Lake during the summers of 1987 and 1988 to determine the potential for application of our ATS techniques to census juvenile sockeye there.

MATERIALS AND METHODS

Instrumentation and survey procedures:
Acoustic surveys were conducted with a Simrad EY-M echosounder. The EY-M has an operating frequency of 70 kHz, power output of approximately 75 watts, and a pulse width of 0.6 ms. The sounder has a dry paper recorder, a calibrated output, and a 40 log r TVG that operates from 3-60 m with an accuracy of + or - 1dB. System gain can be varied by 9 steps in 3 dB increments. Minimum detectable target strength, on axis, at maximum gain, is -81.08 dB (R. Kieser, CDFO, Nanaimo, pers. comm.). The circular piston transducer (No. 70-24-F/FP, 11^{o}, Simrad) was mounted on a hydroplane and lashed alongside a 4 m long, inflatable boat. This positioning allowed depth strata greater than 3 m below the lake surface to be insonified [12].

A survey consisted of executing acoustic transects across the lake in a boat running at 1-2 m/s. We selected transect locations in the highly turbid central and western basins of Owikeno Lake (Fig. 1e and g) because: (i) these basins constitute more than 90 % of the total area available to fish rearing in the lake, and (ii) previous surveys had indicated that fish in these locations presented the greatest difficulty for successful application of acoustic techniques to population census. Acoustic transects were sampled at various times to identify whether different diel intervals offered significant advantages for successful acoustic census of limnetic fish. Transect lengths were initially measured from 1:50,000 topographic maps and then verified through use of a flow meter (General Oceanics Inc. model 2030) as a distance logger.

Echo trace counting and density estimates:
Abundance estimates were based on target traces from echograms. The combination of wide beam, short pulse width, and relatively short range (< 60 m) of the echo-sounder enhanced our ability to detect individual fish [2]. In addition, low in-lake densities usually meant that traces did not overlap on the echograms. Traces were counted within 5 m depth strata on echograms from each survey. We treated each target trace as a return from an individual fish. Adult sockeye were also detected but were easily distinguished from the smaller targets [4].

The number of single-fish traces divided by the sample volume or area provides an estimate of fish density. The angle over which a fish is detected (effective beam width or EBW) depends on the acoustic system gain, fish size (acoustic target strength), and transducer characteristics. Our acoustic surveys were conducted at gain setting 10, which was 4 steps (12 dB) above the lowest setting at which average size (30-40 mm) limnetic fish were detected. According to Love's equation [13], the target strength of a 30 mm fish is -55 dB. Gjernes et al. [12] conducted *in situ* measurements and found an EBW of 14^{o} for fish of this size, when insonified by the EY-M at gain 10. We used a constant beam width of 14^{o} in all calculations of fish densities reported here. Final estimates of fish abundance on transects were adjusted to equivalent counts per unit area to compensate for the distance travelled on different transects.

Trawling:
Trawling was conducted on all surveys to obtain samples for determination of species and size composition of limnetic fish within various depth strata. The trawling system (2m X 2m mouth dimensions) and standard procedures for its use have been described elsewhere [5]. Of note here, trawl catch observations may be used to estimate the abundance of fish in the NISS of Owikeno Lake, given information about the swept volume and catch efficiency of the trawl. In the absence of an independent estimate of fish abundance in the NISS, we assumed that trawl efficiency there would be equivalent to catch efficiency in the shallowest (3-6 m), insonifiable, depth stratum. Calculations of trawl catch and target counts in equivalent volumes of water from the region of the echogram fished by the trawl served as our index of trawl fishing efficiency.

RESULTS

In 1987, acoustic records indicated that the depth distribution of limnetic fish during the day varied between the two transects surveyed (Fig. 3). On transect 7, most limnetic fish appeared concentrated in the 15-20m stratum during the day (Fig. 3a) but on transect 8, fish were evenly distributed between 2 and 20 m (Fig. 3d). By dusk, fish on both transects appeared to have moved closer to the surface (Fig. 3b and e). The shift in vertical distribution was more striking on transect 7. Night surveys indicated further movement towards the surface with most fish occupying the top 5 m of the water column (Fig. 3c and f). Trawl surveys indicated that most limnetic fish in the area of the transects were juvenile sockeye (98 %) and confirmed that fish were distributed below 5 m during the day but strongly aggregated within the top 5 m at night (Fig. 3g and i).

In 1988, acoustic records indicated that differences in the depth distribution of fish between transects were less pronounced during all diel periods than in 1987 (Fig. 4). Fish were generally closer to the surface on all transects than they had been in 1987. Further, a significant proportion of the population continued to occupy the top 5 m of water on all transects, even during the day (Fig. 4 a, d, and g). Intensification of this surface orientation resulted in aggregation of the majority of fish within the top 5 m on all transects during dawn, dusk, and night periods (Fig. 4 b, c, e, h, and i). Results from trawl surveys were in accord with the patterns suggested by acoustic observations (Fig. 4 j, k, and l) and indicated that juvenile sockeye again represented the majority of fish (96 %) present in the limnetic zone. Sticklebacks were present at depth during the day and near surface at night.

Acoustic estimates of total densities of fish on each transect differed by as much as a factor of 2.5 among surveys in 1987 and 1988. Maximum abundance estimates were not consistently associated with one period (i.e. day, dusk/dawn or night) in 1987 and 1988 (Fig. 3 and 4). This is likely due to the variable influence of a number of factors. Diurnal estimates based on echo-counting will tend to be biased low due to the tendency of limnetic fish to school during the day [14] but not during dawn, dusk, and night periods when fish disperse while moving towards the surface. Variations in acoustic estimates during all periods may be influenced greatly by an unknown proportion of limnetic fish which enter the NISS. The significance of the latter event is apparent when trawl catch and acoustic observations are

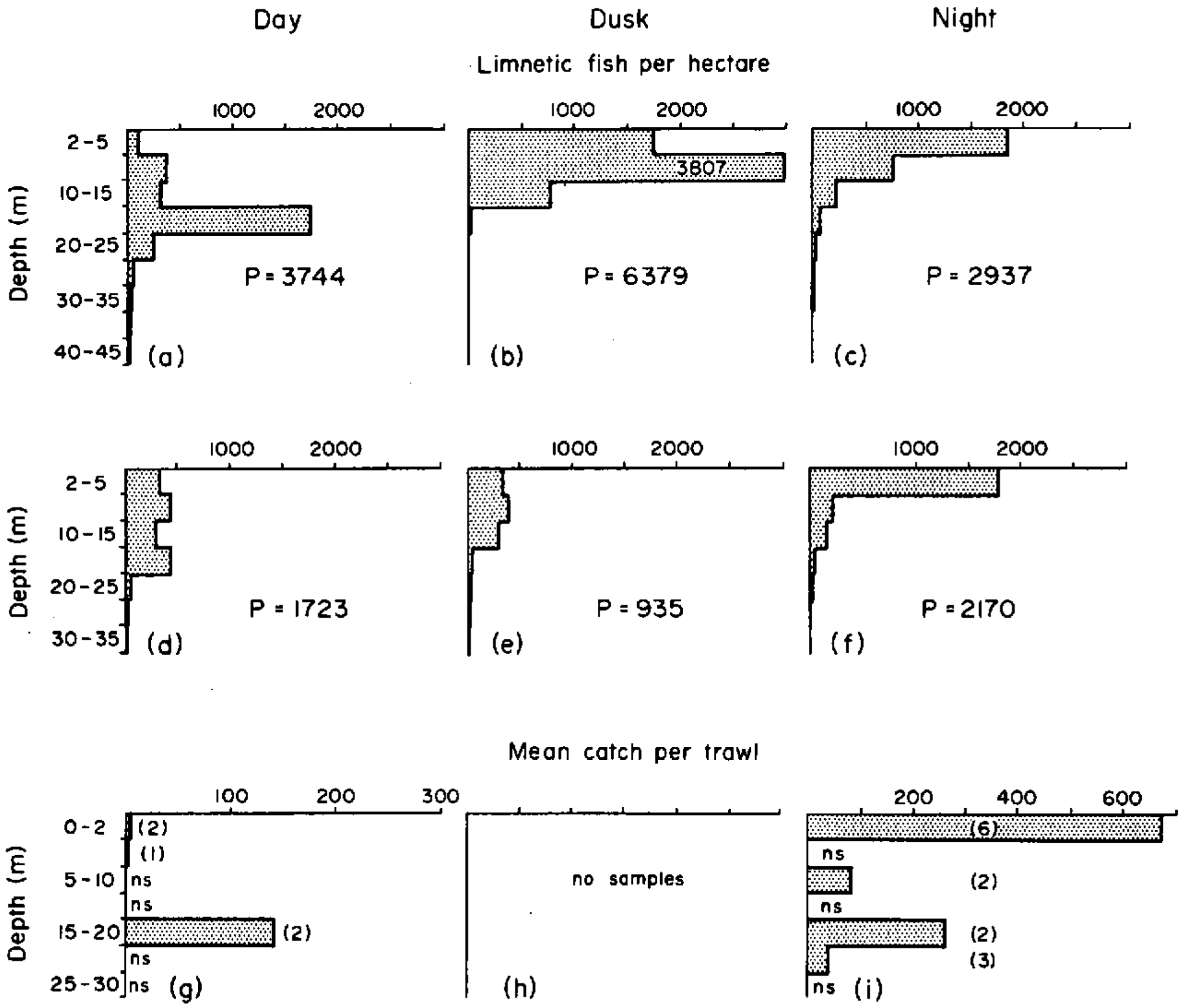

Figure 3. Numbers of limnetic fish per hectare by depth stratum at transect 7(a-c), transect 8(d-f), and the mean catch per trawl (g-i) in Owikeno Lake during August of 1987. Numbers in closed parentheses in panels g and i indicate number of trawls. Juvenile sockeye comprised 98-99 % of the trawl catches in the area around transects 7 and 8. Stickleback (Gasterosteus aculeatus) made up the remainder of the catch. P = total limnetic fish per hectare. ns = not sampled.

combined to generate alternate estimates of fish abundance.

The fishing efficiency of our trawl in the 2-5 m depth stratum of Owikeno Lake was uniformly high as catch averaged 100 % of the fish expected on the basis of acoustic counts (mean proportion 1.0, range 0.91 - 1.11, n=3). This value

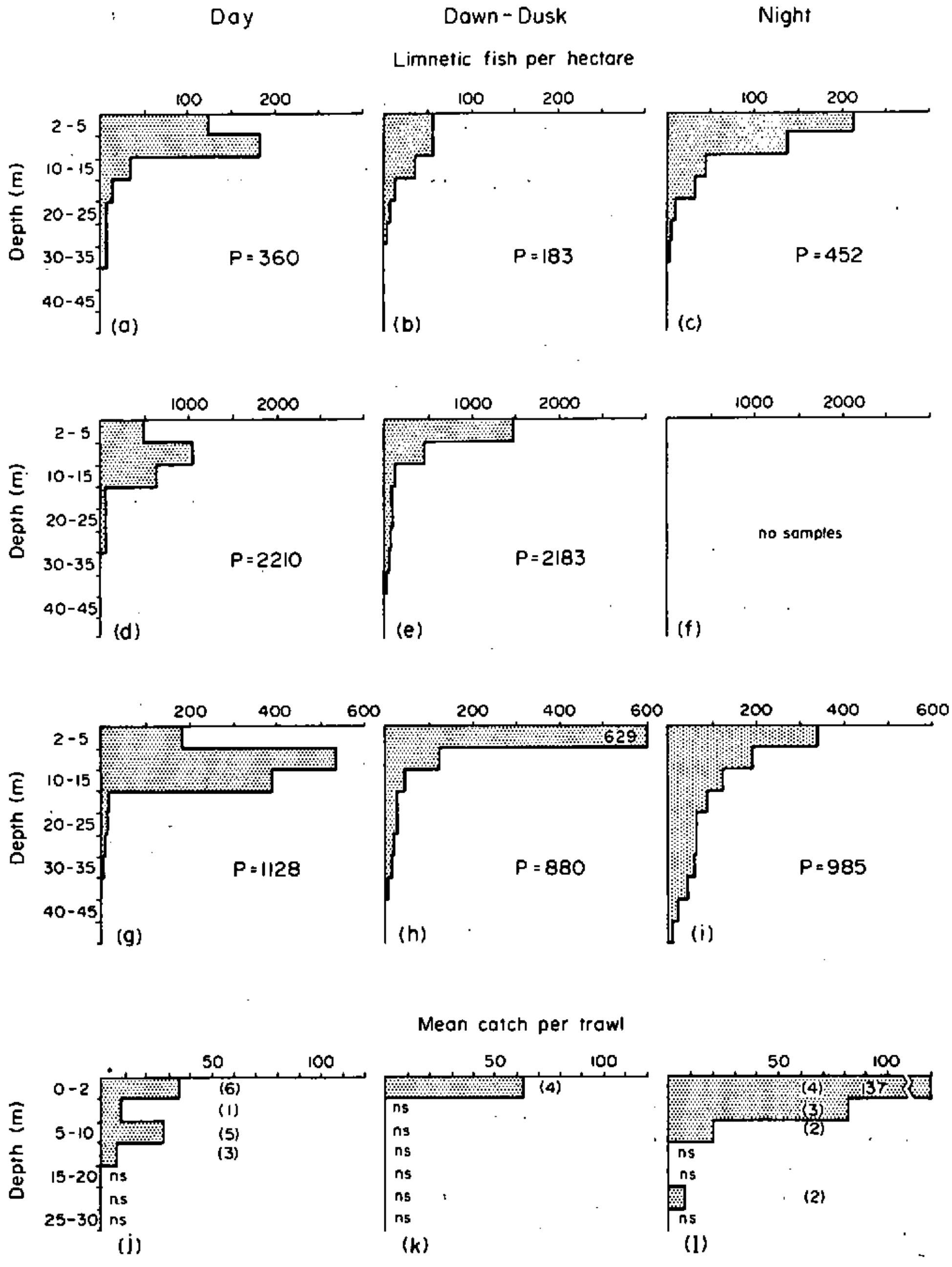

Figure 4. Numbers of limnetic fish per hectare by depth stratum at transect 8(a-c), transect 9(d-f), transect 10(g-i), and the mean catch per trawl (j-l) in Owikeno Lake during September of 1988. Numbers in closed parentheses in panels j-l indicate number of trawls. Juvenile sockeye comprised 96 % of the trawl catches in the area around transects 7 and 8. Stickleback, which made up the remainder of the catch, were found at 10-15m during the day but near the surface at dusk and during the night. P = total limnetic fish per hectare. ns = not sampled.

is substantially higher than the 37 % (mean proportion 0.37, range 0.06 - 0.69, n=4) efficiency for trawl surveys conducted at nearby Long Lake under similar weather conditions (clear skies, no moon). This difference is not surprising given the higher turbidity of the Owikeno Lake transects. Application of data on trawl catch efficiency and swept volume to estimate fish abundance in the NISS, indicates that estimates of fish abundance based on acoustic observations alone are generally biased low (Table 1). Results from night surveys during August of 1987 represent the most extreme case in which the acoustic survey accounted for less than 27 % of the fish present in the limnetic zone.

Table 1. A summary of limnetic fish abundance estimates based on either (1) acoustic records alone or (2) acoustic records and NISS trawl catches. See text for details.

			Fish Abundance (no/ha)	
Date	Location	Time	(1)	(2)
August, 1987.	Transect 7	Night	2,937	10,781
Sept., 1988.	Transect 8	Day	360	370
		Night	452	742
	Transect 9	Day	2,210	2,294
		Dusk	2,188	2,768
	Transect 10	Day	1,128	1,212
		Night	985	2,564

DISCUSSION

Results from the acoustic and trawl surveys reported here have two obvious applications. First, they identify the reasons for the failure of past efforts to provide meaningful assessments of abundance of juvenile sockeye rearing in Owikeno Lake. Second, they permit realistic appraisal of the immediate prospects of developing reliable census procedures for Owikeno fish.

The most striking feature of the limnetic fish in the glacially turbid basins of Owikeno Lake is their consistent bias to occupy the upper 20 meters of water throughout the diel cycle. This contrasts sharply with clear-water lakes where juvenile sockeye rarely occupy depths shallower than 20 m except during the night (Fig. 2 and author's unpublished data). Although, juvenile sockeye migrate vertically over the diel cycle in Owikeno Lake, just as they do in other lakes [11], the migration is compressed both in space and time with the result that conditions considered ideal for either acoustic or trawl census alone persist for too brief a time to permit precise estimation of fish abundance. Trawl surveys alone failed to provide useful estimates of fish abundance in Owikeno Lake because an unknown and highly variable proportion of all limnetic fish were distributed below the surface (0-2m) layer that was routinely fished. Thus, annual trawl surveys conducted over the 18 years between 1960 and 1977 proved to be of limited utility in resolving the origins of productivity changes which resulted in a roughly four fold decline in adult sockeye returns. In addition, variability in the extent of diel vertical migration into the NISS between surveys was undoubtedly the basis for the different conclusions arrived at by Simpson et al. [10] and Levy (pers. comm.) concerning the utility of acoustic census at Owikeno Lake.

Our surveys were not designed to provide abundance estimates of fish throughout Owikeno Lake. Rather, they were designed to assess the feasibility of initiating future surveys for this purpose. We believe this objective has been met and suggest that application and minor refinement of the ATS survey methods reported here would provide a reasonably precise means of indexing seasonal or interannual changes in the abundance of juvenile sockeye rearing in Owikeno Lake.

ACKNOWLEDGEMENTS

We would like to thank Ken Shortreed and John Stockner for providing us with limnological data on Owikeno and Great Central lakes. Dave Peacock provided accommodation for our survey crew at the Genesee River field camp and generously shared his knowledge with us about the recent history of the Owikeno sockeye stock. The paper benefited from review by Greg Steer who also provided useful advice about electronic text transfer. The figures were prepared by Evan Warneboldt. Funding for this project was provided by the Resource Enhancement Branch of the Canadian Department of Fisheries and Oceans.

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