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Shifts in abundance and growth of slimy sculpin in response to changes in the predator population in an arctic Alaskan lake

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Abstract

Lake trout (*Salvelinus namaycush*) in Toolik Lake are tightly coupled to the benthos, since they have no pelagic forage fishes. Slimy sculpins (*Cottus cognatus*) are a prey of lake trout and the soft sediment chironomids are an important prey for the sculpin. Our previous work showed that the median size of lake trout in Toolik Lake had decreased significantly between 1977 and 1986, and smaller lake trout are likely to be less effective as sculpin predators. Using our historic data on the slimy sculpin population from 1978, we took advantage of the recent change in the predator community to examine for subsequent changes in the sculpin community. Between 1978 and 1987, the percentage of slimy sculpin caught in the soft sediments has increased (25% to 39.5%). In 1987 there was a significant difference in the mean weight of sculpin caught on different substrates. The mean individual weight of sculpins increased from the nearshore rock area to the rock/soft-sediment interface to the soft sediments. There was no difference in mean individual weight with habitat in 1978. The mean total length at age for slimy sculpins during this time has also increased significantly. We suggest that the risk of predation while foraging in the soft sediments has declined. The increased use of the soft sediment area appears to have contributed to their increased growth, likely due to greater food abundance.

Introduction

Regulation of temperate lake ecosystem processes by predatory fishes is dependent upon piscivores harvesting zooplanktivorous forage fishes (Shapiro, 1980; Shapiro & Wright, 1984; Carpenter & Kitchell, 1984; Crowder *et al.*, 1987). In arctic lakes, which lack pelagic forage fishes, the effects of a top predator may be very different. In these systems there appears to be a strong benthic-pelagic coupling; adult lake trout (*Salvelinus namaycush*) feed extensively on benthic prey (O'Brien *et al.*, 1979; Merrick *et al.*, 1992). While changes in the predator population in temperate lake systems may result in changes in trophic interactions which cascade (sensu Carpenter *et al.*, 1985) through the ecosystem, the consequences of changes in the predator population of arctic lakes may be very different.

Toolik Lake is a 140 ha lake on the north slope of the Brooks Range in arctic Alaska (see McDonald *et al.*, 1982). The lake consists of a rocky nearshore area, rocky reefs, and a deep, soft sediment bottom (McDonald *et al.*, 1982). The fish community of Toolik Lake consists of lake trout, burbot (*Lota lota*), grayling (*Thymalus arcticus*), round whitefish (*Prosopium cylindraceum*), and slimy sculpin (*Cottus cognatus*) (O'Brien *et al.*, 1979; McDonald & Hershey, 1989).

Slimy sculpin in Toolik Lake are long-lived and slow-growing (McDonald *et al.*, 1982). They rely on a diet of larval chironomids (Hershey & McDonald, 1985) and can control bare sediment chironomid density (Hershey, 1985). Both density and production of slimy sculpin in Toolik Lake in 1978 were highest at the interface between the nearshore rocky area and the deeper soft sediments; presumably, this was due to access to food resources on the soft sediments and to predator protection offered by the rocks (McDonald *et al.*, 1982).

Lake trout in Toolik Lake do eat slimy sculpins, but they occur in only about 12% of the lake trout examined (Merrick *et al.*, this volume). Lake trout in Lake Ontario have been suggested as keystone predators on competing sculpin populations (Brandt, 1986). Lake trout in Toolik Lake were surveyed in 1977 (O'Brien *et al.*, 1979), and by 1986 the median size of lake trout had significantly decreased (578 g to 313 g), presumably due to increased sports angling (McDonald & Hershey, 1989). These smaller-sized individuals are less likely to feed on slimy sculpins (Merrick *et al.*, 1992).

With the reduction in lake trout size, we hypothesized that slimy sculpin should increase their use of the deeper soft sediment areas and should show increased growth. Because of historic data on slimy sculpin in Toolik Lake (McDonald *et al.*, 1982), we had the opportunity to examine changes in the slimy sculpin population with the reduction in predation pressure by lake trout. We repeated the 1978 sampling effort (McDonald *et al.*, 1982) during the summer of 1987 to determine if changes in the slimy sculpin distribution and growth had occurred.

Methods

We used the sampling technique and original sampling sites of McDonald *et al.* (1982) for collecting slimy sculpins. This technique consisted of three jar traps tethered together with three replicate sets on each of four substrate types. These substrate types were: near-shore rocky (0.5 m), mid-rock (1.5 m), rock/soft-sediment interface (3.5–5.0 m), and soft-sediments (7.0 m). These sites were trapped continuously from 26 July to 12 August 1987 and traps were sampled every third day.

Slimy sculpin collected from each substrate were preserved in 95% ethanol for transport to the laboratory and short term storage (< 4 h). In the laboratory slimy sculpin were weighed, total length measured, and sagital otoliths removed and stored in glycerol for later aging. Microscopic aging of otoliths was done *in toto*; mean total length at each age of slimy sculpin caught in 1987 was back-calculated from otolith length (see McDonald *et al.*, 1982).

The expected catch of slimy sculpin for each substrate type in 1987 was based on the percent catch on each substrate in 1978 and on the total number in the 1987 catch. To test the hypothesis that there was no change in slimy sculpin distribution between 1978 and 1987, the squared differences between the observed and expected catch of slimy sculpin on each substrate type in 1987 was summed to yield a single chi-square value for all habitats (Snedecor & Cochran, 1967). Changes in slimy sculpin density between just the rock/soft-sediment interface and the soft sediments from 1978 to 1987 was similarly tested by chi-square (Snedecor & Cochran, 1967). Mean biomass of slimy sculpin found on each substrate type in 1978 (from McDonald *et al.*, 1982) and in 1987 was examined separately using ANOVA. Mean total length at age for slimy sculpin caught in 1987 was compared to that for 1978 (from McDonald *et al.*, 1982) by Wilcoxon signed rank test. Only age groups represented in both 1978 and 1987 were included in the analysis (age groups I–VII, see RESULTS). Differences for all tests were considered significant if $p < 0.05$.

Results

In both 1978 and 1987 > 75% of all slimy sculpin caught were on, or near, the soft sediments (rock/

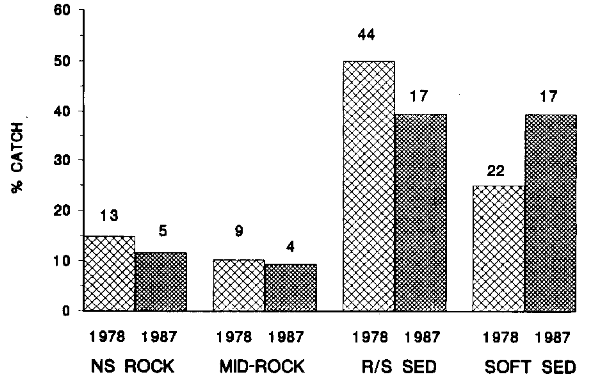

Fig. 1. Per cent of total catch on each substrate type (0.5 m nearshore rocks – NS ROCK, 1.5 m rocky area – MID-ROCK, 3 m to 5 m rock/soft sediment interface – R/S SED, and 7 m soft sediment – SOFT SED) in 1978 (from McDonald *et al.*, 1982) and in 1987. Total number of fish caught in each year on each substrate is given above histograms. Catch at the rock/soft sediment interface and on the soft sediments in 1987 was significantly different than that predicted from the 1978 catch.

soft-sediment interface and soft sediments, Fig. 1). There was no significant difference in the catch of slimy sculpin in the different substrate types in 1987 relative to 1978 ($X^2 = 4.99$, $df = 3$). However, there was a significant change in slimy sculpin density between the soft sediments and

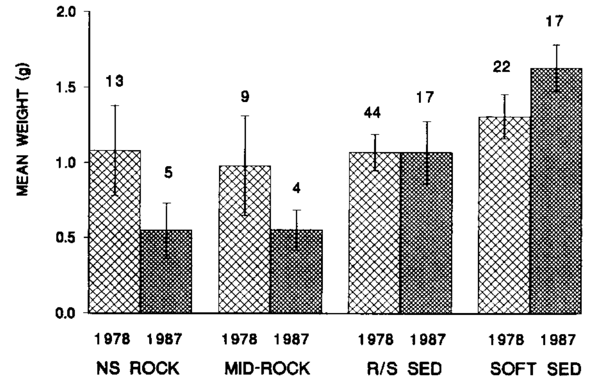

Fig. 2. Mean weight (±1 SE) of slimy sculpin caught on each substrate (0.5 m nearshore rocks – NS ROCK, 1.5 m rocky area – MID-ROCK, 3 m to 5 m rock/soft sediment interface – R/S SED, and 7 m soft sediment – SOFT SED) in 1978 (from McDonald *et al.*, 1982) and 1987. Total number of fish caught on each substrate in each year is given above histograms. Mean slimy sculpin weight was significantly different with habitat in 1987.

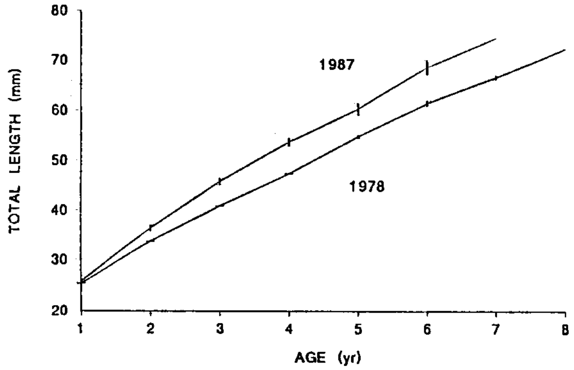

Fig. 3. Mean back-calculated total length (±1 SE) at each age class for slimy sculpin in 1978 (from McDonald *et al.*, 1982) and 1987. In pair-wise comparison across all age groups, slimy sculpin caught in 1987 were significantly larger.

the rock/soft-sediment interface between 1978 and 1987 ($X^2 = 4.65$, $df = 1$).

There were no significant differences in the mean weight of slimy sculpin on the different substrate types in 1978 (Fig. 2). However, in 1987 there was a significant difference in mean slimy sculpin biomass due to habitat ($F = 4.55$). In 1987 the slimy sculpin increased in size with depth from the nearshore rocks to the deeper, soft sediments (Fig. 2).

Slimy sculpins caught in 1987 were significantly larger at age than those caught in 1978 (Fig. 3). Increases in mean total length at age for 1987 slimy sculpin occurred in age groups I–VII and ranged from 1.8% (I) to 13.3% (IV). No sculpin in age group VIII was collected in 1987.

Discussion

The size of the slimy sculpin population in Toolik Lake was estimated and its life history characteristics examined in 1978 (McDonald *et al.*, 1982). Since that time, the slimy sculpin's interaction with its benthic food source has been examined in the nearshore rocks (Cuker, 1983; Hanson *et al.*, 1992) and in the soft sediments, where they control chironomid density (Hershey, 1985; Goyke & Hershey, 1992).

The reduction in median size of the lake trout since 1978 (McDonald & Hershey, 1989) has probably reduced predation on slimy sculpin, since larger lake trout are more likely to exhibit piscivory (Merrick *et al.*, 1992). The significant shift in the slimy sculpin population from the rock/soft-sediment interface out onto the soft sediments between 1978 to 1987 (Fig. 1) may be the result of reduced predation risk while foraging.

McDonald *et al.* (1982) hypothesized that sculpin were concentrated at the rock/soft-sediment interface in order to forage out on the soft sediments, while taking advantage of the predation refuge provided by the rocks. The observed changes in the slimy sculpin distribution and growth, coupled with the observed shift in the lake trout population to a smaller median size (McDonald & Hershey, 1989), provides strong support for the earlier hypothesis.

Toolik Lake slimy sculpin live longer and grow slower than those in north temperate, boreal, and more southerly arctic areas (McDonald *et al.*, 1982). Van Vliet (1964) suggested that water temperature and food supply may limit the growth of more northerly slimy sculpin populations. Hershey (1985) found that 84% of the diet of slimy sculpins in the Toolik Lake area was chironomids and that sculpin could reduce chironomid populations in the bare sediments. Goyke & Hershey (1992) found chironomid density, biomass, and diversity to be higher in lakes containing lake trout and slimy sculpin, than in lakes containing only slimy sculpin. With increased access to the soft sediment chironomid community, the growth rate of slimy sculpins in 1987 was significantly higher than 1978 (Fig. 3). This suggests that while temperature may limit the overall physiological capacity to grow, the Toolik Lake slimy sculpin in 1978 were likely food limited as a result of restricted foraging on the soft sediments due to risk of predation.

Unlike temperate systems, Toolik Lake lacks a pelagic forage fish, and the top predator, lake trout, feeds primarily on snails and, to a much lesser extent, slimy sculpin (Merrick *et al.*, 1992). Lake trout can influence snail populations, controlling the density and size distribution of *Lymnaea* on soft sediments (Merrick *et al.*, 1991). Since *Lymnaea* controls recruitment of the other common snail, *Valvata* (Hershey, 1990), the lake trout are affecting snail community structure. Lake trout also appear to influence the distribution of slimy sculpin in Toolik Lake. Slimy sculpin feed selectively on chironomids and can control bare sediment chironomid densities (Hershey, 1985; Hershey & McDonald, 1985). Thus, lake trout may indirectly affect chironomid populations. It appears that in these systems with strong benthic-pelagic coupling, changes in the predator population have consequences for the structure of the entire benthic community.

Conclusion

The soft sediment habitat offers an increased food supply to slimy sculpin, but access has likely been limited by the risk of lake trout predation. A significant reduction in the median size of lake trout in Toolik Lake by sport fishing harvest likely reduced predation pressure on the sculpin. In response to this reduction, slimy sculpin appear to have increased their use of the soft sediments and their growth has increased. Thus, in arctic lakes with strong benthic-pelagic coupling, even moderate changes in a top predator population may ripple through the benthic community, and may significantly alter its structure.

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