Transactions of the American Fisheries Society 136:1736–1741, 2007
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DOI: 10.1577/T07-023.1

[Article]

Freshwater Sculpins: Phylogenetics to Ecology

SUSAN B. ADAMS*
U.S. Department of Agriculture, Forest Service, Southern Research Station, 1000 Front Street, Oxford, Mississippi 38655, USA

DAVID A. SCHMETTERLING
Montana Fish, Wildlife, and Parks, 3201 Spurgin Road, Missoula, Montana 59084, USA

Abstract.—Freshwater sculpins (Cottidae) are a diverse and ecologically important component of cool- and coldwater ecosystems throughout the northern hemisphere. More than 60 sculpin species occur in a variety of habitats, and sculpin distributions range from highly localized to widespread. Despite the frequently high biomass of sculpins and their numerous ecosystem functions, the traditional fisheries management emphasis on sport fishes has led to a general neglect of small-bodied, nongame fishes, such as sculpins, in both research and management. Ironically, in many coldwater ecosystems, salmonids are used as umbrella species to conserve and protect all aquatic vertebrates; however, many management and conservation goals may be better met by focusing on sculpins. This module arose from a symposium entitled "Ecology and Phylogeny of Freshwater and Diadromous Sculpin," which was held at the 2005 annual meeting of the American Fisheries Society in Anchorage, Alaska, and which brought together researchers studying sculpins from diverse perspectives. The objectives of this special module are to (1) publish a wealth of recent research on sculpins in one place to highlight the various scales at which sculpin research can be informative and useful, (2) stimulate interest in sculpins as targets of research and conservation, and (3) illustrate some conservation needs and management uses of sculpins that are unique from those of salmonids and other sport fishes. The papers in this module cover a range of topics, including phylogenetics of a species complex, tests of behavioral theories, and characteristics of sculpin movements, foraging, and reproduction. Together, these papers illustrate the importance of sculpins to a variety of fish communities and their usefulness in addressing theoretical questions and management objectives.

Freshwater sculpins (Cottidae; most belonging to the genus *Cottus*) are an ecologically important component of many freshwater ecosystems. Over 60 freshwater sculpin species (Kinziger et al. 2005) are distributed throughout diverse, coldwater habitats in the northern hemisphere. Equally diverse are sculpin life histories, including resident, adfluvial, fluvial, and diadromous strategies. The ecological importance of sculpins arises, in part, from their tendency to occur in high abundances, often dominating fish assemblages in terms of numbers and biomass (e.g., Freeman et al. 1988; Beauchamp 1990; Carter et al. 2004; Cyterski and Barber 2006). In many North American coldwater streams, sculpins are the only small-bodied fish species or the only species reaching high abundances. Although research on freshwater sculpins has increased substantially in recent years (Figure 1), reflecting a shift from single-species management toward assemblage- and community-level research and management, the focus on single species (or categories; e.g., sport fish) persists to the detriment of our understanding of fish communities.

This module of sculpin papers follows from the symposium "Ecology and Phylogeny of Freshwater and Diadromous Sculpin" held at the 2005 Annual Meeting of the American Fisheries Society, Anchorage, Alaska. The goals of the symposium and module are to (1) compile a wealth of recent research on sculpins to highlight the various scales at which sculpin research is informative and useful, (2) stimulate interest in sculpins as targets of research and management, and (3) illustrate some conservation needs and management uses of sculpins that are unique from those of salmonids and other large-bodied sport fishes.

The taxonomic confusion surrounding sculpins (Kinziger et al. 2007, this issue), the poor delineation of species' distributions, and the difficulty of identifying and efficiently sampling some species in the field presumably contribute to the lack of ecological research on sculpins, as these factors increase the difficulty of incorporating sculpins into field studies of sport fishes. Despite recent advances, the systematics of freshwater sculpins remain somewhat confusing, and new species are identified regularly (e.g., Freyhof et al. 2005). Recent work has greatly clarified phylogenetic

* Corresponding author: sadams01@fs.fed.us

Received January 26, 2007; accepted June 5, 2007
Published online December 10, 2007

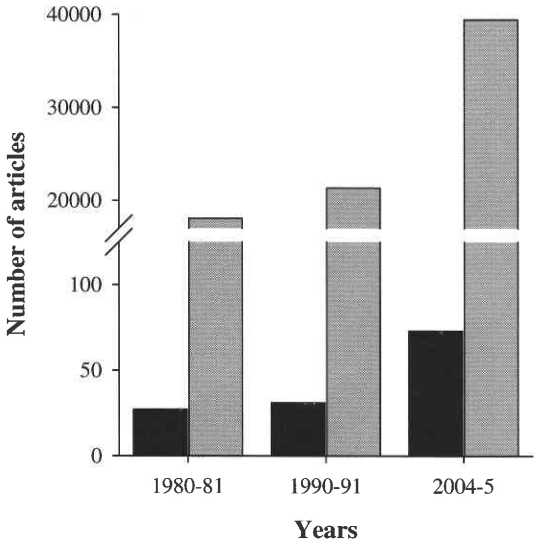

FIGURE 1.—Number of articles written in English that mentioned "sculpin*" or "*Cottus*" in the abstract (black bars) during three time periods. Identical searches were conducted using BIOSIS Previews for each period, and papers about marine sculpins or strictly physiological topics were not counted. We also searched for the term "fish*" in any field (gray bars). Although the numbers of sculpin papers more than doubled over the total period examined, they still constituted less than 0.2% of all papers revealed in the "fish*" search.

relationships and revealed that the genus *Cottus* is not monophyletic (Kinziger et al. 2005; Yokoyama and Goto 2005). In this issue, Kinziger et al. (2007) clarify phylogenetic relationships among Ozark Highlands members of the complex of banded sculpin *C. carolinae*, one of the most taxonomically confusing sculpin groups.

Sculpins exert a major ecological influence via their diverse roles in trophic interactions. In Europe and North America, sculpins have been commonly viewed with contempt as a predator on salmonids (Moyle 1977; Utzinger et al. 1998). Although now considered primarily benthic invertivores (Gibson et al. 2004; Meyer and Poepperl 2004), in some situations sculpins prey extensively on eggs and larvae of sport fishes (Fitzsimons et al. 2002; Tabor et al. 2004 and Tabor et al. 2007, this issue; but see Merz 2002; Bonar et al. 2005) and other fishes (Tabor et al. 2007) or alter larval behavior (Gaudin and Caillere 2000; Mirza et al. 2001). Furthermore, anthropogenic habitat alterations (e.g., artificial lighting and decreased turbidity) have increased sculpin predation efficiency on sport fishes in some systems (Tabor et al. 2004; Gadomski and Parsley 2005).

Sculpin trophic interactions extend beyond a simple predator role. Owing to their abundance, small body size, and sympatric relationships with larger fishes, sculpins can be a critical prey resource for sport fishes (Beauchamp 1990; Poe et al. 1991; Madenjian et al. 2005), birds (Hodgens et al. 2004), reptiles, and mammals (Birzaks et al. 1998; Koczaja et al. 2005). Experimental studies have shown various outcomes of competitive interactions between sculpins and salmonids, whether the limiting resource is food or habitat (Merz 2002; Hesthagen and Heggenes 2003; Ruetz et al. 2003). Some salmonids may also induce behavioral shifts in sculpins, leading to reduced foraging. For example, in stream enclosures, growth of large sculpins was reduced in the presence of nonnative brown trout *Salmo trutta* but not in the presence of native brook trout *Salvelinus fontinalis* despite a lack of difference in diet composition or invertebrate availability among treatments (Zimmerman and Vondracek 2007, this issue). Sculpins can also mediate interactions among lower trophic levels (Konishi et al. 2001; Ruetz et al. 2004), and they can be subject to bottom-up effects, as from invasive mussels *Dreissena* spp. (Owens and Dittman 2003). In some systems, sculpins may be important to the transport of nutrients and energy within drainages (e.g., Goto 1988; Ruzycki and Wurtsbaugh 1999) or between aquatic and terrestrial ecosystems (Hodgens et al. 2004).

Sculpins host a large array of parasites (Muzzall and Bowen 2002) and thus presumably play an integral role in the ecology and distribution of parasites and diseases. As parasite hosts, sculpins contribute to the persistence of some aquatic communities. For example, several freshwater mussels, including the federally endangered dwarf wedgemussel *Alasmidonta heterodon* (Michaelson and Neves 1995), depend on sculpins to host their parasitic glochidia (larvae; e.g., Neves et al. 1985; Martel and Lauzon-Guay 2005). In a slightly different role, sculpins can act as paratenic hosts of salmonid parasites that cause economic losses (Moravec 2001). Along with increasing concerns and costs associated with parasitic diseases, many of which are nonnative (e.g., whirling disease, caused by *Myxobolus cerebralis*, in North America), attention to the ecology of sculpins in relation to their parasites will probably become more important.

Sculpins are emerging as effective study organisms for testing ecological theories (e.g., Englund 2005), in part because they are small and often occur in high densities. Polivka (2007, this issue) used sculpins to test the role of predation risk in influencing foraging behavior and facilitating co-existence between species. Petty and Grossman (2007, this issue) demonstrated nonbreeding territoriality in mottled sculpin *C. bairdii* and found that home range size, overlap, and

abandonment rates were related to adult densities, suggesting a mechanism for population regulation. Natsumeda (2007, this issue) used the Japanese fluvial sculpin *C. pollux* to explore the proximal causes of movements in small-bodied fish. Sculpins may also be appropriate taxa for use in testing distribution and metapopulation models, which are largely derived from data on salmonids or terrestrial organisms; use of sculpins would be advantageous in that tests could be conducted over smaller scales, and high abundances of sculpins would facilitate sampling.

Sculpins are also well suited for use as bioindicators. Often, salmonids or other sport fishes are used as "umbrella species" for management of coldwater ecosystems; however, for many management goals, focusing on or including sculpins would provide a much larger umbrella for several reasons. First, sculpins are poor swimmers relative to most large-bodied fishes; therefore, instream obstructions that do not hinder salmonid movements can prevent passage by sculpins (Utzinger et al. 1998; Natsumeda 2007). Fish passage facilities that are engineered for small-bodied fishes would presumably allow most aquatic organisms to pass (Winter and VanDensen 2001; Schmetterling and Adams 2004). Second, at least some sculpin species are extremely sensitive to some pollutants. For example, sculpins are more sensitive than salmonids to metal enrichment in the field (Maret and MacCoy 2002) and are so sensitive to zinc that they are not adequately protected by existing U.S. federal water quality standards for zinc (Brinkman and Woodling 2005). Nest site characteristics of slimy sculpin *C. cognatus* suggest that nests may be vulnerable to alterations in flow regimes and increases in sediment (Keeler and Cunjak 2007, this issue). Third, sculpins are effective target organisms for biological assessments of anthropogenic impacts over small areas because they are often abundant, tend to be sensitive to a variety of perturbations, and often occupy relatively small areas throughout their lives (Fischer and Kummer 2000; Yeardley 2000; Gray et al. 2004). Over large areas, index of biotic integrity (IBI) approaches integrate a variety of biological metrics to assess the condition of water bodies and provide an example of a shift to fish-community-based management. Sculpins have been included in IBIs developed across the USA. Some IBIs include sculpins in general metrics, such as number of native species, percent intolerant individuals, and percent insectivores (e.g., Lyons et al. 2001; Drake and Pereira 2002), whereas others also incorporate sculpins more specifically in metrics such as number of sculpin age-classes present (Mebane et al. 2003), percent sculpins (McCormick et al. 2001), or number of darters, madtoms *Noturus* spp., and sculpins (Schleiger 2000).

As with many native fishes, sculpin species may be imperiled due to habitat modifications, water quality degradation, species invasions, or historically narrow distributions. Furthermore, undescribed and probably unknown sculpin species exist in North America (Kinziger et al. 2007), making many potential species-level conservation issues difficult to identify. In Canada, two of the three *Cottus* spp. listed as threatened are undescribed (COSEWIC 2005). Several sculpin species, including the only one listed under the U.S. Endangered Species Act (the threatened pygmy sculpin *C. paulus*; USFWS 2006), are restricted to a single spring, lake, or cave (Burr et al. 2001; Espinasa and Jeffery 2003). Species introductions have adversely affected a number of sculpin populations via predation (White and Harvey 2001), resource shifts (Owens and Dittman 2003), and competitive or behavioral interactions (Lauer et al. 2004), and habitat modifications have influenced sculpins in numerous ways (e.g., see Fischer and Kummer 2000; Maret and MacCoy 2002; Lessard and Hayes 2003; Gray et al. 2005).

Some sculpin conservation efforts have been directed toward imperiled species and toward populations of species that are secure elsewhere. The pygmy sculpin has a recovery plan in place (USFWS 1991). In Minnesota, slimy and mottled sculpins were reintroduced to streams from which they had been extirpated, and monitoring of population establishment is ongoing (MNDNR 2003). In Europe, studies have examined causes of extirpations and methods for restoring populations of the bullhead *C. gobio* (e.g., Utzinger et al. 1998; Knaepkens et al. 2004). Researchers are now more likely to include small-bodied fishes when evaluating restoration efforts (e.g., Roni 2003). The most encouraging trend, however, is the ever-increasing use of community metrics rather than single-species approaches to assess water bodies (e.g., Cyterski and Barber 2006). Such metrics can incorporate not only sculpins, but all small-bodied and nonsport fishes, into assessment and management of aquatic ecosystems. By expanding management vision to include such species, managers will increase their ability to maintain the integrity of aquatic ecosystems.

Acknowledgments

The American Fisheries Society International Section and the U.S. Forest Service International Programs provided funding in support of the 2005 symposium.

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