NORTH AMERICAN JOURNAL OF FISHERIES MANAGEMENT

Volume 9 Winter 1989 Number 1

North American Journal of Fisheries Management 9:1-11, 1989

Proposed Biological Management of *Mysis relicta* in Colorado Lakes and Reservoirs

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Abstract. — The opossum shrimp *Mysis relicta* has been introduced into many lakes and reservoirs outside its native range to supplement the prey bases for fish. Colorado has received more introductions of the mysid than any other state or province in western North America, but not all of these introductions have been beneficial or innocuous. Mysid predation on zooplankton, particularly cladocerans, has resulted in diminished food for some fishes, especially for planktivores such as the kokanee *Oncorhynchus nerka* and small trout *Oncorhynchus* spp. Few fishes forage on the often abundant populations of introduced mysids. Management options are limited in lakes where *M. relicta* competes for, or has eliminated, the large zooplankters eaten by fish. Furthermore, the mysid has shown enough vagility to expand its nonnative range and may harm fisheries in waters that it enters. Because its eradication is not now feasible, the development of strategies to control or benefit from established mysid populations is warranted. Biological controls appear most feasible. Amphipods and fishes that have the potential to control or benefit from nuisance mysids through competition or predation are candidates for introduction. Of the 13 species that we examined, the deepwater sculpin *Myoxocephalus thompsoni* was our first choice for introduction into waters containing established mysids. We based this choice on its potential to either control mysid numbers or channel mysid production to predators with little or no adverse effects on the rest of the community.

As a result of widespread introductions intended to supplement the prey base for fishes, the opossum shrimp *Mysis relicta* has become established in many lakes and reservoirs outside its native range in North America and northern Europe (Gosho 1975; Lasenby et al. 1986). Colorado has received more introductions of this mysid than any other state or province in western North America (Table 1).

Mysis relicta, considered a true glaciomarine relict crustacean in its native range, has a circumpolar distribution in the north hemisphere (Segerstrale 1962). In North America, its native distribution is east of the Continental Divide in remnant Pleistocene proglacial lakes (Ricker 1959).

The mysid occurs in deep oligotrophic lakes having cold, well-oxygenated waters (less than 14°C

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[1] The unit is sponsored by the U.S. Fish and Wildlife Service, the Colorado Division of Wildlife, and Colorado State University.

TABLE 1.—Summary of *Mysis relicta* introductions in western North America as of 1987.

	Lakes receiving *M. relicta*				
		Established[a]			
Province or state	Number stocked	Number	Passive transport[b]	Total	Reference
					Canada
Alberta	4	3	0	3	De Henau (1981)
British Columbia	19	10	1	11	Lasenby et al. (1986)
					United States
California[c]	11	4	1	5	Gosho (1975); A. Cordone, California Department of Fish and Game[d]
Colorado	51	13	5	18	Finnell (1977); Nesler (1986)
Idaho	16	3	0	3	Gosho (1975); G. Mauser, Idaho Department of Fish and Game[d]
Montana	8	5	1	6	W. Beatty, Montana Department of Fish, Wildlife, and Parks[d]
Nevada[c]	4	0	0	0	Gosho (1975); P. Coffin, Nevada Department of Wildlife[d]
Oregon	11	2	0	2	Gosho (1975); J. Griggs, Oregon Department of Fish and Wildlife[d]
Utah	7	2	0	2	J. Johnson, Utah Department of Wildlife Resources[d]
Washington	1	1	0	1	Gosho (1975); L. Brown, Washington Department of Game[d]
Wyoming	2	2	0	2	J. Baughman, Wyoming Game and Fish Department[d]
Totals	134	45	8	53	

[a] Not all waters receiving *M. relicta* introductions have been checked to verify the species' establishment.

[b] Populations resulting from dispersal of mysids via downstream transport or water diversion.

[c] Lake Tahoe, California–Nevada, is included in California information.

[d] Personal communication.

with more than 2 mg dissolved oxygen/L). During the day, it is typically found on the bottom in the hypolimnion; at night, it makes extensive vertical migrations that may be influenced by light intensity, thermal stratification, and prey distribution (Beeton and Bowers 1982). *Mysis relicta* is an opportunistic omnivore that feeds on detritus (Lasenby and Langford 1972), phytoplankton (Grossnickle 1979), zooplankton (Cooper and Goldman 1980), amphipods (Parker 1980), possibly other mysids (DeGraeve and Reynolds 1975), dead animals such as chironomids (Lasenby and Langford 1973), and fish larvae (Cooper and Goldman 1980). *Mysis relicta* may reproduce seasonally (Furst 1972b) or continuously throughout the year (Carpenter et al. 1974), at ages 1–4, depending on water temperature and lake productivity (Berrill and Lasenby 1983). It is extremely facultative in exploiting resources and flourishing under a variety of ecological conditions.

Pennak (1978) recommended *M. relicta* as a "logical" transplant because of its importance in diets of lake trout *Salvelinus namaycush* and coregonines and because the "*Mysis* niche" was unoccupied in most lakes. Furst (1972a) reasoned that introductions of *M. relicta* and other glacial relicts among crustaceans would provide a pathway between energy trapped in benthic detritus in the profundal zone and fish. Others believed that the mysid would provide a larger, supplementary food source for predatory salmonids at the size at which their principal diet changes from invertebrates to fish (Sparrow et al. 1964; Frantz and Cordone 1970). Much interest in the USA has been in enhancing growth of kokanee *Oncorhynchus nerka* (Rieman and Falter 1981) as occurred after *M. relicta* was established in Kootenay Lake, British Columbia (Northcote 1972).

Not all mysid introductions have been beneficial or innocuous. An international group of researchers recommended that a worldwide moratorium be imposed on future introductions of *M. relicta* (Morgan 1982) because of the threat this crustacean poses to fisheries and their management. There are no known methods for eradicating mysids from lakes (Rieman and Falter 1981; Lasenby et al. 1986), so methods need to be devised to minimize negative effects or derive benefit from introduced populations.

Current Problems

Cladoceran populations changed in many North American and European waters after *Mysis relicta* became established. Populations of *Daphnia* spp. virtually disappeared in Lake Tahoe, California–Nevada (Goldman et al. 1979), Lake Sturgusjoen, Norway (Langeland 1981), Donner and Fallen Leaf lakes, California (Morgan et al. 1981), and Colorado's Grand Lake, Dillon Reservoir (Nelson 1981), and Twin Lakes (LaBounty et al. 1980).

Seasonal abundance or species composition of daphnia populations changed in Kootenay Lake, British Columbia (Zyblut 1970), Lake Selbusjoen (Langeland 1981), Pend Oreille Lake, Idaho (Rieman and Falter 1981), and Lake Granby, Colorado (Martinez 1986). Mysids prey heavily on zooplankton, but prefer daphnias (Cooper and Goldman 1980; Langeland 1981; Murtaugh 1981).

Mysis relicta has indirectly influenced kokanee by depleting its major food supply (Wydoski and Bennett 1981). The mean size and numbers of spawning kokanee declined in Lake Tahoe (Morgan et al. 1978), Lake Granby (Sealing and Bennett 1980), and Pend Oreille Lake (Rieman and Falter 1981) after the mysid became established.

Most fisheries in Colorado lakes having established mysid populations are supported by salmonids—rainbow trout *Oncorhynchus mykiss* (formerly *Salmo gairdneri*) and kokanee—that do not occur naturally in the native range of *M. relicta* and were not exposed to freshwater mysids as a food source during their evolutionary history. Most salmonids rarely encounter mysids during their active daytime feeding periods when *M. relicta* is in deep waters. Sight-dependent feeders such as trout and salmon typically do not feed extensively when *M. relicta* is available to them during its nocturnal migration into surface waters.

When the mysids are present on the bottom in shallow water, they appear able to evade predators (Janssen 1978). In Colorado lakes where hypolimnetic dissolved oxygen is low before the fall and spring overturns, all sizes of mysids appear to migrate to shallower water. Although numerous potential predators are present in these areas, their stomachs contain few mysids. Stomachs often contain other benthic invertebrates such as isopods *Asellus* sp., fingernail clams *Pisidium* sp., or chironomid larvae and pupae (Martinez 1986).

Predation on mysids is common during periods of ice cover. In Colorado, lake trout, coho salmon *Oncorhynchus kisutch*, rainbow trout, and kokanee that were caught through the ice contained large numbers of mysids (G. L. Bennett, Colorado Division of Wildlife, personal communication). Low water temperatures and subdued light throughout the water column in winter may induce the mysids to enter surface waters during the day, where they are vulnerable to predators.

The limited use of mysids by fish in Colorado lakes discourages the introduction of *M. relicta* elsewhere in the state, particularly in high-elevation, coldwater impoundments where it would enter the zooplankton-producing surface waters yearround. Management options are reduced for waters in which large cladocerans have disappeared since *M. relicta* became established.

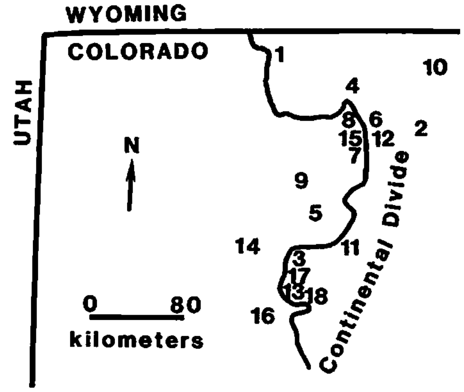

FIGURE 1.—Colorado lakes and reservoirs with established populations of *Mysis relicta*. Passive introductions are indicated by a single asterisk (*) for downstream transport and by a double asterisk (**) for transmountain water diversions (Finnell 1977; Nesler 1986): 1—Big Creek (lower), 2—Carter**, 3—Chalk, 4—Chambers, 5—Dillon, 6—Estes**, 7—Granby, 8—Grand, 9—Green Mountain, 10—Horsetooth, 11—Jefferson, 12—Marys**, 13—Mount Elbert Forebay*, 14—Ruedi, 15—Shadow Mountain*, 16—Taylor Park, 17—Turquoise, 18—Twin (upper and lower). Heavy line through Colorado indicates the Continental Divide.

In Colorado, *M. relicta* from Grand Lake (which is west of the Continental Divide) has become established in various waters east of the Continental Divide (Figure 1). Nesler (1986) reported that mysids were introduced into three foothills lakes and reservoirs through passive transport via pumps, canals, and conduits (components of the Colorado–Big Thompson transmountain water diversion and distribution project). *Mysis relicta* has spread in other systems (Furst 1981; Leathe and Graham 1982; Lasenby et al. 1986). This vagility may further increase the list of waters where the species is less than desirable.

Control Alternatives

The sensitivity of *Mysis relicta* to elevated temperatures (DeGraeve and Reynolds 1975), low dissolved oxygen (Sherman et al. 1987), increased nutrient loading (Colby et al. 1972), and pH change (Nero and Schindler 1983) suggests certain physical means of reducing or eradicating the species. However, potential strategies for effecting physical control, such as extreme drawdown, thermal manipulations, or induction of hypoxia, eutrophication, or acidification, are rarely if ever applicable. Although several aquatic pesticides are toxic to crustaceans, none are known to be specific for *M. relicta*. Both physical and chemical approaches involve undesirable side effects such as jeopardizing or eliminating existing fisheries or reducing water quality.

Introductions of biological control agents such as parasites or diseases have been suggested to control the mysid (Leathe 1984). However, no disease is known to be specific for *M. relicta*. Smith and Lankester (1979) discovered that the mysid is an intermediate host of the swim bladder nematode *Cystidicola cristivomeri*, but laboratory observations did not indicate that the infection was lethal. Smith and Lakester (1979) found that mortality was high when *M. relicta* was experimentally infected by *C. farionis*, another swim bladder nematode that has an amphipod as an intermediate host. Release of such a parasite to attack mysids appears to be of uncertain value and poses a threat to fishes.

Other types of biological mysid control—introductions of predators and competitors—seem more promising, although such control vectors would themselves have to be exotic species in western waters. We have compared selected characteristics of *Mysis relicta* with those of 2 other crustaceans and 11 fishes that might be able to control mysid populations through competition or predation (Tables 2–4). Crustaceans were selected that have close association with benthic *M. relicta* in its native range. Fish species were chosen that are known to eat mysids on more than an occasional, incidental, or seasonal basis.

Other fish species are known to consume mysids, but they do not possess the behavioral or ecological characters believed necessary to provide reliable, persistent predation on mysids. Splake (the hybrids between lake trout and brook trout *Salvelinus fontinalis*), however, are reported to feed heavily on mysids (J. Johnson, Utah Department of Wildlife Resources, personal communication) and may prove to be useful control agents in the future. Presently, splake do not occur with *M. relicta* in many places, and their interactions with mysids are not well documented.

Attributes of Candidate Control Species

Amphipods

Like *M. relicta*, the amphipods *Pallasea quadrispinosa* and *Pontoporeia affinis* are considered true glaciomarine relicts. *Pontoporeia affinis* has a circumpolar distribution similar to that of *M. relicta*; *Pallasea quadrispinosa* is restricted to northern Eurasia (Segerstrale 1962). *Pontoporeia affinis* occurs with *Mysis relicta* in many North American lakes (Ricker 1959), and all three species occur in some Scandinavian and Russian waters (Segerstrale 1962).

Furst (1981) provided most of the information available on *Pallasea quadrispinosa* introductions. In Sweden, this amphipod has been introduced with *M. relicta* to improve fish forage. Despite its

TABLE 2.—Selected species characteristics of *Mysis relicta* compared with those of its potential competitors and predators.

Species	Niche			Size at maturity (mm)[d]	Maximum size (mm)[e]
	Zone[a]	Behavior[b]	Trophic level[c]		
Mysis relicta	B,L,P	E,V	O,P,D	14–22	30
Pallasea quadrispinosa	B	E	D	10–20	30
Pontoporeia affinis	B	E,B	D	5–8	10
Alewife	L	P,S	P,F	120–180	280
Lake herring	L,P	P,S	P	200–300	380
Lake whitefish	L,P	P,D	P,B	350–460	610
Bloater	P	D,P	P,B	170–260	300
Pygmy whitefish	L	D	P,B	100–130	250
Arctic char	L,P	P	P,B	380–450	640
Lake trout	P	P	F,B	400–560	1,200
Rainbow smelt	L	P,S	P	130–200	300
Burbot	P	D	F,B	280–480	890
Slimy sculpin	B	D,E	B	70–90	150
Deepwater sculpin	B	D,E	B	60–80	130

[a] Vertical position typically occupied in water column: B = benthic; L = limnetic; P = profundal.

[b] Characteristic activities displayed in available habitat: B = burrowing; D = demersal; E = epibenthic; P = pelagic; S = schooling; V = vertical migration.

[c] Feeding habits: B = benthivorous; D = detritivorous; F = piscivorous; O = omnivorous; P = planktivorous.

[d] Crustacean lengths were measured from tip of telson to tip of rostrum; fish size is total length.

[e] Approximate maximum length typically attained by the species.

TABLE 3.—Reproductive characteristics of *Mysis relicta* and of its potential competitors and predators. NA = not applicable.

	Spawning			Habitat			Fecundity		
Species	Timing[a]	°C[b]	Hatching[a,c]	Location[d]	Substrate[e]	Depth[f]	Age[g]	Thousands of eggs[h]	Egg type[i]
Mysis relicta	F	NA	V	L	P	NA	I–IV	0.010–0.035	NA
Pallasea quadrispinosa	W	NA	V	L	P	NA	I–III	?	NA
Pontoporeia affinis	W–S	NA	S	L	P	NA	I–II	0.015–0.040	NA
Alewife	5–7	15.5	6d	L,S	S,G	S	II–III	10–22	D
Lake herring	10–12	4.5	4	L	S,G,C	S	II–III	6–20	B
Lake whitefish	10–12	5.0	5	L,S	S,G	S	III–IV	8–25*	B
Bloater	3	1.5	6	L	S,G,C	D	II–III	4–8	B
Pygmy whitefish	10–12	4.5	S	L,S	G	S	II–III	0.4–0.6	D
Arctic char	11–12	4.0	4	L,S	G	S	IV–VI	1.9–3.5*	D
Lake trout	10	11.0	3	L	C,B	S	V–VII	0.9–2.6*	D
Rainbow smelt	3–5	10.0	3w	S,L	G	S	II–III	8–30	A
Burbot	1–3	1.0	5	L,S	S,G	S	III–IV	50–1,500	B
Slimy sculpin	5–6	5.0–10.0	7	S,L	N	S	II–III	0.2–1.4	A
Deepwater sculpin	12–5	1.0	2–7	L	N	D	II–III	0.2–1.2	A

[a] Approximate season (V = spring; S = summer; F = fall; W = winter) or number of months of egg deposition.

[b] Water temperatures associated with spawning activity.

[c] Approximate month or season of release of young or egg hatching, or duration of incubation: d = days; w = weeks.

[d] Major habitat selected for spawning: L = lake; S = stream.

[e] Substrate types selected for egg deposition: P = brood pouch; S = sand; G = gravel; C = cobble; B = boulder; N = nest.

[f] Relative spawning depth: S = shallow; D = deep.

[g] Age (years) at maturity.

[h] Average number of eggs per female or average egg number per kilogram of female (*).

[i] Egg behavior upon deposition: A = adhesive; B = semibuoyant; D = demersal.

higher birth rates, however, its populations do not develop as quickly or reach densities as great as those of the mysid. This difference has been attributed to intense fish predation on the amphipod, possibly because it is large (Table 2) and does not burrow into the substrate. *Pallasea quadrispinosa* does not make vertical migrations but swims just above the bottom at night. Once established, it seems to have more positive effects on fish populations than does *M. relicta*—probably because its influence on zooplankton communities is minor and it is available to fish, including species that feed in the littoral zone (Furst 1972a).

Pontoporeia affinis is a burrower (Marzolf 1965a) that remains almost entirely on and in the bottom during daylight (Wells 1968a; Robertson et al. 1968). It is often the most abundant benthic macroinvertebrate in many glaciated lakes, composing 50–80% of all macroinvertebrates on or near the bottom in several Canadian lakes (Rawson 1953), in the St. Lawrence Great Lakes (Cook and Johnson 1974), and in Lake Vattern (Grimas 1969).

The diel vertical migrations of *Pontoporeia affinis* are shorter than those of *M. relicta*. Large numbers of mysids may enter the upper strata of lakes at night, but *P. affinis* remains largely below the metalimnion and relatively few individuals reach the surface (Mundie 1959; Wells 1960). Marzolf (1965b), who found that not more than 7% of the *P. affinis* population in Lake Michigan migrated into the water column at night, concluded that these migrations of predominantly adult and subadult instars were for mating and not for feeding. This amphipod feeds nonselectively by ingesting large quantities of bottom sediment (Marzolf 1965a).

Though *Mysis relicta* and *Pontoporeia affinis* most commonly live in well-oxygenated hypolimnetic waters, Juday and Birge (1927) found the amphipod tolerant of low oxygen concentrations (<1 mg/L). *Mysis relicta*, however, dies at oxygen concentrations below 2 mg/L (Sherman et al. 1987). W. E. Smith (1972) reported that the maximum temperature tolerated by *P. affinis* in the laboratory was about 11°C. Larkin (1948) found that reproduction by *P. affinis* was inhibited in Athabaska, Great Bear, and Great Slave lakes by temperatures above 7°C. This amphipod appears to be less tolerant of high water temperatures than *M. relicta*, which has been collected in surface waters at 20°C (Mundie 1959). Thus *P. affinis* presumably would occur at the greater depths in lakes and reservoirs where temperatures and dissolved oxygen concentrations are both low.

The importance of *Pontoporeia affinis* in the diets

TABLE 4.—Management considerations for *Mysis relicta* compared with those for its potential competitors and predators. NA = not applicable.

	Introductions			Populations			Potential		
Species	History[a]	Acquisition[b]	Vagility[c]	Number[d]	Stability[e]	Controllability[f]	Fishery[g]	Forage[h]	Disease[i]
Mysis relicta	W	S	M	H	M	L	NA	H	L
Pallasea quadrispinosa	L	F	L	M	L	H	NA	H	H
Pontoporeia affinis	L	F	L	H	L	L	NA	H	H
Alewife	W	S	H	H	H	L	L	H	H
Lake herring	L	S	L	H	L	L	M	H	H
Lake whitefish	L	S	M	H	L	L	M	M	H
Bloater	N	S	L	M	L	L	L	H	H
Pygmy whitefish	N	D	H	M	L	L	NA	H	H
Arctic char	W	S	M	M	L	H	H	L	M
Lake trout	W	S	L	L	L	H	H	L	M
Rainbow smelt	W	S	H	H	M	M	M	H	H
Burbot	N	F	M	M	L	M	M	L	H
Slimy sculpin	N	D	M	H	L	L	NA	H	H
Deepwater sculpin	N	D	L	H	L	L	NA	H	H

[a] Previous introduction attempts: N = none; L = limited; W = widespread.
[b] Relative availability: S = simple; F = feasible; D = difficult.
[c] Propensity for dispersion or colonization (self-introduction): L = low; M = moderate; H = high.
[d] Relative abundance the species may achieve in new environment: L = low; M = moderate; H = high.
[e] Relative variation in population numbers over time: L = low; M = moderate; H = high.
[f] Capacity to manage population levels once established: L = low; M = moderate; H = high.
[g] Relative capacity of species to provide sport harvest: L = low; M = moderate; H = high.
[h] Relative suitability of species as fish forage: L = low; M = moderate; H = high.
[i] Potential for transmittal of major pathogens or parasites: L = low; M = moderate; H = high.

of many fish species is well documented (Scott and Crossman 1979). Because of its close association with the substrate, preference for cold water, and detritus diet, *P. affinis* should have a more predictable effect if established, and may provide a more reliable food source for fish, than would *M. relicta.* Brownell (1970) advised caution in the transfer of *P. affinis* to waters where the acanthocephalan *Echinorhynchus salmonis* is not already present, because the amphipod is an intermediate host for this fish parasite.

If these two amphipods were introduced into Colorado waters, they might compete with *Mysis relicta* for food (detritus) and space. Grimas et al. (1972) reported rapid growth rates for most fish species in Lake Vattern, Sweden, where *Mysis relicta, Pontoporeia affinis,* and *Pallasea quadrispinosa* occur together. Chars, trouts, and whitefishes fed on these glacial relicts, which were believed to contribute to an "ideal food web" for both pelagic- and bottom-feeding predators.

Fish

The 11 fish species listed in Tables 2–4 prey on *Mysis relicta,* and several, including Arctic char *Salvelinus alpinus,* rainbow smelt *Osmerus mordax,* burbot *Lota lota,* and sculpins *Myxocephalus* spp., have circumpolar distributions (Scott and Crossman 1979). Introduction of one or more of these species to increase predation on mysids may also enhance a fishery by supplementing forage or sport-fish populations. Before destructive perturbations occurred in the Great Lakes, the food web composed of large invertebrates (*Mysis relicta* and *Pontoporeia affinis*) for young lake trout and multispecies forage (coregonines and cottids) for large lake trout was believed to be the most stable and productive predator–prey system in the Great Lakes (S. H. Smith 1972).

The alewife *Alosa pseudoharengus* appears to have invaded many lakes containing natural mysid populations (Miller 1957; Youngs and Oglesby 1972). In Lake Michigan, the vertical migration of alewives is believed to be an adaptation for feeding on vertically migrating mysids. Adult alewives also feed extensively on *M. relicta* at night (Janssen and Brandt 1980). Despite this apparently perfect match of predator and prey and the nomination of alewife by Leathe (1984) as a species capable of controlling problem mysid populations, other aspects of alewife ecology are discouraging. Alewives are extremely efficient feeders (Janssen 1978) that can induce shifts in zooplankton composition and size distribution toward smaller forms; such shifts may adversely affect other planktivores, including young-of-year sport species (Kohler and Ney 1981). Alewives are also considered potentially important predators on fish larvae, and may have contributed to the collapse of certain native Great Lakes fish populations (Crowder 1980; Kohler and Ney 1980). Kohler and Ney (1980) suggested that this characteristic of the alewife should be seriously considered before the species is introduced elsewhere. Landlocked alewife populations are subject to periodic mass die-offs (Kohler and Ney 1981), and they readily spread through lake and reservoir systems (Ney et al. 1982).

Pelagic lake herring *Coregonus artedii* and profundal bloaters *Coregonus hoyi* are known to feed heavily on mysids (Scott and Crossman 1979). Rawson (1951) showed that lake herring were an important link between mysids and large predators in Great Slave Lake, Ontario. In Lakes Michigan and Superior, large bloaters feed heavily on mysids throughout the year (Dryer and Beil 1968); these fish eat both plankton and benthos (Janssen 1978). Although lake whitefish *Coregonus clupeaformis* and pygmy whitefish *Prosopium coulteri* also eat plankton, they are typically benthic feeders (Lindsey 1981) that readily consume mysids (Eschmeyer and Bailey 1955; Johnson 1975; Wydoski and Bennett 1981). Because lake whitefish stocks are extremely adaptable in their feeding behavior (Lindsey 1981) and pygmy whitefish have a highly disjunct distribution (Lindsey and Franzin 1972), the selection of donor sources from lakes where these species coexist with *Mysis relicta* should be considered.

When *Mysis relicta* has been introduced into lakes and reservoirs containing Arctic char and lake trout, the results have been mixed (Gosho 1975; Furst 1981; Lasenby et al. 1986). Arctic char and lake trout are sport species that might be more widely introduced to prey on mysids. Populations of Arctic char differ considerably (Kornfield et al. 1981), so donor stocks probably should be taken from waters in which Arctic char coexist with and eat *M. relicta*. Much of the information on interactions of Arctic char and mysids comes from Scandinavia, where Arctic char are littoral and profundal benthivores and limnetic planktivores (Lasenby et al. 1986). Generally, planktivorous Arctic char compete with mysids but do not eat them, whereas benthic-feeding Arctic char usually feed heavily on introduced mysids (Furst 1981; Langeland 1981). All Arctic char, however, appear to feed most heavily on mysids under winter ice cover (Furst 1972a; Lasenby et al. 1986).

Mysis relicta is an important food of lake trout, particularly of the young (Scott and Crossman 1979). Juvenile lake trout in Twin Lakes, Colorado, fed primarily on mysids, which was believed to be responsible for their faster-than-usual growth, but consumption decreased among older fish (Griest 1976). In Lake Tahoe, mysid consumption produced no significant improvement in lake trout condition, but the fish ate mysids to the exclusion of traditional food sources such as crayfish and fish (Morgan et al. 1978). Further lake trout introductions should be considered carefully to avoid complicating or precluding the establishment of forage species that may be essential for effective mysid control.

The rainbow smelt is anadromous, but indigenous landlocked populations also occur. This fish offers limited recreational fishing opportunities, but has been widely introduced as prey for many fish species. *Mysis relicta* is a primary food of rainbow smelt (Scott and Crossman 1979). However, rainbow smelt are suspected predators of small fish (Scott and Crossman 1979; Crowder 1980). Jones (1985) indicated that young rainbow smelt in Horsetooth Reservoir, Colorado, competed with game fish for zooplankton, whereas larger rainbow smelt (longer than 80 mm) ate primarily mysids. Because rainbow smelt are capable of exploiting a wide variety of foods, their introduction into waters where stocking of planktivorous or young fish is important in the management of a fishery should be carefully considered. Caution in the use of rainbow smelt also is advised because the species appears to be highly vagile (Burr and Mayden 1980; Suttkus and Conner 1980).

All sizes of burbot feed on *Mysis relicta*, but large burbot are primarily piscivorous and are believed to compete with other predaceous species for food (Bailey 1972; Scott and Crossman 1979). Burbot are often regarded as "rough fish." In Wyoming, however, this species is managed as a game fish because of its potentially large size (Bjorn 1940) and excellent food quality (Baxter and Simon 1970). Managers who consider transplanting burbot should think about the species' potential effect on existing fisheries and on future introductions of other species.

The slimy sculpin *Cottus cognatus* is widespread in lakes and streams of northern North America. The deepwater sculpin *Myoxocephalus thompsoni* appears to be restricted exclusively to deep, cool lakes within or near basins of formerly glaciated lakes (Scott and Crossman 1979). The deepwater sculpin, like *Mysis relicta*, is generally referred to as a true glacial relict, but Bailey and Smith (1981) indicated this reference to be incorrect. However, *M. relicta* and the deepwater sculpin have similar distributions in North America, and mysids occur in all waters known to contain deepwater sculpins (McAllister 1961; McAllister and Ward 1972; Dadswell 1972). Deepwater sculpins typically live in deeper water than that occupied by slimy sculpins (Wells 1968b; Johnson 1975; Scott and Crossman 1979). Both species feed on *Mysis relicta* and *Pontoporeia affinis* (Kraft 1977; Wells 1980; Kraft and Kitchell 1986), but slimy sculpins tend to feed on a wider variety of benthic organisms (Scott and Crossman 1979). Although deepwater sculpins eat other benthic animals (Jacoby 1953; Scott and Crossman 1979), their diet often consists almost entirely of mysids and *P. affinis* (Kraft 1977; Wells 1980). Slimy sculpins generally eat more *P. affinis* and fewer mysids than deepwater sculpins (Kraft 1977; Kraft and Kitchell 1986).

Recommendations

In the selection of additional exotic organisms to stock in a lake, the protocols prescribed by Li and Moyle (1981) and Kohler and Stanley (1984) should be considered before introductions are made. First among the recommendations listed by Li and Moyle (1981) is that candidates for introduction should be part of a coadapated trophic assemblage involving species already present in the system. This guideline was violated in the widespread introduction of *Mysis relicta* outside its native range (Lasenby et al. 1986); introduced lake trout often were the only fish present that had coevolved with the mysid. None of the species discussed here is proposed as the sole solution for mysid problems. However, all may be candidates for species complexes that might be developed to control introduced mysids. Kohler and Stanley (1984) recommended that species proposed for introduction match the need. Because the deepwater sculpin provides the major link between mysids and lake trout in a straight, simple food chain (Johnson 1975), it represents a logical first choice for introduction into waters where the lake trout is the only species coadapted with *M. relicta.*

The second and third recommendations outlined by Li and Moyle (1981) are that candidate species have narrow niche breadth and low vagility. Aside from amphipods, the deepwater sculpin appears to best fulfill these criteria. It is a benthivore that is restricted to the cold depths of lakes and should, therefore, not spread to other waters or seriously compete with sport species. Because of its affinity for mysids and deep water, the deepwater sculpin again represents a good candidate for introduction.

Lastly, Li and Moyle (1981) suggested that candidates for introduction should not transfer contagious diseases or parasites exotic to the system. All of the species discussed have been cultured in hatchery or laboratory facilities. As is commonly practiced in salmonid culture, eggs should be treated when this is feasible to preclude the transfer of diseases and parasites (Kohler and Stanley 1984). If the capacity to rear them is developed, the acquisition, propagation, introduction, and establishment of these species would be facilitated. For species that are difficult to culture, donor sources should be selected carefully and fish should be held in isolation for inspection to minimize risks from diseases and parasites.

Acknowledgments

We thank Robert Behnke for his guidance in this review. Also recognized are the fishery personnel who provided information on the introduction and establishment of *Mysis relicta* in western North America. A special thanks is extended to Anita Martinez for her assistance in producing this manuscript.

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