Habitat Associations of Introduced Smallmouth Bass and Native Signal Crayfish of Lake Whatcom, Washington During November 1998

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Abstract

Little information exists concerning the impact of introduced smallmouth bass on native signal crayfish in Washington. Diver observations quantified the effects of habitat type on smallmouth bass and signal crayfish densities in a lake renowned for its smallmouth bass fishery. Relationships were examined between smallmouth bass density and signal crayfish density, but also between their densities and proportional substrate types including boulder/bedrock, gravel/cobble, silt/sand, submersed vegetation, and coarse woody debris. Although diver observations were consistent with previously demonstrated smallmouth bass-crayfish habitat associations, the impact of introduced smallmouth bass on native signal crayfish remains enigmatic. Still, the results should provide direction on ways to improve our understanding and management of predator and prey species alike.

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Introduction

The association between the piscine predator, smallmouth bass *Micropterus dolomieu*, and its crayfish prey (Decapoda: Astacidae and Cambaridae) is well known. Within the predator's native range of east central North America, the two appear to be inexorably linked with one another. For example, Rabeni (1992) concluded that size-selective predation of smallmouth bass on crayfishes *Orconectes* spp. influenced crayfish population dynamics, whereas Roell and Orth (1998) showed that human exploitation of one affected biomass, production, and harvest of the other. Not surprisingly, in the lab or field, smallmouth bass influence crayfish behavior, abundance, and habitat use directly or indirectly in a variety of ways (Stein and Magnuson 1976; Stein 1977; Mather and Stein 1993).

Smallmouth bass were first transplanted from their native range to Washington State during the early 1920s. However, it was not until the early 1980s that the predator found its way (intentional or otherwise) from its original point-of-entry, the Columbia River drainage system, to several lakes throughout Washington (Pflug and Pauley 1983; Bennett et al. 1991; Mueller et al. 1999). Little information exists concerning the impact of introduced smallmouth bass on Washington's native signal crayfish *Pacifastacus leniusculus*. In fact, no recent studies exist of signal crayfish resources in Washington (Clifton 1986) beside scant commercial landing records (e.g., WDF 1993). However, before designing rigorous field studies that examine the interaction between introduced smallmouth bass and native signal crayfish, simple baseline information is needed that explores their use of habitat and establishes an association between predator and prey. To this end, we investigated the relationship between densities of smallmouth bass and signal crayfish and habitat variables in a lake renowned for its smallmouth bass fishery.

Lake Whatcom (Figure 1) is located in the northwest corner of the state and supports one of the most popular smallmouth bass fisheries in the Pacific Northwest (Ledeboer 2000). The intentional release of smallmouth bass into Lake Whatcom first occurred in the early 1980s. The Washington Department of Fish and Wildlife (WDFW), formerly the Washington Department of Game, introduced the predator to augment an ailing sport fishery as recommended by Fletcher (1982). By late summer 1998, the smallmouth bass population in Lake Whatcom was thriving and characterized by rapid growth, excellent relative weights, and relative stock density values that indicated a predator population in balance with its prey base (Mueller et al. 1999). As expected, the native signal crayfish was found to be an integral part of its diet (Downen 1999). Given the lack of information regarding the intertwined roles of smallmouth bass and signal crayfish in Washington, the purpose of this study was to provide an initial examination of the potential influences of predator abundance and habitat type on signal crayfish density.

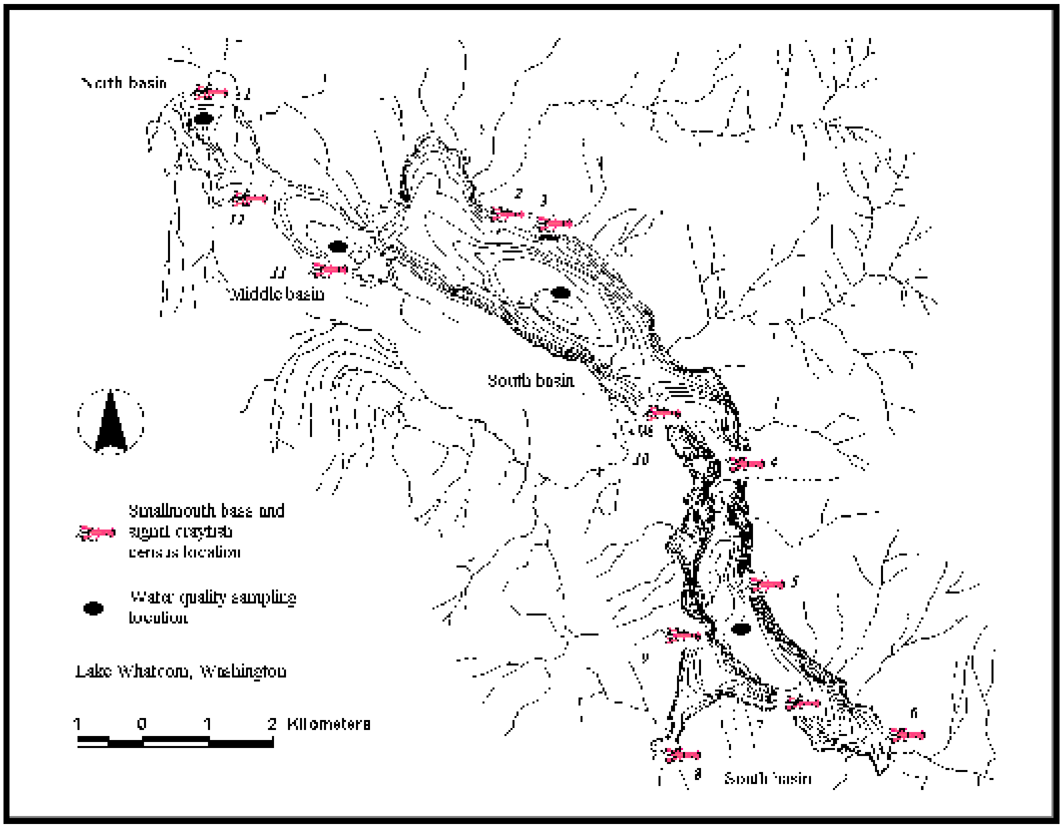

Figure 1. Map of Lake Whatcom showing smallmouth bass and signal crayfish census and water quality sampling locations.

Materials and Methods

Study Site

Lake Whatcom is a large (surface area = 2,030 ha, volume = 936,651,000 m^3), natural body of water located directly east of the City of Bellingham in Whatcom County (48E 44' 18" N, 122E 19' 32" W). The lake consists of three basins separated by distinct glacial sills. The north and middle basins (Basin 1 and 2, respectively) are relatively small (210 and 160 ha, respectively) and shallow (20 – 25 m maximum depth), whereas the south basin (Basin 3) is considerably larger (1,660 ha) and deeper (85 – 100 m maximum depth) (Figure 1). The lake serves as the drinking water source for residents of Bellingham and the surrounding area. Water quality studies have shown a tendency toward increased eutrophication in the north and middle basins in recent years, whereas the south basin remains oligotrophic (Matthews et al. 2000).

Like many large bodies of water, Lake Whatcom exhibits patches of distinct habitat types with associated fish assemblages. For example, with few exceptions, brown bullhead *Ameiurus nebulosus* and juvenile largemouth bass *Micropterus salmoides* occur in Basin 1 only, whereas yellow perch *Perca flavescens* and pumpkinseed *Lepomis gibbosus* reside in the shallow, vegetated habitats of all three basins. Peamouth *Mylocheilus caurinus*, cutthroat trout *Oncorhynchus clarki*, and kokanee *O. nerka* are ubiquitous throughout the lake, yet longnose sucker *Catostomus catostomus* occur only in the lower half of Basin 3, mostly on the steep, rocky drop-offs of the east shore. Likewise, large numbers of smallmouth bass can be found along rocky outcroppings and points, while marginal habitats (e.g., barren gravel or sandy substrates) are dominated by a paucity of other species, including sculpin *Cottus* sp. and three-spine stickleback *Gasterosteus aculeatus* (Mueller et al. 1999).

Smallmouth Bass and Signal Crayfish Census Locations

Smallmouth bass are known to display site fidelity and establish home ranges (Pflug and Pauley 1983; Todd and Rabeni 1989; Kraai et al. 1991). Thus, to better understand the relationship between introduced smallmouth bass and native signal crayfish in Lake Whatcom, 12 census locations (Figure 1) were selected from areas frequented by the predator as previously determined by Mueller et al. (1999). The number of census locations surveyed was based on personal experience of the maximal effort expended by a three-person crew (two scuba divers, one tender) during a three-day period.

Census locations 1, 3, 8, and 12 (Figure 1) were characterized by their shallow depth (5 m), gentle slope (< 20% grade) comprised of silt or sand, and the presence of submersed vegetation. Census locations 4, 5, 7, and 9 were deep (17 m) with steep slopes (> 40% grade) lacking vegetation, and substrate comprised mostly of boulders and bedrock, whereas census locations 2, 6, 10, and 11 had intermediate depth (11 m), slope (20 – 40% grade), and substrate characteristics, and lacked submersed vegetation. Classification of habitat at these locations was adapted from the work of Pflug and Pauley (1984), who studied a population of smallmouth bass from another large lake in Washington. Consideration was also given to depth, slope, and substrate preferences of smallmouth bass reported by several authors (Munther 1970; Hubert and Lackey 1980; Probst et al. 1984; Rankin 1986; Todd and Rabeni 1989; Kraai et al. 1991).

Water quality data was collected from four locations proximal to the census locations (Figure 1) on November 3 - 4, 1998 and analyzed using a Hydrolab® probe and digital recorder or an independent laboratory (Matthews et al. 2000). Appendix A summarizes Matthews et al.'s (2000) findings on temperature (EC), dissolved oxygen (mg/l), pH, alkalinity (mg/l), turbidity (NTU), and nitrate (Fg/l).

Diver Observations and Estimation of Smallmouth Bass and Signal Crayfish Densities

During daylight hours on November 2 - 4, 1998, the density of smallmouth bass and signal crayfish at each of 12 census locations was estimated using a sampling technique developed by WDFW to assess subtidal stocks of marine benthic invertebrates (Bradbury et al. 2000). A series of three strip transects, each comprising an area of 1.82 m wide by 45.72 m long (a total area of 83.21 m^2), was taken along the 5, 11, or 17 m depth contour by a pair of scuba divers at each census location.

Each transect was initiated by planting a metal stake in the substrate which temporarily anchored a spooled, 45.72 m long transect line. Divers swam side by side, unspooling the transect line (Figure 2) along a given depth contour and predetermined compass course that generally directed the long axis of the transect parallel to the shoreline. Divers counted all smallmouth bass within 5 m (the limit of their visibility) of the transect line, or a swath 10 m wide by 45.72 m long (a total area of 457.2 m^2). Divers only considered those fish measuring > 100 mm total length, or the approximate size at which the predator first feeds on crayfish (Pflug and Pauley 1984; Probst et al. 1984; Gilliland et al. 1991; Roel and Orth 1993; Scott and Angermeier 1998). Individual fish were easily recognized by size, shape, or fin anomalies and counted only once to insure independence between transects. Using submersible lights, divers located and counted all exposed signal crayfish as well as those seeking shelter (e.g., within rock crevices or under coarse woody debris). Each diver was responsible for counting signal crayfish directly underneath his half of the 1.82 m wide transect rod and spool. Thus, each diver surveyed a swath 0.91 m wide by 45.72 m long (Figure 2).

At the end of each transect, one diver remained at the terminus, recording data and observations on a dive slate (i.e., counts and habitat characteristics), while the second diver swam back along the transect to re-spool the transect line. The minimum and maximum size of smallmouth bass and signal crayfish for

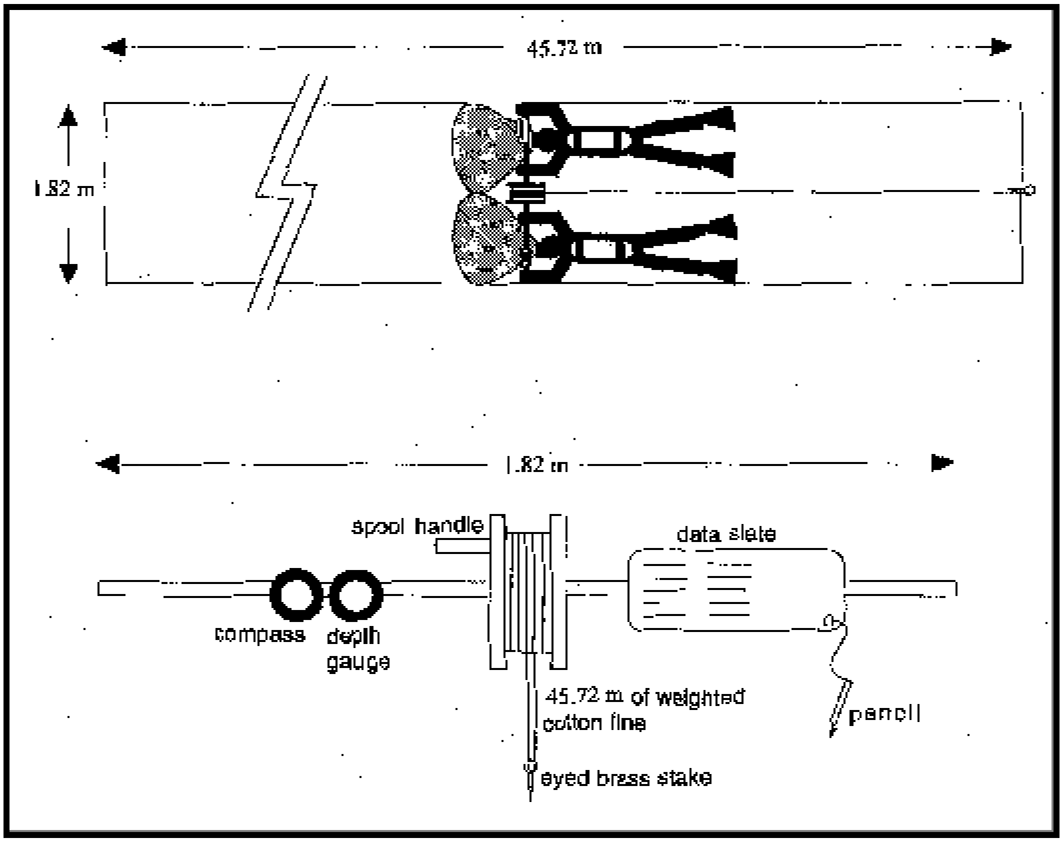

Figure 2. Schematic of divers performing a strip transect survey of smallmouth bass and signal crayfish within a 83.21 m^2 transect, including details of transect spool (redrawn from Bradbury et al. 2000).

all transects was estimated visually by comparing their total lengths to a known scale (460-mm length of a handheld underwater slate). Proportional composition of substrate type (silt/sand, gravel/cobble, or boulder/bedrock), submersed aquatic vegetation, and coarse woody debris was estimated visually for each transect (Appendix B). To avoid pseudoreplication (Hurlbert 1984), the sum of the two diver counts on an individual transect was the total observed number of smallmouth bass or signal crayfish on that transect (Appendix B). Subsequent transects were separated by 4 to 6 m along the depth contour to further insure independence between transects (Anderson et al. 1979). Each transect required five to seven minutes to complete.

The estimate of smallmouth bass density (number/100 m^2) for an individual transect (457.2 m^2) was simply calculated as the total number of smallmouth bass observed by both divers divided by 457.2 then multiplied by 100. The estimate of signal crayfish density (number/100 m^2) for an individual transect (83.21 m^2) was similarly calculated as the total number of signal crayfish observed by both divers divided by 83.21 then multiplied by 100.

Data Analysis

Since the data were not normally distributed, as determined by the Wilk-Shapiro test ($P < 0.05$), a nonparametric rank correlation procedure was used (Zar 1984) to identify factors (Appendix B) affecting the density of introduced smallmouth bass and native signal crayfish at Lake Whatcom. The Spearman correlation coefficient, r_s, is computed from the rank scores of the data and ranges from –1 to +1, with values close to 0 indicating little or no correlation between variables. All computations were run using Statistix® analytical software (Analytical Software, Tallahassee, Florida).

Results

During daylight hours on November 2 - 4, 1998, smallmouth bass densities ranged from 0.0 to 0.7 fish/100 m^2. The overall mean (± SE) smallmouth bass density observed by divers at Lake Whatcom was 0.13 ± 0.03 (n = 36 transects). Signal crayfish densities ranged from 0.0 to 19.2 crayfish/100 m^2 with an overall mean (± SE) of 5.7 ± 0.9 (n = 36 transects). The minimum and maximum size of smallmouth bass observed for all transects was approximately 150 and 460 mm total length, respectively. For signal crayfish, 80 and 140 mm total length (measured from tip of rostrum to end of telson), respectively.

Table 1 summarizes the results of the Spearman rank correlation procedure. A significant positive correlation was detected between smallmouth bass density and signal crayfish density. There was no significant correlation between smallmouth bass density and depth; however, there was a significant positive correlation between signal crayfish density and depth. Smallmouth bass and signal crayfish densities were significantly and positively correlated with proportional boulder/bedrock substrate, yet no significant correlation was detected between densities and proportional gravel/cobble substrate. There was a significant negative correlation between density and proportional silt/sand substrate for predator and prey alike; however, there was no significant correlation between densities and proportional submersed vegetation. A significant positive correlation was detected between smallmouth bass density and proportional coarse woody debris, but no significant correlation was detected between signal crayfish density and proportional coarse woody debris.

Table 1. Results of Spearman rank correlation, corrected for ties, between smallmouth bass and signal crayfish densities and habitat variables at Lake Whatcom, Washington during November 2-4, 1998. The Spearman correlation coefficient, r_s is computed from the rank scores of the data and ranges from -1 to +1, with values close to 0 indicating little or no correlation between variables.

Species or habitat variable	Smallmouth bass density	Signal crayfish density
Signal crayfish density	0.367[a]	
Depth	0.217	0.509[a]
Boulder/bedrock	0.510[a]	0.742[a]
Gravel/cobble	0.231	0.313
Silt/sand	-0.538[a]	-5.49[a]
Submersed vegetation	-0.004	-2.06
Coarse woody debris	0.360[a]	0.029

[a] Correlation is significant, $P < 0.05$.

Discussion

Fish predators frequently cause shifts in the abundance, behavior, and habitat use of their crustacean prey. Mather and Stein (1993) consistently found that wherever smallmouth bass and rock bass *Ambloplites rupestris* densities were high, crayfish *Orconectes* spp. densities were low. However, in Lake Whatcom, the density of introduced smallmouth bass was significantly and positively correlated with native signal crayfish density (Table 1). This pattern differs somewhat from those derived from controlled field experiments in analogous freshwater stream and tropical marine systems. For example, in Sweden, at a small spatial scale, Dahl (1998) found that direct predation by the sculpin *Cottus gobio* significantly reduced the density of lotic signal crayfish. In the Caribbean Sea, predation risk from the nurse shark *Ginglyostoma cirratum* influenced the distribution and abundance of another decapod crustacean, the spiny lobster *Panulirus argus*, at Bahia de la Ascension, Mexico (Eggleston and Lipcius 1992). And off St. Croix, U.S. Virgin Islands, densities of stomatopod crustaceans or mantis shrimps, *Gonodactylus* sp. and *Meiosquilla* sp., were significantly higher on experimental reefs with lower numbers of fish predators compared to experimental reefs with higher numbers of fish predators (Reaka 1985). Similar mechanisms may be occurring at Lake Whatcom, especially given the spatial and temporal overlap between introduced smallmouth bass and native signal crayfish (Table 1, Appendix B); however, these need to be rigorously tested.

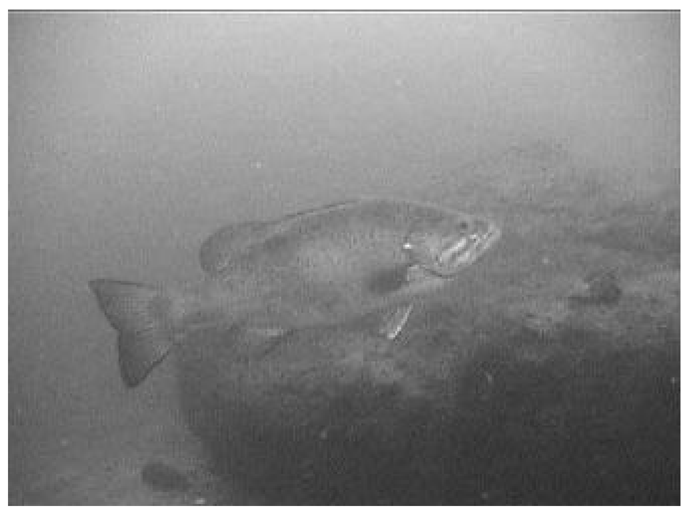

Figure 3. Smallmouth bass hovering over boulder (Photo by Don P. Rothaus).

Lake Whatcom smallmouth bass preferred coarse substrate types such as boulders (Figure 3) compared to fine substrate types like silt (Table 1). This association is supported by several studies both locally (Munther 1970; Pflug and Pauley 1984) and nationally (Rankin 1986; Todd and Rabeni 1989; Gilliland et al. 1991; Kraai et al. 1991). Furthermore, their affinity for coarse woody debris is consistent with other studies. For example, Probst et al. (1984) and Todd and Rabeni (1989) found that stream-dwelling smallmouth bass were closely associated with woody structure such as logs and branches. Lentic smallmouth bass generally prefer unvegetated littoral habitats (Pflug and Pauley 1984; Weaver et al. 1997), supporting our findings of no correlation between submersed vegetation and the density of smallmouth bass at Lake Whatcom.

Like smallmouth bass, Lake Whatcom signal crayfish preferred coarse substrate types (Figure 4) over fine substrate types (Table 1). Abrahamsson and Goldman (1970), Daniels (1980), and Light et al. (1995) reported a similar pattern for signal crayfish in Nevada and California. Ostensibly, this is related to the strong antipredator response and increased refuge use by signal crayfish when encountering fish predators (SØderb¬ck 1994). Indeed, Stein and Magnuson (1976) demonstrated crayfish *Orconectes propinquus* preference for pebble vs. sand substrates in the presence of smallmouth bass in its native range. Moreover, *O. propinquus* densities on sand were inversely related to smallmouth bass densities, while foraging smallmouth bass were less inclined to select *O. propinquus* from larger, more structurally complex substrate types compared to simpler ones (Stein 1977). Although not significant, the negative correlation between the density of Lake Whatcom signal crayfish and submersed vegetation is consistent with Daniels' (1980) findings in California, whereas the significant positive correlation with depth is similar to that reported by Abrahamsson and Goldman (1970). The latter hypothesized that lower signal crayfish densities in the shallows (< 10 m) of Lake Tahoe were a result of light avoidance, strong wave action, and predation.

Figure 4. Signal crayfish seeking refuge underneath boulder (Photo by Don P. Rothaus).

In summary, at a limited spatial and temporal scale, I have shown that the density of introduced smallmouth bass in Lake Whatcom is significantly and positively correlated with native signal crayfish density. Furthermore, I have provided evidence of the influence of habitat type on the densities of smallmouth bass and signal crayfish in the lake. Although diver observations were consistent with previously demonstrated smallmouth bass-crayfish habitat associations, the impact of introduced smallmouth bass on native signal crayfish of Lake Whatcom remains enigmatic. Although inherent biases exist, these results should provide direction on ways to improve our understanding and management of predator and prey species alike.

References

Abrahamsson, S.A.A., and C.R. Goldman. 1970. Distribution, density and production of the crayfish *Pacifasticus leniusculus* Dana in Lake Tahoe, California-Nevada. Oikos 21: 83-91.

Anderson, D.R., J.L. Laake, B.R. Crain, and K.P. Burnham. 1979. Guidelines for line transect sampling of biological populations. Journal of Wildlife Management 43: 70-78.

Bennett, D.H., J.A. Chandler, and L.K. Dunsmoor. 1991. Smallmouth bass in the Pacific Northwest: benefit or liability. Pages 126-135 *in* D.C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agriculture and Forestry Experiment Station, Mississippi State University.

Bradbury, A., B. Sizemore, D. Rothaus, and M. Ulrich. 2000. Stock assessment of subtidal clams (*Panopea abrupta*) in Washington. Washington Department of Fish and Wildlife, Marine Resources Unit, Technical Report # FPT 00-01, Olympia.

Clifton, R.M. 1986. Crayfish in Washington. Washington Department of Fisheries, Informational Bulletin, Olympia.

Dahl, J. 1998. Effects of a benthivorous and a drift-feeding fish on a benthic stream assemblage. Oecologia 116: 426-432.

Daniels, R.A. 1980. Distribution and status of crayfishes in the Pit River Drainage, California. Crustaceana 38: 131-138.

Downen, M.R. 1999. Some evidence for the importance of crayfish in the diet of smallmouth bass of Lake Whatcom, Washington. Washington Department of Fish and Wildlife, Warmwater Enhancement Program, Technical Report # FPT 99-01, Olympia.

Eggleston, D.B., and R.N. Lipcius. 1992. Shelter selection by spiny lobster under variable predation risk, social conditions, and shelter size. Ecology 73: 992-1011.

Fletcher, D.H. 1982. Lake Whatcom, Whatcom County fishery survey. Pages 180-191 *in* Warm water fishery investigations in Washington State. Washington Department of Game, annual report submitted to the U.S. Fish and Wildlife Service under Federal Aid in Fish Restoration Program, Project No. F-71-R, Olympia.

Gilliland, E., R. Horton, B. Hysmith, and J. Moczygemba. 1991. Smallmouth bass in Lake Texoma, a case history. Pages 136-142 *in* D.C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agriculture and Forestry Experiment Station, Mississippi State University.

Hubert, W.A., and R.T. Lackey. 1980. Habitat of adult smallmouth bass in a Tennessee River Reservoir. Transactions of the American Fisheries Society 109: 364-370.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54: 187-211.

Kraai, J.E., C.R. Munger, and W.E. Whitworth. 1991. Home range, movements, and habitat utilization of smallmouth bass in Meredith Reservoir, Texas. Pages 44-48 *in* D.C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agriculture and Forestry Experiment Station, Mississippi State University.

Ledeboer, L. 2000. Washington's spring smallmouths. Washington-Oregon Game and Fish 2000(5): 17-19.

Light, T., D.C. Erman, C. Myrick, and J. Clarke. 1995. Decline of the Shasta crayfish (*Pacifastacus fortis* Faxon) of northeastern California. Conservation Biology 9: 1567-1577.

Mather, M.E., and R.A. Stein. 1993. Direct and indirect effects of fish predation on the replacement of a native crayfish by an invading congener. Canadian Journal of Fisheries and Aquatic Science 50: 1279-1288.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews. 2000. Lake Whatcom monitoring project. 1998/99 final report to the Department of Public Works, Bellingham, Washington.

Mueller, K.W., M.R. Downen, and D.H. Fletcher. 1999. 1998 Lake Whatcom survey: the warmwater fish community 15 years after the introduction of smallmouth bass. Washington Department of Fish and Wildlife, Warmwater Enhancement Program, Technical Report # FPT 99-12, Olympia.

Munther, G.L. 1970. Movement and distribution of smallmouth bass in the Middle Snake River. Transactions of the American Fisheries Society 99: 44-53.

Pflug, D.E., and G.B. Pauley. 1983. The movement and homing of smallmouth bass, *Micropterus dolomieui*, in Lake Sammamish, Washington. California Fish and Game 69: 207-216.

Pflug, D.E., and G.B. Pauley. 1984. Biology of smallmouth bass (*Micropterus dolomieui*) in Lake Sammamish, Washington. Northwest Science 58: 118-130.

Probst, W.E., C.F. Rabeni, W.G. Covington, and R.E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society 113: 283-294.

Rabeni, C.F. 1992. Trophic linkage between stream centrarchids and their crayfish prey. Canadian Journal of Fisheries and Aquatic Science 49: 1714-1721.

Rankin, E.T. 1986. Habitat selection by smallmouth bass in response to physical characteristics in a natural stream. Transactions of the American Fisheries Society 115: 322-334.

Reaka, M.L. 1985. Interactions between fishes and motile benthic invertebrates on reefs: the significance of motility vs. defensive adaptations. Pages 439 – 444 *in* Proceedings of the fifth international coral reef congress, 1985, Tahiti.

Roell, M.J., and D.J. Orth. 1993. Trophic basis of production of stream-dwelling smallmouth bass, rock bass, and flathead catfish in relation to invertebrate bait harvest. Transactions of the American Fisheries Society 122: 46-62.

Roell, M.J., and D.J. Orth. 1998. Indirect effects of fishery exploitation and pest control in a riverine food web. North American Journal of Fisheries Management 18: 337-346.

Scott, M.C., and P.L. Angermeier. 1998. Resource use by two sympatric black basses in impounded and riverine sections of the New River, Virginia. North American Journal of Fisheries Management 18: 221-235.

Söderbäck, B. 1994. Interactions among juveniles of two freshwater crayfish species and a predatory fish. Oecologia 100: 229-235.

Stein, R.A. 1977. Selective predation, optimal foraging, and the predator-prey interaction between fish and crayfish. Ecology 58: 1237-1253.

Stein, R.A., and J.J. Magnuson. 1976. Behavioral response of crayfish to a fish predator. Ecology 57: 751-761.

Todd, B.L., and C.F. Rabeni. 1989. Movement and habitat use by stream-dwelling smallmouth bass. Transactions of the American Fisheries Society 118: 229-242.

WDF (Washington Department of Fisheries). 1993. 1991 Washington marine fish and shellfish landings. Washington Department of Fisheries, Olympia.

Weaver, M.J., J.J. Magnuson, and M.K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 54: 2277-2289.

Zar, J.H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall, Englewood Cliffs, New Jersey.

Appendix A

Water quality data near locations where smallmouth bass and signal crayfish were counted at Lake Whatcom, Washington during November 2 - 4, 1998 (from Matthews et al. 2000)

Site #	WDFW #	Basin #	Transect #	Depth (m)	Temperature (EC)	Dissolved oxygen (mg/l)	pH	Alkalinity (mg/l)	Turbidity (NTU)	Nitrate (Fg/l)
1	3	1	1	5	12.5	8.7	7.4	21.2	1.6	54
			2	5	12.5	8.7	7.4	21.2	1.6	54
			3	5	12.5	8.7	7.4	21.2	1.6	54
2	18	3	4	11	13.8	9.4	7.7	18.9	0.3	178
			5	11	13.8	9.4	7.7	18.9	0.3	178
			6	11	13.8	9.4	7.7	18.9	0.3	178
3	19	3	7	5	13.5	9.5	7.7	19.3	0.5	159
			8	5	13.5	9.5	7.7	19.3	0.5	159
			9	5	13.5	9.5	7.7	19.3	0.5	159
4	29	3	10	17	13.7	9.2	7.6	18.2	0.3	373
			11	17	13.7	9.2	7.6	18.2	0.3	373
			12	17	13.7	9.2	7.6	18.2	0.3	373
5	32	3	13	17	13.7	9.2	7.6	18.2	0.3	373
			14	17	13.7	9.2	7.6	18.2	0.3	373
			15	17	13.7	9.2	7.6	18.2	0.3	373
6	39	3	16	11	13.7	9.2	7.7	19.1	0.4	195
			17	11	13.7	9.2	7.7	19.1	0.4	195
			18	11	13.7	9.2	7.7	19.1	0.4	195
7	43	3	19	17	13.7	9.2	7.6	18.2	0.3	373
			20	17	13.7	9.2	7.6	18.2	0.3	373
			21	17	13.7	9.2	7.6	18.2	0.3	373
8	48	3	22	5	13.7	9.3	7.7	19	0.3	194
			23	5	13.7	9.3	7.7	19	0.3	194
			24	5	13.7	9.3	7.7	19	0.3	194
9	52	3	25	17	13.7	9.2	7.6	18.2	0.3	373
			26	17	13.7	9.2	7.6	18.2	0.3	373
			27	17	13.7	9.2	7.6	18.2	0.3	373
10	61	3	28	11	13.8	9.4	7.7	18.9	0.3	178
			29	11	13.8	9.4	7.7	18.9	0.3	178
			30	11	13.8	9.4	7.7	18.9	0.3	178
11	74	2	31	11	13.5	9.3	7.7	19.5	0.7	154
			32	11	13.5	9.3	7.7	19.5	0.7	154
			33	11	13.5	9.3	7.7	19.5	0.7	154
12	77	1	34	5	12.5	8.7	7.4	21.2	1.6	54
			35	5	12.5	8.7	7.4	21.2	1.6	54
			36	5	12.5	8.7	7.4	21.2	1.6	54

Appendix B

Habitat characteristics of locations where smallmouth bass and signal crayfish were counted at Lake Whatcom, Washington during November 2 – 4, 1998. Proportional substrate type, submersed vegetation, and coarse woody debris were based on visual estimates by scuba divers.

Site #	WDFW #	Basin #	Transect #	Depth (m)	Boulder/bedrock	Gravel/cobble	Silt/sand	Submersed vegetation	Coarse woody debris	# smallmouth bass	# signal crayfish
1	3	1	1	5	0.05	0.10	0.60	0.15	0.10	1	8
			2	5	0.05	0	0.75	0.05	0.15	1	9
			3	5	0	0	0.90	0.05	0.05	0	4
2	18	3	4	11	0	0	0.90	0	0.10	0	0
			5	11	0	0	0.80	0	0.20	0	0
			6	11	0	0	0.95	0	0.05	0	0
3	19	3	7	5	0	0.35	0.35	0	0.30	0	1
			8	5	0	0.40	0.40	0	0.20	2	1
			9	5	0	0.40	0.40	0	0.20	0	3
4	29	3	10	17	0.80	0	0	0	0.20	2	2
			11	17	0.10	0.70	0.10	0	0.10	1	10
			12	17	0.70	0	0.20	0	0.10	3	7
5	32	3	13	17	0.30	0.10	0.30	0	0.30	1	9
			14	17	0.80	0	0.10	0	0.10	3	12
			15	17	0.80	0	0.10	0	0.10	0	11
6	39	3	16	11	0	0	0.90	0	0.10	0	0
			17	11	0	0	0.90	0	0.10	0	1
			18	11	0	0	0.90	0	0.10	0	0
7	43	3	19	17	0.60	0.30	0.10	0	0	1	12
			20	17	0.20	0.45	0.25	0	0.10	0	5
			21	17	0.40	0.30	0.10	0	0.20	1	14
8	48	3	22	5	0	0	0.60	0.30	0.10	1	0
			23	5	0	0	0.30	0.60	0.10	0	1
			24	5	0	0.10	0.30	0.40	0.20	2	1
9	52	3	25	17	0.70	0.15	0.05	0	0.10	1	16
			26	17	0.10	0.20	0.60	0	0.10	0	7
			27	17	0	0.30	0.70	0	0	0	2
10	61	3	28	11	0.20	0	0.70	0	0.10	0	7
			29	11	0.70	0	0.25	0	0.05	0	6
			30	11	0.10	0	0.60	0	0.30	1	2
11	74	2	31	11	0	0	0.90	0	0.10	0	4
			32	11	0	0	0.80	0	0.20	0	8
			33	11	0	0	0.90	0	0.10	0	2
12	77	1	34	5	0	0	0.30	0.70	0	0	0
			35	5	0	0	0.50	0.50	0	0	4
			36	5	0	0	0.30	0.70	0	0	2