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ABUNDANCE AND PRESENCE OF FISH IN RESTORED VEGETATION IN NORTH-CENTRAL MINNESOTA LAKES

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Abstract.— Removal of aquatic vegetation, common along developed shoreland, can degrade fish habitat. To evaluate if fish habitat can be restored, we assessed nearshore fish and invertebrate relative abundance and presence in restored and unrestored aquatic vegetation in ten north-central Minnesota lakes. Linear mixed models were used to evaluate variation in abundance and presence due to lake, site, month, time, and vegetation density. Restored aquatic vegetation was used by fish as frequently as unrestored vegetation. Bluegill and Yellow Perch abundance increased in dense vegetation as did the presence of cyprinids, Bluegill, Pumpkinseeds, Yellow Perch, Tadpole Madtoms, and snails. Like natural unrestored aquatic vegetation, restored vegetation provides habitat for phytophylic fish and invertebrates.

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As lakes are developed, aquatic vegetation is commonly removed by lakeshore owners for boat access, dock and lift installation, and to improve swimming opportunities. The loss of aquatic vegetation along developed shorelines is visually evident. From aerial photographs of lakeshore, Radomski and Goeman (2001) documented reduced emergent and floating-leaf vegetation with increased homes per kilometer of shoreline. In Minnesota, the Department of Natural Resources Section of Fisheries requires a permit for removal of any emergent vegetation and limits harvest of submerged and floating-leaf vegetation. But as shoreland development rates increase in Minnesota (Kelly and Stinchfield 1998), the cumulative loss of nearshore vegetation could have increasingly negative effects on fish populations (Jennings et al. 1999).

Removal of aquatic vegetation directly harms fish by eliminating important habitat for vegetation-dependent fish. Diverse fish communities and abundant populations were associated with dense aquatic vegetation (Bryan and Scarnecchia 1992), growth rates of adult Bluegills *Lepomis macrochirus* was greater in lakes with diverse, high quality aquatic plant communities (Tomcko and Pereira 2006), and the relative weight per net and mean weight of Pumpkinseed *Lepomis gibbosus*, Bluegill, and Northern Pike *Esox lucius* was correlated with the occurrence of emergent and floating-leaf aquatic vegetation (Radomski and Goeman 2001). Research also has documented fish associated with vegetation - juvenile Yellow Perch *Perca flavescens* and darters *Etheostoma* species (Keast et al. 1978, Lyons 1987), Black Crappie *Pomoxis nigromaculatus*, Bluegill, Largemouth Bass *Micropterus salmoides* and other centrarchids (Keast et al. 1978, Engel 1985), Blackchin Shiner *Notropis heterodon* and Banded Killifish *Fundulus diaphanus* (Valley et al. 2010). Aquatic vegetation provides a complex structural framework within which competitive and predatory interactions occur in aquatic ecosystems. Aquatic vegetation provided predatory refuge (Savino and Stein 1982, Gotceitas and Colgan 1987, Warfe and Barmutta 2004), increased abundance of invertebrate prey (Gilinsky 1984, Schramm et al. 1987, Schramm and Jirka 1989), and was used as spawning substrate and for nest protection (Engel 1985). Removal of vegetation and other aquatic structure may have prompted avoidance of developed shorelines detected for nesting Black Crappie and Largemouth Bass (Reed and Pereira 2009).

Removal of nearshore vegetation indirectly harms fish by increasing erosion and reducing water quality. Suspended eroded sediment harms fish by blanketing spawning nests and reefs, reducing oxygen for fish eggs and larvae. Aquatic vegetation reduced incoming wave energy (Good 1994, Rea 1998) and long roots of native terrestrial vegetation maintain shore integrity during storm events. Lakeshore owners frequently hard-armor shoreline to control erosion but anglers (Wilde et al. 1992) and scientists recognize that hard-armor cannot replace the complex fish habitat provided by aquatic vegetation (Jennings et al. 1999).

The Minnesota Department of Natural Resources Fisheries developed a Shoreland Habitat Program to mitigate development-related habitat loss by restoring nearshore vegetation. To determine if restored vegetation provided fish habitat, we documented fish relative abundance and presence, invertebrate presence, and vegetation density in restored and unrestored aquatic vegetation in ten north-central Minnesota lakes. We hypothesized that restored and unrestored aquatic vegetation both provide habitat so would be frequented by similar number and taxa of fish and invertebrates. We developed linear mixed models to determine the relative importance of lake, site, month, time and vegetation density in predicting abundance and presence. If patterns of abundance and presence are similar in restored as unrestored vegetation, we will conclude that restored and unrestored vegetation provide similar habitat, that shoreland restoration can replace nearshore fish habitat and mitigate habitat loss.

METHODS

To compare habitat quality of restored and unrestored aquatic vegetation, we estimated fish abundance and presence, invertebrate presence, and vegetation density in ten lakes, Itasca County, in north-central Minnesota (Figure 1). Two lakes were assessed each year, 2006-2010. Lakes with the oldest restorations were chosen first to assure maximum vegetation maturity (Table 1). Lakes varied widely in size, trophic status, and aquatic plant community condition (plant IBI; Beck et al.

2010; Table 1) because few northern Minnesota lakes had restorations at the start of the study. Northern lakes were chosen over southern lakes because we expected their fish communities would be relatively unstressed and better able to recolonize restored aquatic vegetation. Terrestrial vegetation alone was planted in most restorations, but aquatic vegetation usually reestablished itself provided conditions supported plant growth.

We estimated fish abundance and presence using above-water observations. Observations allowed the frequent assessment necessary to estimate month and time effects in models. Six sites were chosen on each lake, including a restored site. The five unrestored sites were randomly chosen. Sites were visited on three consecutive days in each of May, June, and July. Visits occurred on the hour. Site order and first lake visited was randomized. At each site, a 60 m transect was established. Fish were counted and taxa identified if possible. Additional species identification was available from seining and electrofishing at each site to estimate a fish index of biotic integrity (fish IBI; Drake and Pereira 2002).

We estimated aquatic vegetation density to quantify habitat. Vegetation is the predominant structural element in the lakes. We estimated vegetation density by two methods - underwater coverage and the more traditional stem density (Savino and Stein, 1982). Density was assessed at two locations at the six observation sites in May, June, and July. We estimated underwater coverage by photographing a white PVC pipe through ½ meter of vegetation (Litvaitis et al. 1996, Weimer 2004). Coverage was estimated as the ratio of vegetation-covered pipe area to total area, calculated using ArcView GIS. To estimate stem density, stems were counted in a ½ meter quadrat. Generalized linear mixed effect models (GLMM) of fish abundance and presence were used to compare coverage and stem density. Vegetation density was a fixed effect in models and lake, a random effect.

Fish use of habitat was estimated as fish abundance and presence in restored and unrestored habitats. Abundance and presence were modeled using GLMM with month, time (both ordinal), and vegetation density as fixed effects and site nested in lake, a random effect. Abundance models had a Poisson error structure and natural log link function. Vuong (1989) statistics were used to establish the improved performance of generalized poisson models compared to poisson, zero-inflated poisson, or zero-inflated generalized poisson models (Czado et al. 2007). Abundance overdispersion was estimated using generalized linear models. Presence GLMM had a binomial error structure and logistic link function. Residual plots were examined to evaluate fit (Weisberg 1985). We assumed abundance and presence were underestimated because detection was imperfect, but presence to a lesser extent because only a single individual was needed to score presence. We did not model extremely rare species because overly frequent zero occurrences made such models unreliable (Czado et al. 2007).

We estimated prey availability as presence of aquatic and terrestrial food resources. Aquatic organisms were captured using quatrefoil light traps (Secor et al. 1992). Two traps per site were deployed overnight at the six observation sites in June and July. Organisms were counted and identified to taxa. The 6 mm entrance slots of the traps excluded most adult fish, many juvenile fish, and large-bodied invertebrates, such as some *Anisoptera* species. Terrestrial insects were captured on 'sticky traps', 100 mm^2 plastic coated with insect adhesive. Traps were staked onshore overnight at the six observation sites in May, June, and July. Insects were counted and identified to order. Prey presence was modeled using GLMM with month a fixed effect, and 'site nested within lake', a random effect, binomial error structure and logistic link function.

RESULTS

The six taxa we most commonly observed were cyprinids (*Notropis* sp., *Pimephales* sp., cyprinid-like *Fundulus* sp.), Bluegill, darters, Largemouth Bass, Yellow Perch, and Pumpkinseed (Figure 2). We rarely observed Rock Bass *Ambloplites rupestris* ($N = 13$), bullhead *Ameiurus* sp. ($N = 2$), Black Crappie *Pomoxis nigromaculatus* ($N = 1$), Mottled Sculpin *Cottus bairdi* ($N = 9$), Bowfin *Amia calva* ($N = 1$), Logperch *Percina caprodes* ($N = 24$). Smallmouth Bass *Micropterus dolomieu* were also rarely observed but in large schools of approximately 500 juveniles.

Observed fish abundance varied with vegetation density, whether estimated as coverage or stem density (Table 2). Both Bluegills and Yellow Perch were abundant in dense vegetation, i.e., coverage parameter estimates were positive, while cyprinids were abundant in barren areas (Table 3). Both cyprinid and Yellow Perch abundance exhibited overdispersion (Table 3), suggesting that model structure did not sufficiently account for variation (Burnham and Anderson 2002). Observed abundance varied by month for all species except Largemouth Bass (Table 3). Bluegill and cyprinids were abundant in May (Table 3) though detection could have declined in June and July as vegetation density increased (Figure 3). Darter and Pumpkinseed were abundant in June, and Yellow Perch in July (Table 3). Cyprinids and Yellow Perch abundance varied by time-of-day but time parameter estimates were small, indicating minimal effect (Table 3).

Observed fish presence varied with vegetation density. Cyprinids, Bluegill, and Pumpkinseed were frequently observed in vegetation; darters were frequently observed over barren areas (Table 4, Figure 2). Cyprinid, centrarchid, and Yellow Perch presence varied by month, with cyprinids and Yellow Perch least frequently observed in May, and Bluegill and Pumpkinseed most frequently in June (Table 4). Time-of-day did not affect fish presence (Table 4) and residual patterns did not suggest nonlinearity (Figure 4).

Tadpole Madtoms (*Noturus gyrinus*) were frequently seined and electroshocked in dense vegetation (Table 5, Figure 5). Johnny Darters tended to be captured more frequently over barren sediment (P = 0.07; Table 5). Other species were not associated with a particular habitat (Table 5, Figure 5-7). Lake was a significant source of variation in the presence of many taxa (Table 5). Residuals suggest Bluegill were more frequently present in vegetation of intermediate density (Figure 8).

Snails were trapped more frequently in dense vegetation (Table 6, Figures 9); other species exhibited no habitat association (Table 6, Figures 9-12). Month and lake explained variation in the presence of many prey taxa (Table 6).

DISCUSSION

Restored vegetated habitat provided habitat for Bluegill, Yellow Perch, and cyprinids, generally considered phytophilic (Scott and Crossman 1978, Phillips 1982). Lake sampling and observations indicate association with vegetation for Bluegill (Werner et al. 1977, Weaver et al. 1997), Yellow Perch (Keast et al. 1978, Hatzenbeler et al. 2000), and the cyprinids, Blackchin Shiner (Keast et al. 1978, Pratt and Smokorowski 2003, Valley et al. 2010), Mimic Shiner (*Notropis volucellus*; Moyle 1973, Keast et al. 1978, Pratt and Smokorowski 2003), and bluntnose minnow (*Pimephales notatus*; Keast et al. 1978). In contrast, Lyons (1987) found Bluntnose Minnows associated with barren habitat in Sparkling Lake, Wisconsin, Moyle (1973) reported Bluntnose Minnows schooled in barren areas with Mimic Shiners, and Pratt and Smokorowski (2003) described Bluegill, Pumpkinseed, Perch, and Bluntnose Minnows as habitat generalists based on their sampling. However these three studies were conducted on single lakes and may not reflect general habitat associations. Our models suggest nearshore property owners who restore vegetation can provide habitat for phytophilic cyprinids, centrarchids, and Yellow Perch. Restoration can mitigate habitat losses for these taxa.

Restoring vegetation will not provide habitat for all species. We found darters associated with barren sites so restoring vegetation along barren shorelines would remove darter habitat. We also found evidence suggesting that darter habitat association varies by species. Iowa Darters (*Etheostoma exile*) tended to be captured more frequently in vegetation and Johnny Darters (*Etheostoma nigrum*) over barren areas. Lyons (1987) detected a somewhat similar pattern, sampling Iowa Darters, young-of-the-year Darters, and Logperch in vegetation and Johnny Darters near coarse wood. Other fish species were reported associating with barren areas. Spottail Shiner (*Notropis husonius*) and Walleye (*Sander vitreus*) were electroshocked foraging at night over barren sand flats in a Minnesota lake (Pierce et al. 2006). Naturally rocky or sandy shoreline should be maintained by lakeshore owners to provide habitat for benthic-oriented species.

Fish presence provided a more sensitive indicator of vegetation-related habitat use than abundance. Coverage was related to the presence of four commonly observed taxa but was related to the abundance of only three taxa, and for two of those taxa, cyprinids and Yellow Perch, overdispersion factors suggested poor model fit. The extremely large abundances for schooling cyprinids and perch produce strongly skewed poisson distributions, which are difficult to model. Frequent zero values also contribute to strongly skewed poisson distributions. Frequent recording of zero abundance may occur because mobile fish have numerous habitat choices in the patchy, dense, diversely vegetated nearshore habitat common in these lakes and which contributes to relatively high plant IBIs (Table 1; Beck et al. 2010).

Month was a source of variation in the presence of many nearshore fish. Non-destructive observations allowed us to conduct the frequent sampling necessary to establish that seasonal effects were significant in these models. However, observation allows identification of only a few distinctively colored, and larger species species. Cyprinids and darters tend to be difficult to identify observationally underwater (Werner et al. 1977, Keast et al. 1978) unless one species dominates (Bluntnose Minnow, Lyons 1987). Development of habitat association models for specific cyprinids and darters will require sampling where capture allows species identification though mortality may result. Electroshocking and seining will be useful to develop species-specific models but sample size was must be sufficient given the considerable lake and site variation detected.

The considerable lake-to-lake variation in the presence of many species underscores the necessity of using multiple lake studies to describe habitat associations. Unique patterns of fish presence in individual lakes suggest single-lake studies (Keast et al. 1978, Lyons 1987, Bryan and Scarnecchia 1992, Pratt and Smokorowski 2003) will not produce generalized models. Sampling a large number of lakes with widely varying characteristics is necessary to produce widely applicable models. Developing habitat associations of rare species may be especially difficult because their presence is confined to few lakes. But if lakes are targeted where rare species were known to exist, and many sites assessed in those lakes, it should be possible to establish habitat association models even for rare species. Because site variation was also considerable, future sampling should include many sites exhibiting a full range of habitat in each lake. Such extensive sampling may require development of more rapid fish assessment techniques.

Coverage was better than stem counts to estimate vegetation density. Both coverage and stem density performed well in models. But photographs were much easier logistically, requiring only an underwater digital camera, a quadrat to standardize visual distance, and GIS software to calculate areas from .jpg files. Coverage produced more objective and realistic estimates of density than did stem counts for low-growth, highly branched, multi-stemmed *Chara* and *Najas* species. Finally photographs capture a fish-eye view of vegetation, so may more accurately capture characteristics important to fish – prey colonization surface area and quality of refuge from predators. Realistic portrayal of habitat quality should improve correlation between fish and habitat metrics potentially improving the tracking of the response of aquatic plant communities and fish populations to development and climate stress.

The importance of scale in developing realistic habitat association models was evident in the many insignificant models for trapped, seined, and electroshocked taxa. Only Tadpole Madtoms (Phillips 1982) and snails (Pennak 1978) were associated with vegetation; both are recognized as phytophilic. However, water scorpions (Ohba and Goodwyn 2010) and crawling water beetles (Pennak 1978) also are, yet exhibited no association with vegetation. The scale of sampling may have been too large given the patchy, diverse habitat. Electroshocking and seining transects may have been too long. Both gear tend to herd fish. Herding fish between patches would average catch across different habitats. The two coverage photographs per transect also averaged habitat quality, which together with averaged catch, could remove correlation between fish presence and coverage. Prey sampling had a different problem. Sampling and coverage estimation locations were slightly separated from each other, traps set in deep water to avoid storm damage (~ 3 ft) and vegetation density estimated in shallower water (2 ft or less) to facilitate stem counts, plant species identification, and to produce clear photographs. Different patch quality in trap and vegetation locations would weaken correlation between presence and coverage. To improve correlations and produce more believable habitat association models, scale could be reduced to a single, consistent patch, and presence and coverage assessments made within the same patch.

SUMMARY

Restored aquatic vegetation provided usable habitat for phytophilic fish, similar to unrestored, natural aquatic vegetation. Lakeshore owners who restore aquatic vegetation can expect to provide habitat for phytophilic fish and mitigate vegetation removals and habitat loss for vegetation-associated taxa. We developed habitat association models for cyprinids, Bluegill, darters, Largemouth Bass, Yellow Perch, and Pumpkinseed but not for specific cyprinids and darters. Gear that allows capture and assures species identification will rectify this problem. The models we developed clarified the importance of lake, and month and vegetation density in explaining variation in fish presence. Because month explained variation in the presence of some species, seasonal effects should be considered when modeling new species. Lake and site were also sources of considerable variation in presence. Generalized habitat models will require sampling on many lakes at many sites, which should exhibit the full range of potential habitat. Generalized models can also be developed for rare species if lakes are targeted where the species is known to exist and sample size is sufficient. To accomplish this extensive sampling, rapid assessment methods should be developed. Habitat can be quickly characterized using photographs of underwater coverage. We recommend reducing scale to consistent patches in patchy habitat to improve correlations of fish presence and habitat. By following these recommendations, generalized habitat association models can be developed for additional nearshore fish species. Additional models would further justify shoreland restoration as a method to improve fish habitat for phytophilic species. And if lakeshore owners maintain naturally rocky or sandy shorelines for benthic-oriented species, a full spectrum of habitats can be established, necessary to fulfill the requirements of a diverse complement of nearshore fish.

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Table 1. Year of shoreline restoration on ten north-central Minnesota lakes, studied in 2006-2010 (SYear). Vegetation was planted in all restorations but the one on Prairie Lake, which was rip-rapped. Lakes are identified by a Minnesota Department of Natural Resources' DOW number. Lake characteristics included surface area (SA; ha), trophic status index (TSI), Secchi depth (Secchi; m), total phosphorus concentration (Phos; ppb), and a macrophyte index of biotic integrity (plant IBI; Beck et al. 2010).

Lake	Year	Syear	DOW	SA	TSI	Secchi	Phos	Plant IBI
Trout	2000	2006	31021600	795	42	5.1	35	63.9
Little Bass	1999	2006	31057500	63	38	4.1	12	65.7
Little Jay Gould	2002	2007	31056600	61	-	3.7	44	60.0
Siseebakwet	2001	2007	31055400	529	37	3.6	10	57.9
Jessie	1999	2008	31078600	709	46	2.6	36	73.2
Maple	1999	2008	31077300	92	37	3.0	14	75.9
Prairie	1999	2009	31038400	431	53	1.7	33	73.9
Wabana	2005	2009	31039200	899	35	5.0	10	71.4
Deer	2005	2010	31071900	1657	37	4.7	8	67.9
Moose	2007	2010	31072200	515	42	4.0	16	52.4

Table 2. Mixed effect models of the relative abundance (Abund) and presence of Cyprinids, Bluegill, and Darters in ten north-central Minnesota lakes, 2006-2010. Fixed effects included aquatic vegetation density (fixed), estimated as coverage (Cover) or stem density (Stems). Lake was a random effect. Statistics for the intercept and fixed effects included a parameter estimate (Est), indicating magnitude and direction, standard error of the estimate (SE), *Z* test statistic and its significance probability (*P*). Variation in the random effect was described by its standard deviation. The number of observations was 488.

Sp		Est	SE	*Z*	*P*	SD		Est	SE	X^2	*P*	SD
<u>Cyprinid</u>												
Abund	Intercept	3.00	0.39	7.61	<0.01		Intercept	2.98	0.39	7.67	<0.01	
	Cover	0.56	0.03	17.58	<0.01	1.25	Stems	0.02	<0.01	22.81	<0.01	1.23
Presence	Intercept	-0.80	0.36	-2.22	0.03		Intercept	-0.68	0.32	-2.12	0.04	
	Cover	3.21	0.53	6.06	<0.01	1.02	Stems	0.08	0.01	5.83	<0.01	0.90
<u>Bluegill</u>												
Abund	Intercept	-0.77	0.63	-1.23	0.22		Intercept	-0.92	0.65	-1.42	0.15	
	Cover	1.22	0.14	8.82	<0.01	1.95	Stems	0.05	<0.01	14.1	<0.01	2.01
Presence	Intercept	-2.11	0.43	-4.94	<0.01		Intercept	-2.27	0.48	-4.71	<0.01	
	Cover	2.39	0.55	4.37	<0.01	1.16	Stems	0.08	0.01	5.36	<0.01	1.36
<u>Darter</u>												
Abund	Intercept	-0.12	0.54	-0.22	0.82		Intercept	-0.50	0.57	-0.87	0.38	
	Cover	-1.50	0.21	-7.01	<0.01	1.68	Stems	0.01	<0.01	1.41	0.15	1.78
Presence	Intercept	-0.76	0.48	-1.58	0.11		Intercept	-1.05	0.49	-2.14	0.03	
	Cover	-1.69	0.62	-2.72	0.01	1.39	Stems	-0.01	0.02	-0.70	0.49	1.44

Table 3. General linear mixed effect models of the relative abundance of observed Cyprinids, Bluegill, Darters, Largemouth Bass, Yellow Perch, and Pumpkinseed in ten north-central Minnesota lakes, 2006-2010. Fixed effects included aquatic vegetation coverage (Cover), month (May, June, and July), and time. July was aliased. Site nested in lake (Site:Lk) was the random effect. Statistics for the intercept and fixed effects included a parameter estimate (Est), indicating magnitude and direction, standard error of the estimate (SE), *Z* test statistic and its significance probability (*P*). Probabilities $\leq$ 0.05 are bolded. Variation in the random effect was described by its standard deviation (SD). Overdispersion (Ov) was estimated from a general linear model having the same structure as the general linear mixed model. The number of observations was 488.

Sp	Intercept or Cover					Month or Time					Site:Lk	Lake	Ov
	Effect	Est	SE	*Z*	*P*	Effect	Est	SE	*Z*	*P*	SD	SD	
Cyprinid	Intercept	-0.02	0.42	-0.06	0.95	May	1.03	0.02	43	**<0.01**	1.85	1.06	221
	Cover	-0.32	0.05	-6.14	**<0.01**	June	0.49	0.02	23	**<0.01**			
						Time	<0.01	<0.01	50	**<0.01**			
Bluegill	Intercept	-2.88	0.67	-4.31	**<0.01**	May	1.60	0.12	12.87	**<0.01**	1.60	1.86	9
	Cover	2.90	0.30	9.71	**<0.01**	June	1.24	0.11	11.23	**<0.01**			
						Time	<-0.01	<0.01	-0.76	0.45			
Darter	Intercept	-1.28	0.62	-2.06	**0.04**	May	0.37	0.15	2.43	**0.02**	1.27	1.72	6
	Cover	-0.49	0.40	-1.21	0.22	June	0.59	0.12	4.92	**<0.01**			
						Time	<0.01	<0.01	0.74	0.46			
Largemouth Bass	Intercept	-3.48	0.68	-5.09	**<0.01**	May	0.18	0.33	0.54	0.59	1.64	1.09	2
	Cover	1.05	0.95	1.10	0.27	June	-0.14	0.29	-0.84	0.63			
						Time	<0.01	<0.01	0.31	0.75			
Yellow Perch	Intercept	-2.15	1.20	-1.79	0.07	May	-2.48	0.11	-22.88	**<0.01**	2.98	3.32	47
	Cover	1.38	0.28	4.93	**<0.01**	June	-1.57	0.06	-24.95	**<0.01**			
						Time	<-0.01	<0.01	-15.66	**<0.01**			
Pumpkinseed	Intercept	-7.17	1.36	-5.26	**<0.01**	May	-0.41	1.23	-0.33	0.74	1.43	1.86	2
	Cover	2.16	1.54	1.40	0.16	June	3.31	0.74	4.49	**<0.01**			
						Time	<0.01	<0.01	0.61	0.54			

Table 4. General linear mixed effect models of the presence of observed Cyprinids, Bluegill, Darters, Largemouth Bass, Yellow Perch, and Pumpkinseed in ten north-central Minnesota lakes, 2006-2010. Fixed effects included aquatic vegetation coverage (Cover), month (May, June, and July), and time. July was aliased. Site nested in lake (Site:Lk) was the random effect. Statistics for the intercept and fixed effects included a parameter estimate (Est), indicating magnitude and direction, standard error of the estimate (SE), *Z* test statistic and its significance probability (*P*). Probabilities ≤ 0.05 are bolded. Variation in the random effect was described by its standard deviation (SD). The number of observations was 488.

Sp	Intercept or Cover					Month or Time					Site:Lk	Lake
	Effect	Est	SE	*Z*	*P*	Effect	Est	SE	*Z*	*P*	SD	SD
Cyprinid	Intercept	-0.03	0.48	-0.07	0.94	May	-0.59	0.27	-2.23	**0.03**	0.58	0.23
	Cover	1.55	0.50	2.90	**<0.01**	June	-0.23	0.25	-0.93	0.35		
						Time	<0.01	<0.01	-0.28	0.78		
Bluegill	Intercept	-2.86	0.82	-3.48	**<0.01**	May	0.09	0.40	0.22	0.83	1.48	1.27
	Cover	2.10	0.94	2.24	**0.02**	June	0.79	0.35	2.26	**0.02**		
						Time	<0.01	<0.01	0. 21	0.83		
Darter	Intercept	-0.49	0.53	-0.92	0.36	May	-1.62	0.29	-0.55	0.58	0.58	0.23
	Cover	-2.11	0.64	-3.32	**<0.01**	June	0.01	0.27	0.04	0.96		
						Time	<0.01	<0.01	0.13	0.90		
Largemouth Bass	Intercept	-3.19	0.89	-3.58	**<0.01**	May	-0.27	0.50	-0.54	0.59	1.09	1.04
	Cover	1.16	1.04	1.11	0.27	June	-0.15	0.45	-0.33	0.74		
						Time	<0.01	<0.01	-0.10	0.92		
Yellow Perch	Intercept	-3.21	0.97	-3.29	**<0.01**	May	-1.46	0.54	-2.72	**<0.01**	0.23	1.72
	Cover	1.22	0.87	1.40	0.16	June	-0.55	0.41	-1.34	0.18		
						Time	<0.01	<0.01	0.56	0.58		
Pumpkinseed	Intercept	-5.80	1.46	-3.96	**<0.01**	May	-0. 13	1.26	-0.10	0.92	<0.01	1.05
	Cover	3.24	1.33	2.43	**0.01**	June	2.51	0.72	3.46	**<0.01**		
						Time	<0.01	<0.01	-0.12	0.90		

Table 5. General linear mixed effect models of the presence of electroshocked and seined fish in 10 north-central Minnesota lakes, 2006-2010. Aquatic vegetation coverage (Cover) was a fixed effect and lake was random. Statistics for the intercept and coverage included a parameter estimate (Est), indicating magnitude and direction, standard error of the estimate (SE), *Z* test statistic and its significance probability (*P*). Probabilities ≤ 0.05 are bolded. Variation in the random effect was described by its standard deviation (SD). The number of samples was 60.

Sp	Intercept				Coverage				Lake
	Est	SE	*Z*	*P*	Est	SE	*Z*	*P*	SD
Banded Killifish	-0.34	0.54	-0.62	0.54	0.60	1.12	0.53	0.60	0.86
Blackchin Shiner	-1.88	0.59	-3.19	<**0.01**	1.45	1.18	1.23	0.22	0.38
Bluntnose Minnow	-0.34	0.54	-0.64	0.52	0.67	1.11	0.60	0.55	0.85
Blacknose Shiner	-2.63	1.18	-2.24	**0.02**	-1.46	2.06	-0.71	0.48	2.43
Mimic Shiner	-1.82	0.70	-2.61	**0.01**	0.60	1.36	0.44	0.66	1.13
Bluegill	-0.97	0.45	-2.16	**0.03**	1.80	1.00	1.79	0.07	0.07
Iowa Darter	-0.70	0.71	-1.00	0.32	1.17	1.37	0.86	0.39	1.36
Johnny Darter	1.45	0.70	2.09	**0.04**	-2.36	1.31	-1.80	0.07	1.24
Largemouth Bass	0.07	0.63	0.12	0.91	-0.59	1.23	-0.48	0.63	1.16
Yellow Perch	0.85	0.98	0.86	0.39	-0.55	1.64	-0.34	0.74	2.28
Smallmouth Bass	-1.78	0.75	-2.37	**0.02**	-3.72	2.96	-1.26	0.21	0.75
Rock Bass	-1.68	0.62	-2.71	**0.01**	0.85	1.34	0.64	0.52	0.72
White Sucker	-4.86	1.76	-2.75	**0.01**	0.89	2.48	0.36	0.72	3.15
Golden Shiner	-2.73	1.00	-2.73	**0.01**	-1.12	2.50	-0.45	0.65	1.08
Spottail Shiner	-1.95	0.83	-2.34	**0.02**	-1.98	2.14	-0.93	0.35	1.23
Tadpole Madtom	-4.03	1.14	-3.54	<**0.01**	3.95	1.87	2.11	**0.03**	0.83

Table 6. General linear mixed effect models of the presence of light-trapped fish and invertebrates and sticky-trapped terrestrial insects in 10 north-central Minnesota lakes, 2006-2010. Fixed effects included aquatic vegetation coverage (Cover), month (May, June, and July (aliased)). Site nested in lake (Site:Lk) was the random effect. Statistics for the intercept and fixed effects included a parameter estimate (Est), indicating magnitude and direction, standard error of the estimate (SE), *Z* test statistic, and its significance probability (*P*). Probabilities $\leq$ 0.05 are bolded. The variation in the random effect was described by its standard deviation (SD). Probabilities $\leq$ 0.05 are bolded. The sample size was 262 for light trap models, and 200 for the sticky trap model.

Gear Species	Intercept				Cover				Month				S:Lk	Lk
	Est	SE	*Z*	*P*	Est	SE	*Z*	*P*	Est	SE	*Z*	*P*	SD	SD
Light trap														
Mimic Shiner	-6.68	1.88	-3.56	**<0.01**	-3.46	2.22	-1.56	0.12	-1.56	0.89	-1.74	0.08	6. 95	1.50
Blackchin Shiner	-5.72	1.17	-4.91	**<0.01**	2.13	1.36	1.57	0.12	0.26	0.76	0.34	0.74	0.84	2.02
Bluntnose Minnow	-8.95	2.25	-3.98	**<0.01**	2.78	2.50	1.11	0.27	-0.76	1.18	-0.65	0.52	6.09	<0.01
Cyprinid sp.	-2.11	0.59	-3.57	**<0.01**	0.79	0.71	1.11	0.27	-0.09	0.41	-0.22	0.83	0.76	1.46
Brook Silverside	-15.2	11.5	-1.32	0.19	5.52	3.29	1.68	0.09	-17.7	>50	0.00	1.00	0.00	12.5
Banded Killifish	-4.48	1.14	-3.93	**<0.01**	1.84	1.23	1.49	0.14	-1.30	0.80	-1.63	0.10	1.04	2.64
Bluegill	-3.59	0.73	-4.90	**<0.01**	-0.19	1.36	-0.14	0.89	-0.11	0.84	-0.13	0.89	<0.01	0.74
Darter sp.	-2.93	0.65	-4.53	**<0.01**	0.40	0.89	0.45	0.65	0.85	0.45	1.89	0.06	1.32	1.35
Largemouth Bass	-0.83	0.32	-2.59	**0. 01**	0.35	0.55	0.64	0.52	-1.06	0.36	-2.94	**<0.01**	0.27	0.59
Yellow Perch	-0.25	0.52	-0.48	0.63	0.38	0.60	0.63	0.53	-1.33	0.35	-3.80	**<0.01**	0.00	1.38
Smallmouth Bass	-10.2	5.65	-1.80	0.07	0.08	1.63	0.05	0.96	-0.52	0.71	-0.73	0.47	1.58	8.86
Fish larvae	-0.76	0.35	-2.18	0.03	0.35	0.52	0. 68	0.50	1.95	0.34	5.83	**<0.01**	<0.01	0.75
Zooplankton	4.22	1.10	3.83	**<0.01**	1.32	1.90	0.70	0.49	1.82	0.87	2.09	**0.04**	0.74	2.31
Chironomid	1.60	0.51	3.14	**<0.01**	-1.28	0.67	-1.91	0.06	-0.02	0.37	-0.05	0.96	1.00	1.17
Ceratopogonid	-1.63	0.45	-3.64	**<0.01**	0.99	0.60	1.64	0.10	1.20	0.35	3.38	**<0.01**	0.66	0.99
Diptera pupae	0.67	0.47	1.44	0.15	-0.30	0.60	-0.50	0.61	-0.06	0.33	-0.17	0.86	0.63	1.15
Amphipod	2.78	0.68	4.07	**<0.01**	-0.07	0.78	-0.09	0.93	-1.19	0.47	-2.53	**0.01**	0.90	1.69
Ostracod	-0.81	0.33	-2.46	0.01	0.07	0.57	0.13	0.90	0.39	0.31	1.24	0.21	1.00	0.44
Hydracarina	2.28	0.50	4.59	**<0.01**	0.87	1.03	0.85	0.40	0.55	0.52	1.07	0.28	1.02	0.80
Zygoptera	-1.16	0.41	-2.84	**<0.01**	0.14	0.65	0.21	0.83	1.75	0.35	4.97	**<0.01**	1.06	0.75
Ephemeroptera	0.22	0.38	0.58	0.56	0.38	0.56	0.68	0.50	0.73	0.33	2.18	0.03	0.66	0.82
Anisoptera	-3.33	0.68	-4.89	**<0.01**	0.10	1.07	0.09	0.93	-1.40	0.92	-1.53	0.13	0.58	1.20
Trichoptera	-1.79	0.50	-3.56	**<0.01**	0.85	0.62	1.36	0.17	1.39	0.38	3.68	**<0.01**	0.74	1.14
Coleoptera	-2.75	0.79	-3.49	**<0.01**	0.12	0.88	0.13	0.90	-0.97	0.53	-1.81	0.07	0.50	1.93
Hemiptera	-8.85	2.13	-4.16	**<0.01**	3.11	2.17	1.43	0.15	0.83	1.06	0.78	0.44	5.38	1.64
Crawl water beetle	0.33	0.94	0.36	0.72	-1.27	0.78	-1.64	0.10	1.37	0.46	2.94	**<0.01**	0.71	2.67
3-stripe beetle	-1.82	0.96	-1.90	0.06	0.40	0.86	0.46	0.64	1.25	0.50	2.47	**0.01**	1.46	2.60
Corixid	-0.11	0.53	-0.21	0/83	1.00	0.65	1.54	0.12	1.56	0.38	4.12	**<0.01**	0.89	1.32
Snails	-2.44	0.68	-3.62	**<0.01**	1.74	0.70	2.49	**0.01**	0.95	0.42	2.26	**0.02**	0.00	1.70
Water scorpion	-2.38	1.12	-2.12	0.03	0.60	0.92	0.66	0.51	-0.01	0.54	-0.02	0.98	1.03	3.09
Sticky trap														
Diptera	7.28	3.84	1.90	0.06	0.88	11.3	0.08	0.94	18.3	>50	<0.01	1.00	5.33	**<0.01**

Figure 1. Ten north-central Minnesota lakes where fish and habitat quality were assessed, 2006-2010.

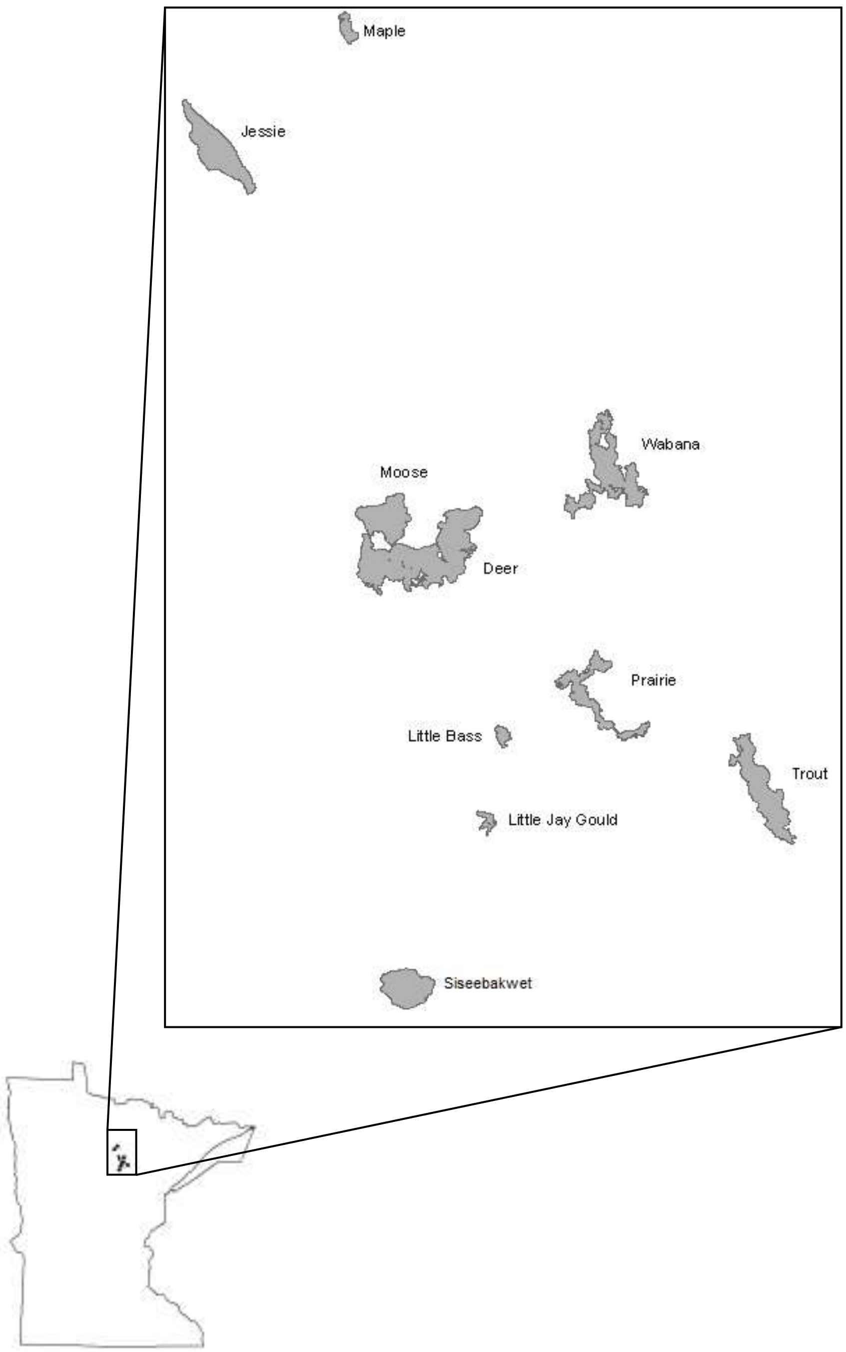

Figure 2. The probability of observing Cyprinids, Darters, Bluegill, Yellow Perch, Largemouth Bass, and Pumpkinseed versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

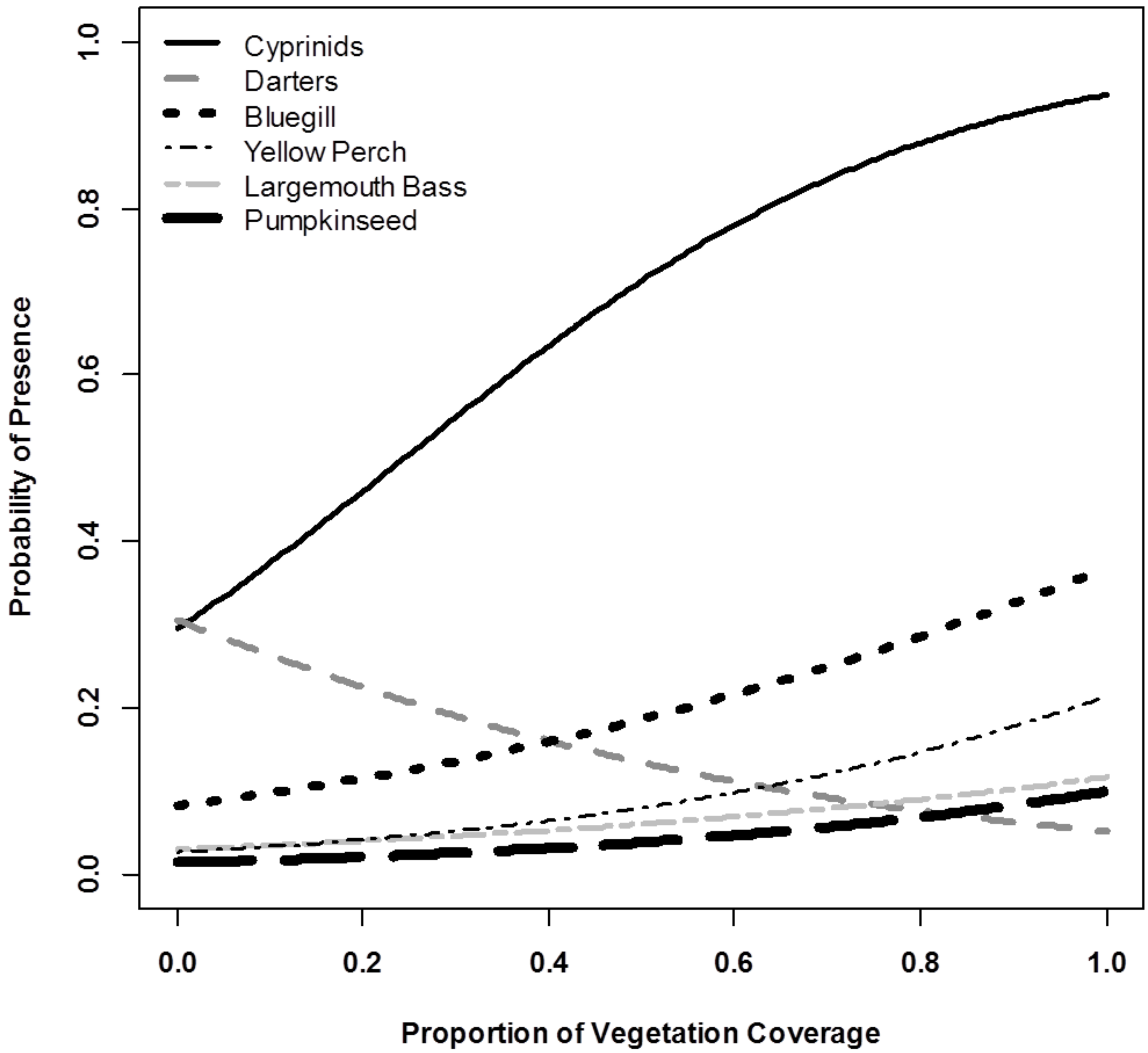

Figure 3. The proportion of aquatic vegetation coverage estimated in May, June, and July in ten north-central Minnesota lakes, 2006-2010.

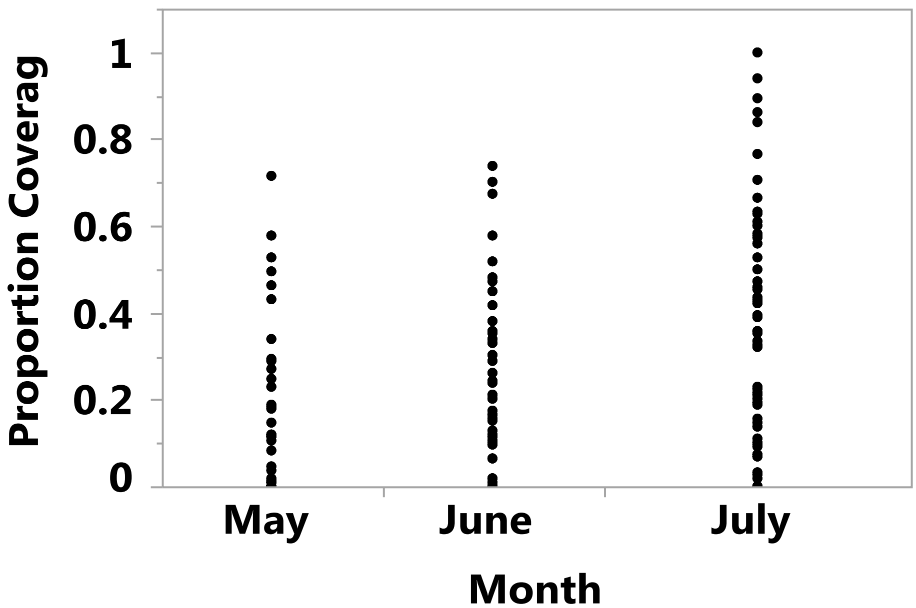

Figure 4. Residual plots (jiggered residuals versus fitted values) of logistic regressions of the presence of observed Bluegill, Cyprinids, Darters, Largemouth Bass, Yellow Perch, and Pumpkinseed versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010. Lowess-smoothed curves indicate central tendency.

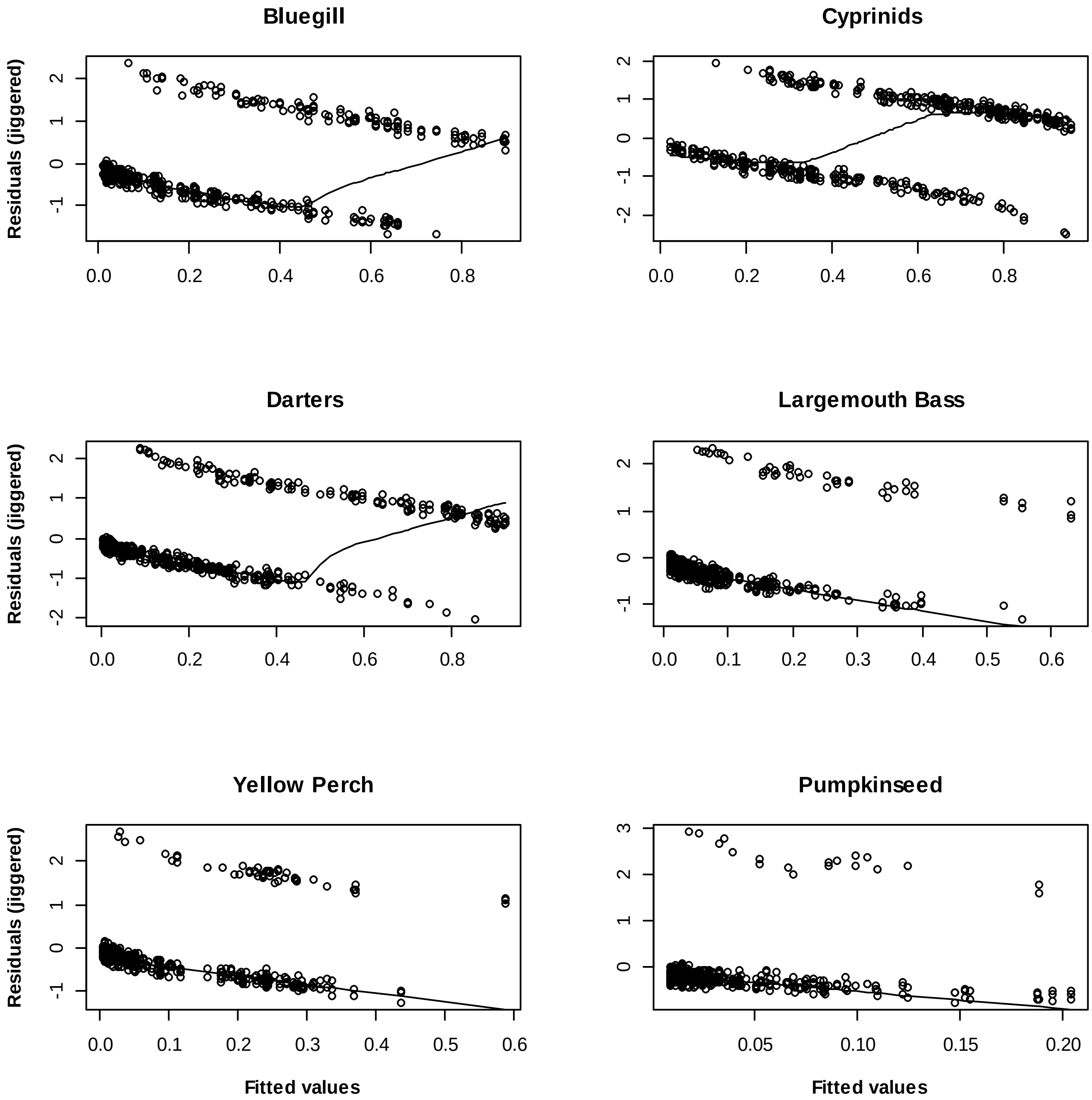

Figure 5. The probability of seining and electrofishing Johnny Darter, Iowa Darter, Spottail Shiner, Golden Shiner, and Tadpole Madtom versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

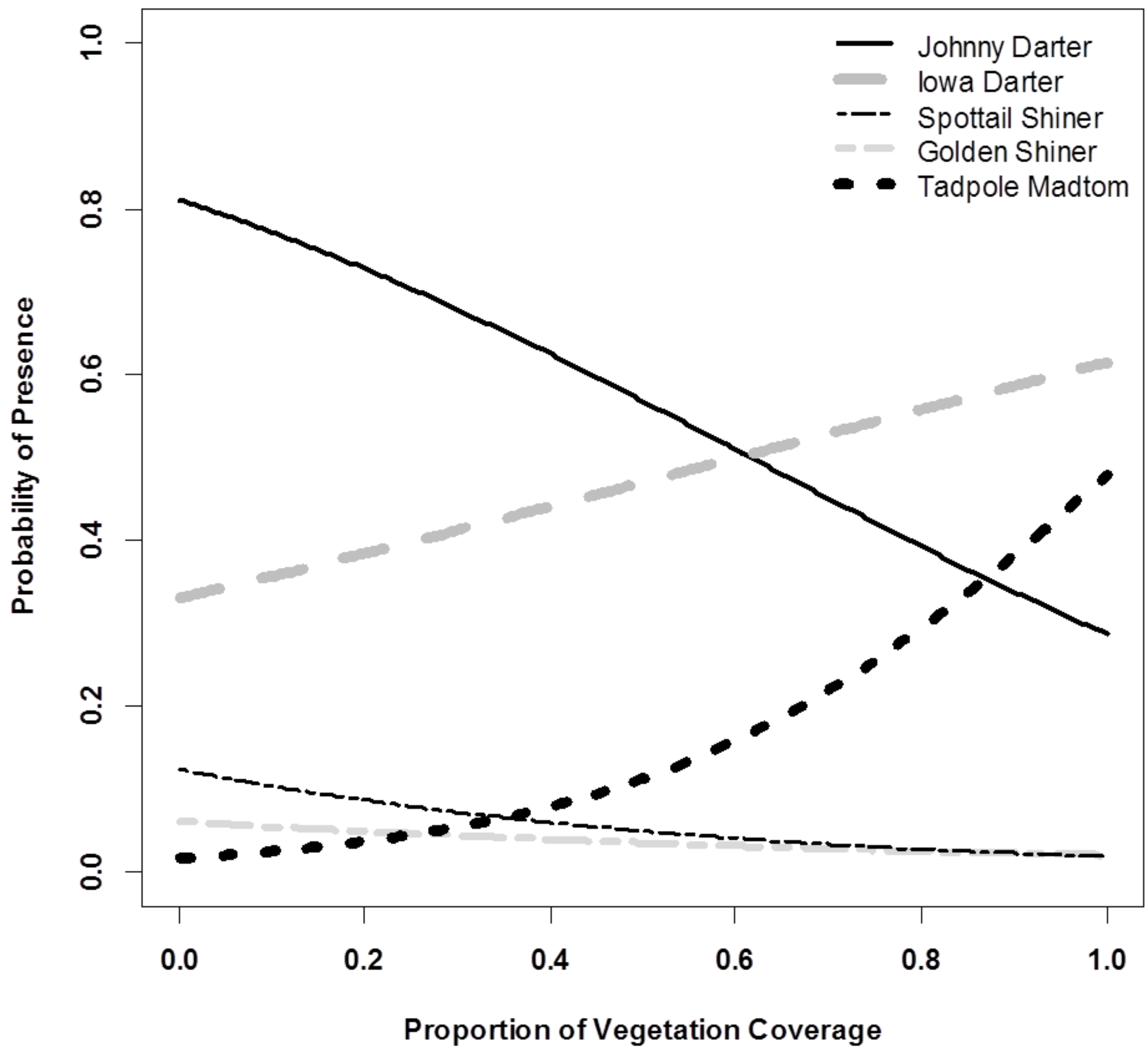

Figure 6. The probability of seining and electrofishing Bluntnose Minnow, Banded Killifish, Blackchin Shiner, Mimic Shiner, and Blacknose Shiner versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

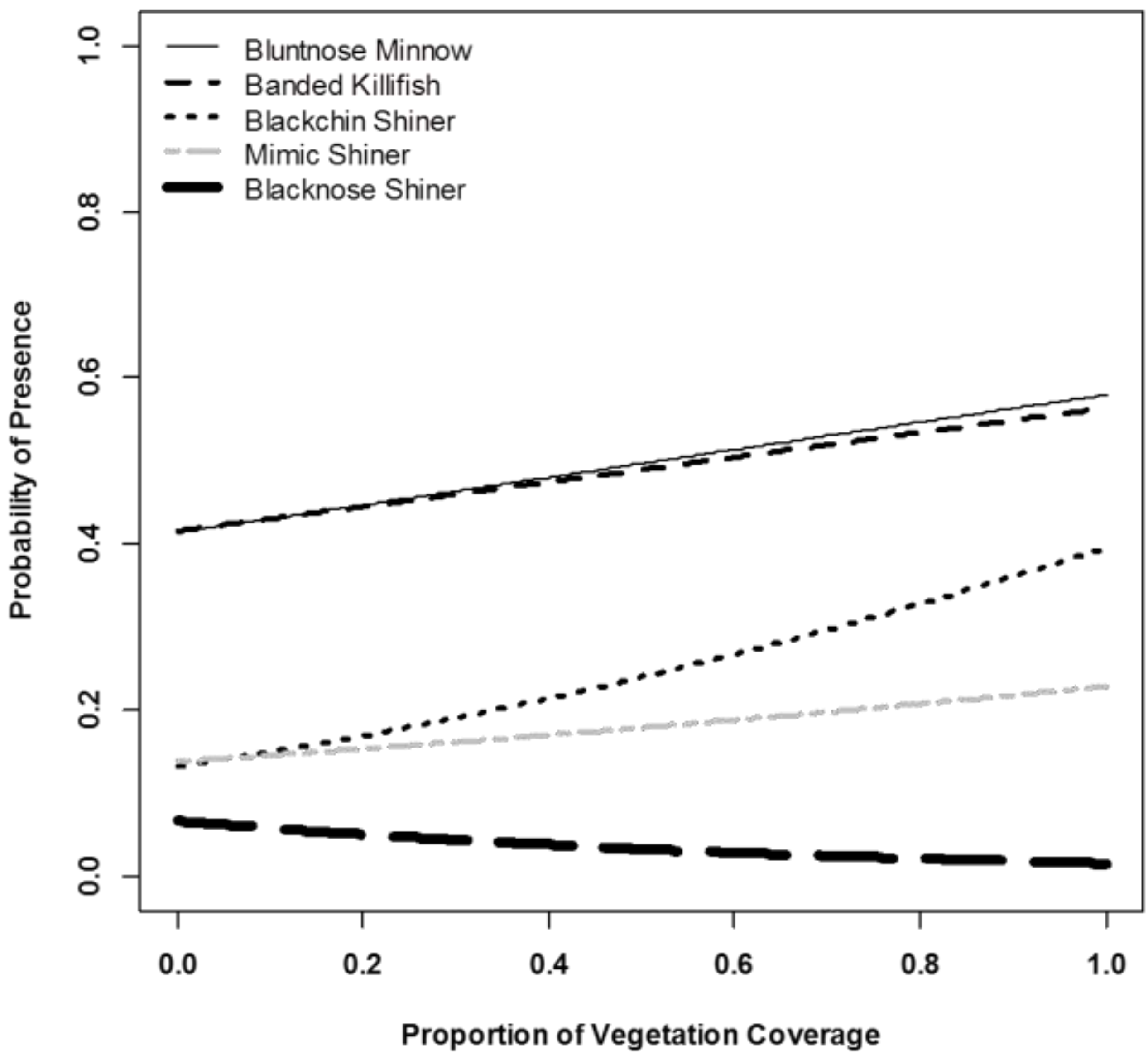

Figure 7. The probability of seining and electrofishing Yellow Perch, Largemouth Bass, Bluegill, Rock Bass, Smallmouth Bass, and White Sucker versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

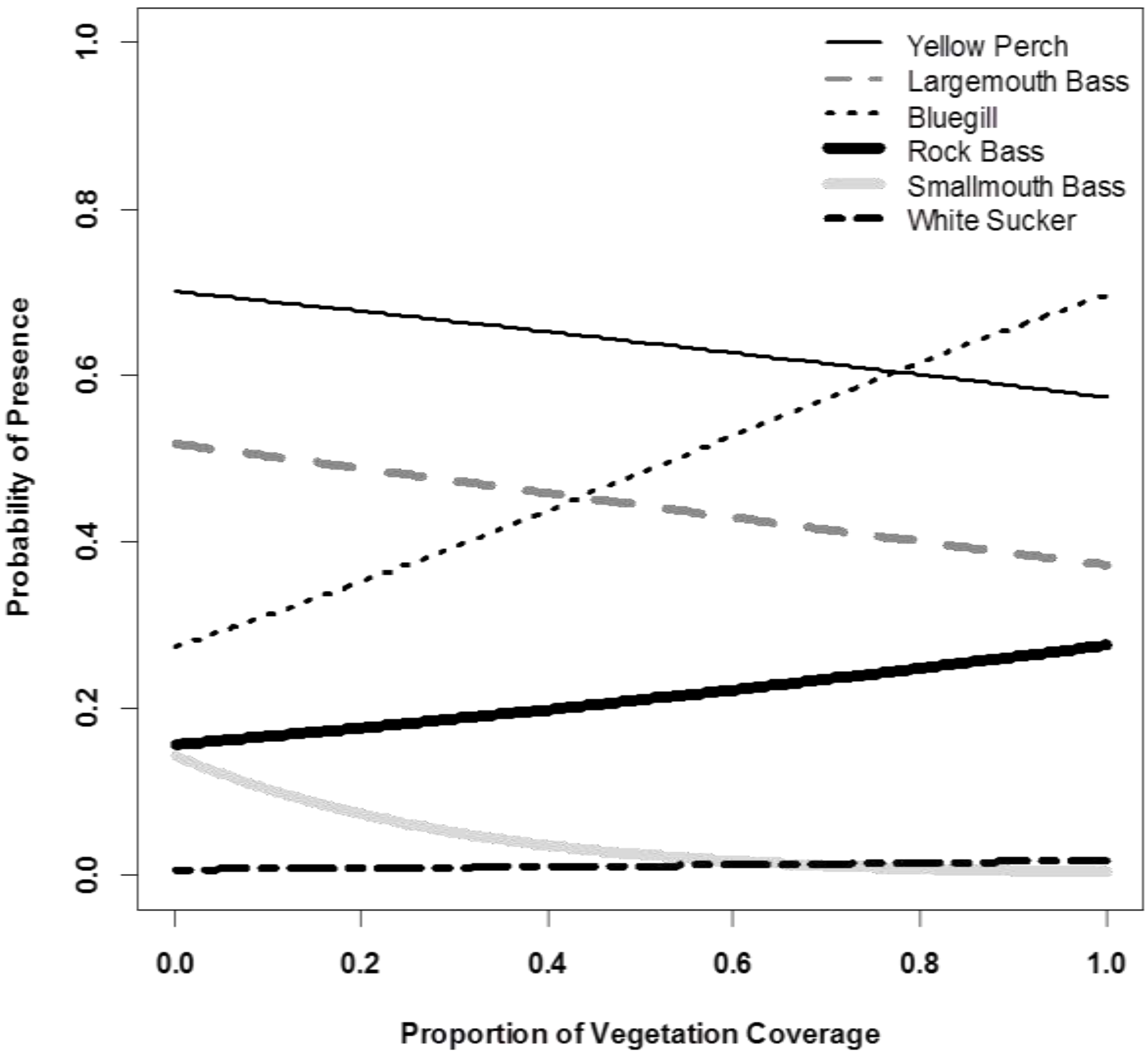

Figure 8. The residual plot (jiggered residuals versus fitted values) of the logistic regression of Bluegill sampled by seining and electrofishing versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010. The lowess-smoothed curve indicates central tendency.

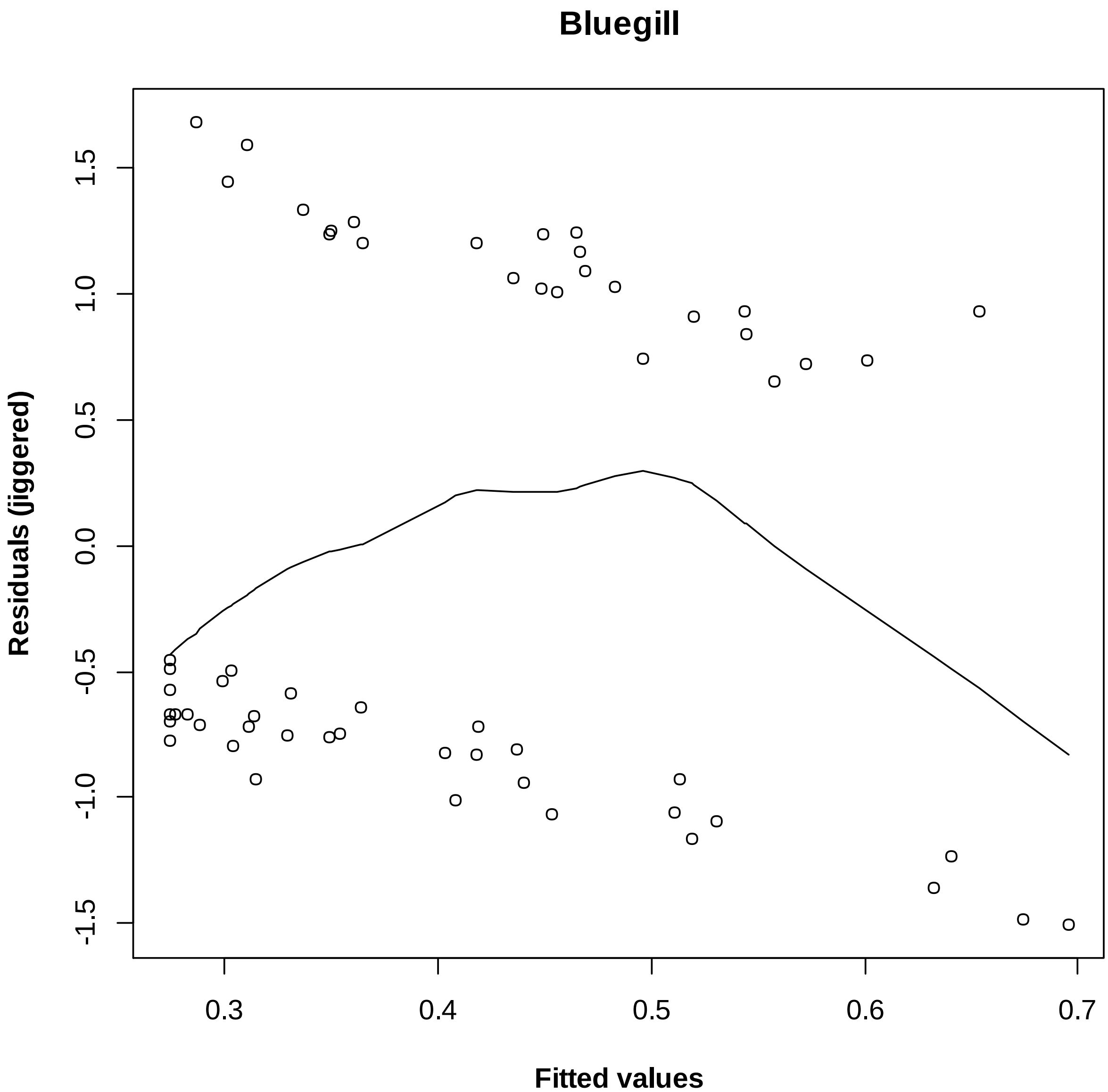

Figure 9. The probability of light-trapping crawling water beetles, corixids, 3-stripe beetles, snails, and water scorpions versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

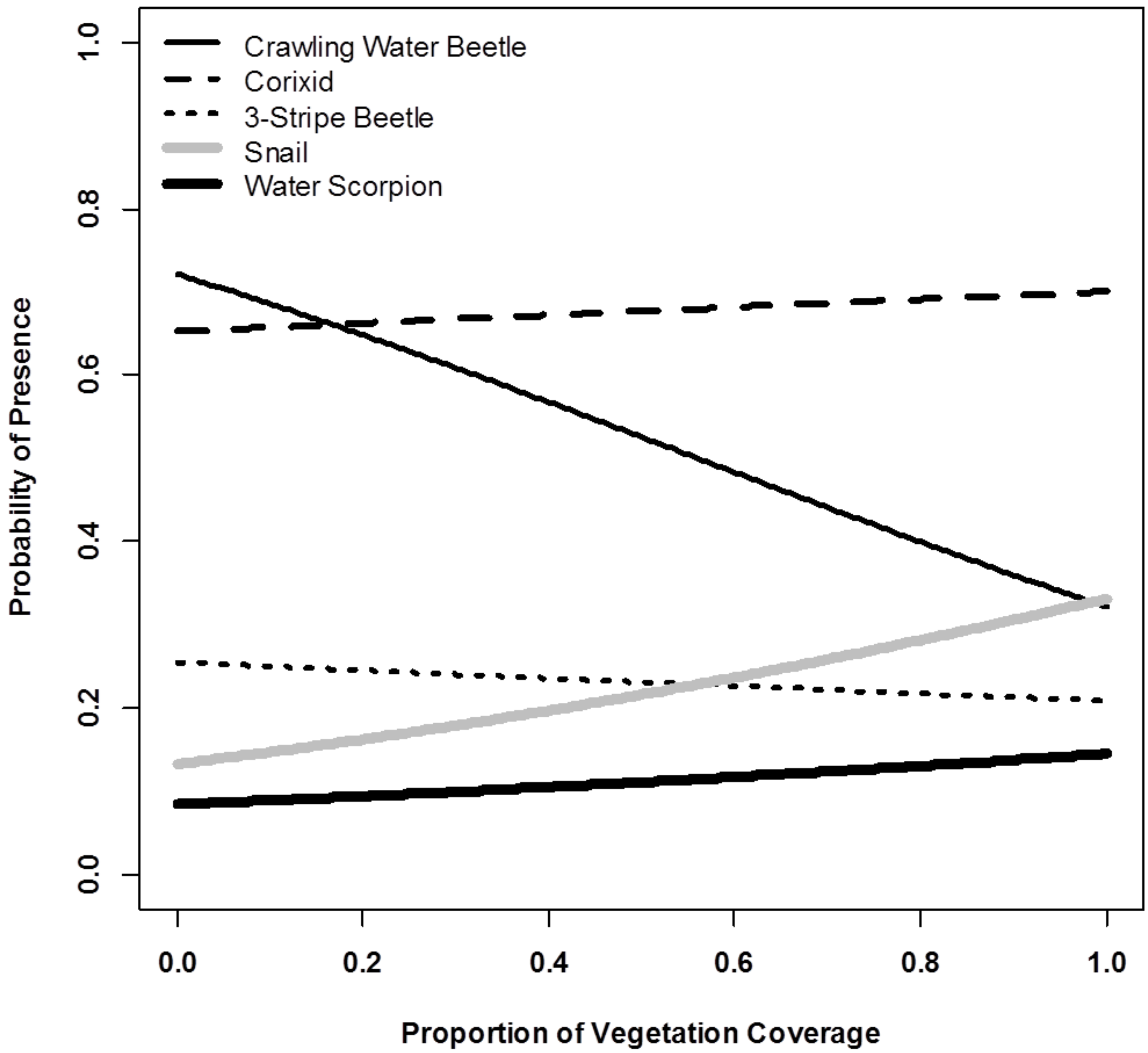

Figure 10. The probability of sticky-trapping terrestrial diptera and light-trapping aquatic zooplankton, hydracarina, amphipods, chironomids, diptera pupae, ceratopogonids, and ostracods versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.

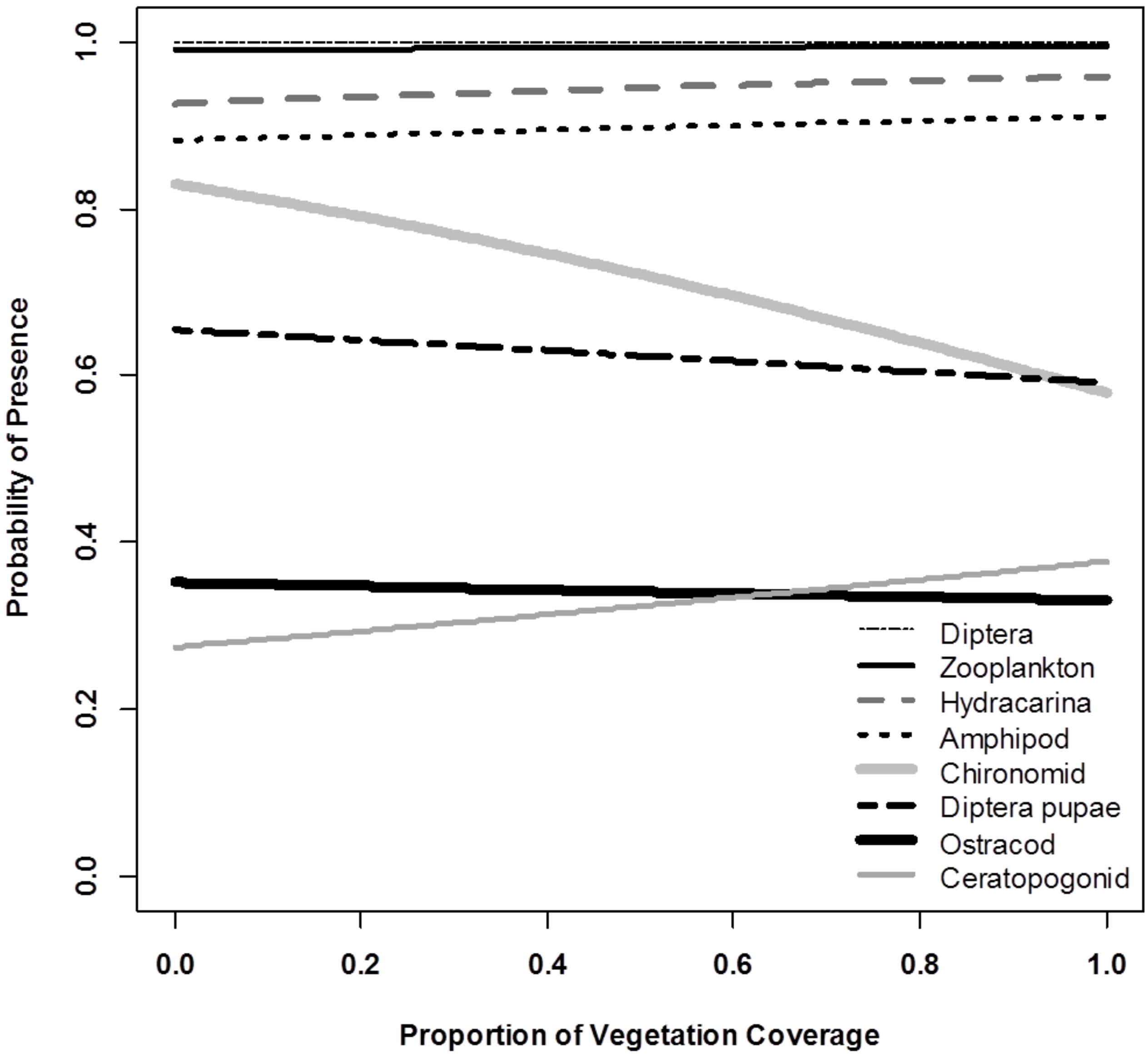

Figure 11. The probability of light-trapping fish larvae, and juvenile Yellow Perch, Largemouth Bass, Cyprinids, Darters, Bluegill, Banded Killifish, and Smallmouth Bass versus the proportion of aquatic vegetation coverage, in ten north-central Minnesota lakes, 2006-2010.

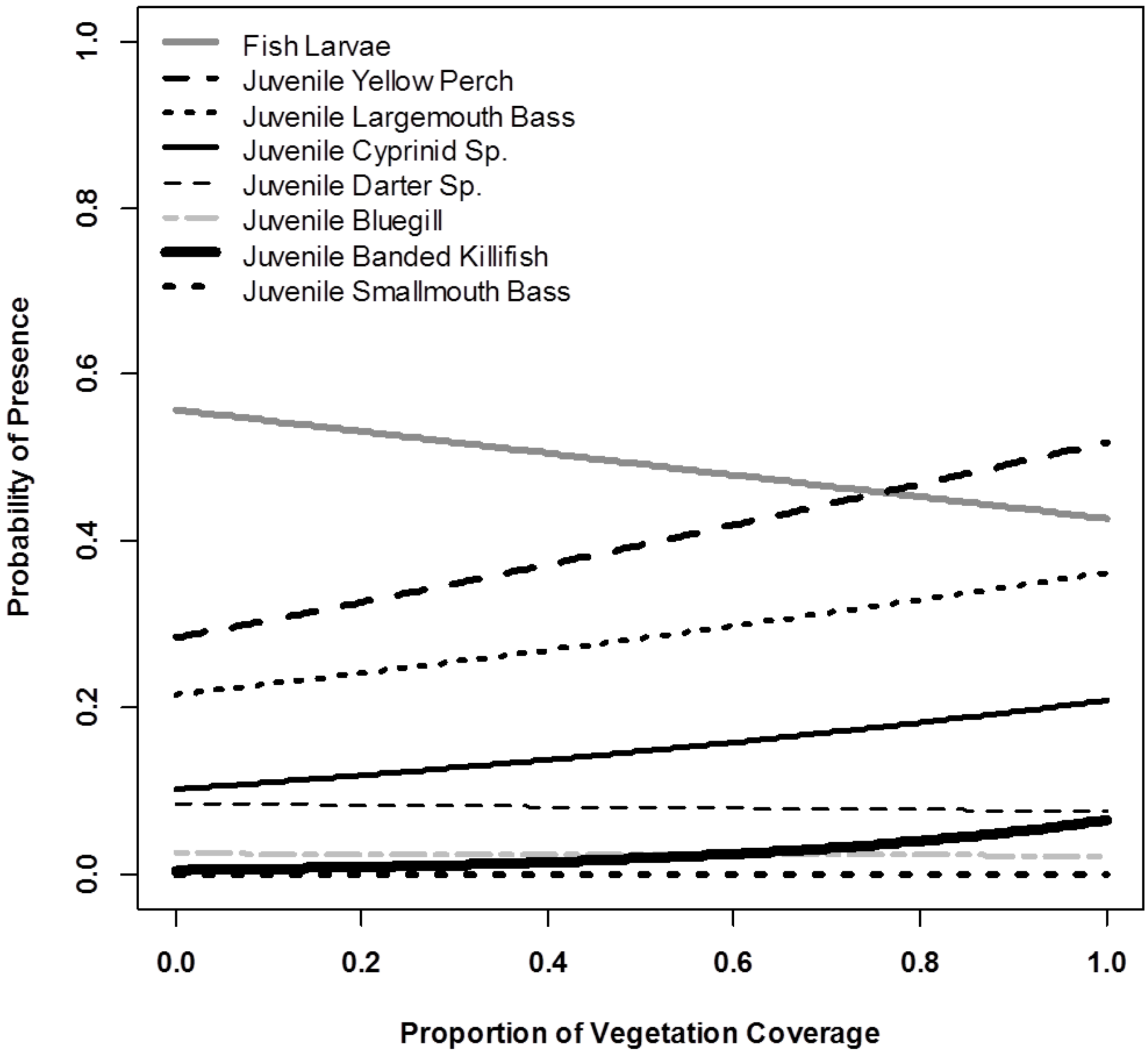

Figure 12. The probability of light-trapping Zygoptera, Ephemeroptera, Trichoptera, Coleoptera, Anisoptera, and Hemiptera versus the proportion of aquatic vegetation coverage in ten north-central Minnesota lakes, 2006-2010.