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Effects of water flow on fish abundance and migration time in the St.Lawrence River.

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Introduction

Fish communities are often used as indicators of environmental quality and integrity in large river ecosystems (Karr 1981; Fausch et al. 1990). Changes in the structure and behavior of the fish community, such as abundance, diversity or timing in migration, can reflect the effect of various stressors on the biotic integrity of the river as a whole (Fausch et al. 1990). Because of their long life cycle (i.e. ≥ 3 years), most fish species are considered good indicators of effects integrated over long term and because of their high mobility, some (i.e. diadromous fish) represent good indicators of short term effects in large rivers. Flow regime is one of the main factors used in linear statistic models to predict fish diversity in large rivers (Oberdorff et al. 1995). Flow regimes in large rivers have also been related to variation in fish annual abundance (Scarnecchia 1981; Armor and Herrgessell 1985). Water flow has been identified as an important factor influencing the timing and the intensity of many fish species migration (Jonsson 1991; Quinn et al. 1997). However, most of these studies investigating the possible relationships between flow regimes and fish abundance, diversity or migration timing, have been done on very short time scale (< 5 years) and/or on river ecosystem relatively smaller than the St.Lawrence River.

Studies investigating a fish community of more than 40 species at a large time scale (i.e. more than 10 years) in a river as large and complex as the St.Lawrence River are, to our knowledge, virtually inexistent in the literature. No recent studies have been performed to evaluate the influence of year to year variations in habitat conditions on fish communities in the St.Lawrence River. Empirical relationships between fish communities of large river ecosystems like the St.Lawrence River and flow regime attributes are lacking (Johnson et al. 1995; Galat and Zweimuller 2001; Dettmers et al. 2001). Several ecologists continuously argue that additional research is needed to better quantify the link between main channel variability (flow regime) and fish communities structure and the link between the main channel and other habitats in large rivers ecosystem (i.e. Floodplain, backwater or tributaries).

Fish diversity in the St.Lawrence River, as in many other large river systems, is composed of many migratory fish species. There are two types of migratory fish : those that move between fresh and seawater (i.e. Diadromy) and those that move solely within freshwater habitats (i.e. Potamodromy). Diadromous species can be classified as anadromous if they migrate up rivers to spawn in freshwater (e.g. Atlantic tomcod, Sea lamprey) or catadromous if they migrate down rivers to spawn at sea (e.g. American eel) (McDowall 1993). Classification of potamodromous species is not as clear cut and has not been studies as much as diadromous fish. These species can migrate between lakes and rivers, within rivers, between rivers and estuaries, or between estuaries and lakes. These migrations can be over very short or very long distance between different freshwater habitats. These displacements are considered migration only when it involves a large proportion of the fish population moving between different habitats.

Water flow, temperature and light intensity are the three principal environmental factors that influence the timing and intensity of fish migration (Northcote 1984; Jonsson 1991). They will influence both upstream and downstream migration and their relative influence will vary among habitats or fish species. Most migrations are related to a transition between life history stages corresponding to different habitats needs (i.e. spawning, feeding and survival habitats). Thus, most environmental factors affecting the cue to begging these transitions may also affect the timing of fish migration itself (e.g. water temperature or flow).

Objective

As part of the IJC plan of study, a project was initiated to determine both the short and long time effects of river flow fluctuations on the diversity, abundance and seasonal occurrence (timing of migration) of various species of freshwater fish in the lower section of the St.Lawrence River. This project is essentially based on the analysis of already available data on the diversity and abundance of fish captured at an experimental trap fishery operated by the Aquarium du Québec in Quebec City. The project is divided in two parts. First, we evaluate the influence of freshwater flow variation on the timing of migration and seasonal occurrence of different fish species at the experimental trap fishery. Second, we evaluate the influence of freshwater flow variation on the diversity and abundance of fish.

As a first step to this overall project, the objective of the present report is to make a first assessment of the potential existing relationships between fish community responses and fluctuations of river flow in the St.Lawrence River. These will serve as a basis for further investigations in subsequent years. We hypothesized that a majority of fish species would be most affected by the flow regime during a « critical period » characterized by high variability between years.

Material and methods

Data acquisition

For the benefit of their exhibits, the Aquarium du Québec operates an experimental trap fishery located at St-Nicolas (Figure 1), on the south shore of the St.Lawrence River at ~ 10km upstream of Quebec City. Twice a day (at low tides), fish of all species captured by the trap are identified, enumerated and then released back into the river. The fishing season extends from May 15 to October 31 every year and catch data have accumulated since 1975. A fish tagging experiment conducted in 1999 and 2000 revealed that only a small proportion (<5%) of fish are recaptured at the trap and the vast majority (>90%) of them are recaptured within 48 h after first capture (de Lafontaine, unpubl. data). All records of fish capture have been compiled on a database. Validation and annual update of this database have been recently completed by the St.Lawrence Center. Data from 1975 to 2000 were used for the present analysis. Data of mean daily flow (in m^3/sec) were extracted from the HYDAT database from Environment Canada. Mean daily flow estimates at Quebec City were reconstructed by summing up the daily flow values measured at the Beauharnois dam and all tributaries flowing into the St.Lawrence River between Beauharnois and Québec City. This was required because of the difficulty of measuring flow in the tidal sector of St-Nicolas - Quebec City. The time series of daily mean flow between 1975 and 2000 was generated by an algorithm developed at the St.Lawrence Center (Pierre Gagnon et Bernard Rondeau, Centre Saint-Laurent, pers. comm.).

Data treatment

The principal attributes of the flow regime used in our analysis were : the mean flow, median flow, minimum flow, maximum flow, coefficient of variation of flow, skewness of flow, date of maximum flow, date of minimum flow, and number of days exceeding a seasonal limit of flow. Skewness of flow was calculated as the difference between mean and median flow divided by the median flow (Puckrigde et al. 1998). Each of these attributes were estimated for the whole year (annual basis) and for each flow season. The coefficient of variation and the skewness of flow are used to describe variability in flow pattern within a year (see different patterns of flow; Figure 2). The percent water originating from the Great Lakes has been estimated by dividing the measured annual flow at Beauharnois by the estimated annual flow at Québec city

Between 1975 and 2000, 57 different fish species have been reported at the St-Nicolas experimental trap fishery (Table 1). Seventeen of these 57 species can be considered rare and were excluded from subsequent statistical analysis. A species is rare when less than 100 individuals have been captured during the 26 years and when it occurred in less than 16 years. Forty species were thus kept for statistical analysis (Table 1). These 40 species were divided into 5 groups, exhibiting relatively similar pattern of seasonal occurrence (Table 2). Some species were present throughout the entire fishing season from May to the end of October, others at both the beginning and the end of the fishing season, and others present either only in the spring, or mid-summer, or fall. For example, the American eel (*Anguilla rostrata*) represents a fall species while Yellow perch (*Perca flavescens*) is a species occurring both in spring and fall (Figures 3a and 3b). We selected the date at which 50 % of the total catch was captured (i.e. Julian day when half of the total abundance of fish had been captured at the experimental trap in any given year) as an index of the median day of migration. This index of migration has been widely used by previous workers (Talbot 1953; Leggett and Whitney 1972; Quinn and Adams 1996). These median dates of abundance were very variable within each group for the 26 years period analyzed (Table 2).

Statistical treatment

A first series of empirical analysis was performed to assess the possible relationships between fish migration time and the flow regime attributes. This allowed us to identify which species would be more susceptible to be influenced by flow variation at short and immediate time scales (i.e. within a year). Analyses were performed at a species level since different species have different life strategies and life-cycles. In attempt to evaluate effects at longer time scale (i.e. between years), a second series of empirical analysis were realized to determine the possible relationships between fish abundance or diversity and flow regime attributes. This analysis was also done by introducing a time lag between fish data and flow regime variables in order to explore the possible effects of flow variability on fish recruitment.

Results

Freshwater flow

The mean annual flow of the St.Lawrence River varied between 10589 and 13772 m^3/sec between 1975 and 2000 (Figure 4a). The annual maximum flow varied between 16969 and 28564 m^3/sec (Figure 4a), a 50% difference in the maximum flow over 26 years, while the annual minimum flow varied between 6589 and 10069 m^3/sec (Figure 4a). The skewness of annual flow ranged from 0.0015 to 0.121 and the coefficient of variation between 13.2 and 27.4 % (Figure 4b). The proportion of the total discharged water originating from the Great Lakes varied between 62.4 and 73.6 % (Figure 4c).

The annual flow regime was divided into four « hydrological seasons », with spring being the most variable from year to year (Figures 5a, 5b). This high variability is principally due to variation in the timing and the intensity of the spring freshet, and correspond to the period between the 40^{th} and 175^{th} Julian date. This 135 days interval encompasses all early and late spring freshet events over the last 26 years (1975-2000) (Figure 5a, 5b).

Fish migration

Among autumn species, both American eel (*Anguilla rostrata*) and Atlantic tomcod (*Microgadus tomcod*) appeared to delay their fall migration with a decrease in the fall water flow (Figures 6a and 6b). These two species exhibited a significant negative relationship with the minimum flow during the fall. A significant positive relationship was noted between the median date of occurrence of Longnose sucker (*Catostomus catostomus*) and the CV of the fall flow (Figure 7b). The coefficient of variation in fall flow was negatively correlated to the minimum fall flow ($r = -0.45$; $p = 0.01$). All other fall occurring species did show some significant relationships with various flow regime variables, but were much less significant and other factors seem to have a greater influence on their migrations.

For species usually captured in both spring and fall, Yellow perch (*Perca flavescens*) delayed its spring migration with an increase in water flow from the previous winter (Figure 7a). Similarly, Lake whitefish (*Coregonus clupeaformis*) delayed its spring migration during years of high spring water flow (Figure 8a) and delayed its fall migration during of low fall water flow (Figure 8b). The spring migration of Lake whitefish showed a positive relationship with the spring minimum flow while the fall migration was significantly influenced by the CV in the fall flow (Figures 8a and 8b). Other species from that group did show weaker relationships with various flow regime variables and their migration timings were related to multiple factors.

For the spring species group, Channel catfish (*Ictalurus punctatus*) catches occurred over a longer time period in years characterized with high winter flow (Figure 9b). Here again, other spring species did show significant relationships with different flow regime variables, but were less significant and their occurrences were best explained using multiple regression models.

Among resident or summer species, Black crappie (*Pomoxis nigromaculatus*) seasonal occurrence was retarded during years of lower water flow in summertime (Figure 9a). In years with high summer maximum water flow, there were more Black crappies in the spring than in the fall. Other resident and summer fish showed significant but weaker relationships with the water flow variables.

Fish abundance and diversity

Species richness varied between 37 and 47 fish species per year (Figure 10a) while the total fish abundance varied between 6132 and 19516 fish (Figure 10b). Total catches generally declined from 1975 to 1989, the year at which the lowest number of fish were captured. A slight increase was observed afterwards but total abundance has not returned to historically reported values (Figure 10b). Annual species richness was positively correlated with the minimum flow measured 2 and 3 years before catches (Figures 11a and 11b). Fish abundance at the experimental trap in any given year tends to increase with the maximum spring flow recorded 2 years before (Figure 12a) and was also negatively correlated with the daily percent decrease in water flow following that spring freshet (Figure 12b). These two relationships were significant and individually explained approximately 20 % of the variation in fish abundance. A multiple regression model including these two attributes of the spring flow contributed to 41% of the overall variation in fish abundance (Table 3). Fish abundance per year was also positively related to the skewness and the CV of annual flow measured 2 years before (Figures 13a and 13b).

Out of the 40 species retained, a preliminary examination allowed us to isolate two cases of interest, Yellow perch (*Perca flavescens*) and Northern pike (*Esox lucius*). Annual abundance of Yellow perch was positively related to the skewness of the annual flow recorded 2 years before (Figure 14a). Annual abundance of Yellow perch was also related to the minimum and maximum values of the spring flow during the preceding year and 3 years before (Figure 14b). Results of a multiple regression model showed that 64 % of the variation in Yellow perch abundance could result from flow variability attributes (Table 4). In the case of Northern pike, annual abundance was positively related to the minimum spring flow of the previous year (Figure 15). In a multiple regression model, both the spring minimum flow and the CV of annual flow explained 35 % of the variation in annual Northern pike abundance at the experimental trap fishery in Saint-Nicolas (Table 5).

Discussion

Results from our analysis indicate that fluctuations of the freshwater flow does have a direct influence on the seasonal occurrence and migration time of different fish species in the St.Lawrence River. American eel, Atlantic tomcod and Longnose sucker, all tended to delay their fall migration during years of low flow during the fall. Given the negative correlation between fall minimum flow and the CV of fall flow, our results suggest that the upstream migration of Lake whitefish during the fall is also delayed during years of weak flow during the autumn. It thus appears that a decrease in flow during the fall has a similar effect on migration timing of various fish species, even when moving, in some cases, in complete opposite direction (i.e. Catadromous vs Anadromous fish). Vøllestad et al. (1986) observed a similar pattern for the downstream migration of European eel in response to the autumn flow fluctuation. For upstream migrating fish, Potter (1988) observed that migrating Atlantic salmon stayed in the estuary for several weeks before coming into freshwater because of unusually low flow during the fall. Reduction in freshwater flow will reduce the transition habitat between fresh and seawater so that catadromous and anadromous fish will have to face a greater and more rapid salinity gradient. Their migration time will therefore vary with this change in the transition habitat. Increases in freshwater flows, which would increase the zone of salinity gradient from freshwater to seawater, will impact positively and facilitate their upstream or downstream migrations.

Spring catches of Yellow perch, Lake whitefish and Channel catfish at the experimental trap appeared to extended over a longer time period during years of high flow. Yellow perch and Channel catfish spring occurrence was significantly associated to high flow during the proceeding winter, while Lake whitefish responded positively to the minimum flow during spring.

Our results provide further evidence that the migration behavior of potamodromous fish is influenced by variation in freshwater flow. Such influence could result from the fact that fishes need some cue to begin their migrating movement, have to position themselves within the main channel, actively swim out of backwaters, and control their descend during downstream migration. Flow fluctuations can have, in many cases, a direct effect on the cue to migrate, on the speed of migration and the direction that fish would choose over the length of their migration. Similar variation in freshwater flow can influence upstream migration by helping fish to find the river mouth (or tributaries) that they have to move up (O'Connor and Power 1973; Northcote 1978; Northcote and Ennis 1994). Previous studies have indicated that high water discharge can stimulate different fish species to migrate upstream (Potter 1988; Van den Berghe and Gross 1989; Jonsson et al. 1990). In several cases, the cue for fish to begin their upstream migration was delayed by a decrease in freshwater flow in small and large rivers.

Our analysis showed that freshwater flow fluctuations had a direct influence on fish abundance of different species in the St.Lawrence River. High spring flow, which is often associated to larger variability, has been associated to higher spawning success in many freshwater fish (Nelson 1980; Clark 1992). The two year lag between total fish catch and the flow regime attributes of the St.Lawrence River can be explained by the high proportion of +2 year-old fish in annual catches (de Lafontaine, unpubl. results), and the quality of the habitat where these individuals spent their first year as young-of-the-year (YOY). Quality habitat for YOY depends on the availability of spring flows high enough to flood extensive spawning and hatching grounds, and to insure that larvae get flushed out of these spawning areas toward deeper downstream food-rich marshes ("larval drift"). Habitat quality also requires that spring peak water levels recede at a rate slow enough to avoid dry-out of eggs and larvae due to long exposure to air. In the St.Lawrence River, the flood plains of Lake St.Pierre, ~100 km upstream of St.Nicolas, represent important spawning areas for different fish species. High water flows and slow receding rates at the time of fish spawning and hatching should therefore contribute to better survival and higher recruitment. This higher recruitment may correspond to higher catches of +2 year-old fish at the downstream location (i.e. St.Nicolas) two years later. A similar two year lag was noted between the total catch of Coho salmon (*Oncorhynchus kisutch*) and the annual mean flow (Scarnecchia, 1981). Many authors have reported a similar relationship between mean annual flow and annual catch of fish species measured two years later. (Neave 1949; Smoker 1955; Zillges 1977; Scarnecchia 1980). It is worth mentioning that main channel habitats can also serve as nurseries for which the relative importance has yet to be evaluated (Humphries et al.

1999). Flow fluctuations may have a different impact on fish species, depending on their choice of nurseries habitats (i.e. main channel vs floodplain). Our results suggest that fish recruitment in the St.Lawrence River would be relatively more influenced by the seasonal pattern of the flow regime than by its annual mean. This would imply that the possibility of maintaining high spring water flow should have a positive effect on fish abundance and diversity in the St.Lawrence River within a response time of 2 to 3 years.

Conclusion

These first results provided evidence of direct and indirect influences of freshwater flow fluctuations on fish migration and abundance in the St.Lawrence River. They indicated possible relationships at both short and long time scales between various attributes of the flow regime and fish diversity, abundance and migration time. These relationships require further investigations to better understand and quantify the relative effect of flow fluctuation on fish community dynamics in the St.Lawrence River.

There is no doubt that water temperature should have some effect on the fish life cycle, including growth, reproduction and migration (Jonsson 1991; Quinn et al. 1997). For most fish species, water temperature may be an important factor controlling the upstream or downstream migration. As a second step in our analysis, we propose to analyze the effect of water temperature on the relationships reported above. Historical water temperature data measured in the Québec City area have been found but have yet to be compiled and validated on datafile. Relative importance between the effect of water temperature and flow fluctuations on fish abundance and their migration time will then be re-assessed.

In addition, empirical analysis similar to those realized with Yellow perch and Northern pike (Tables 4 and 5, figures 14 and 15) will be performed with other species. Information on age structure of fish will be incorporated to account for relative importance of cohorts in either total annual or seasonal abundance.

Table 1. List of species included in cumulative catches at the St.Nicolas experimental trap.

Common names	Scientific names	Species analyzed on an individual basis	Total catch for 26 years	Number of year present	Maximum catch for one year	Annual mean catch
Largemouth bass	*Micropterus salmoides*		21	10	7	0.81
Smallmouth bass	*Micropterus dolomieu*	*	11397	26	944	438.35
Gizzard shad	*Dorosoma cepedianum*	*	2417	26	570	92.96
American shad	*Alosa sapidissima*	*	5637	24	2689	216.81
American eel	*Anguilla rostrata*	*	8186	26	583	314.85
White bass	*Morone chrysops*		65	15	13	2.50
Striped bass	*Morone saxatilis*		1	1	1	0.04
Brown bullhead	*Ameiurus nebulosus*	*	816	26	116	31.38
Stonecat	*Noturus flavus*	*	104	20	23	4.00
Channel catfish	*Ictalurus punctatus*	*	33841	26	4602	1301.58
White perch	*Morone americana*	*	2607	26	315	100.27
Goldfish	*Carassius auratus*		2	2	1	0.08
Common carp	*Cyprinus carpio*	*	11606	26	3508	446.38
Miroir carp	*Cyprinus carpio*		39	6	15	1.50
Silver redhorse	*Moxostoma anisurum*	*	394	26	90	15.15
Greater redhorse	*Moxostoma valenciennesi*		3	2	2	0.12
Shorthead redhorse	*Moxostoma macrolepidotum*	*	2700	26	282	103.85
Quillback	*Carpiodes cyprinus*	*	110	25	9	4.23
Pumpkinseed	*Lepomis gibbosus*	*	436	26	68	16.77
Bluegill	*Lepomis macrochirus*		4	3	2	0.15
Rock bass	*Ambloplites rupestris*	*	1571	26	126	60.42
Walleye	*Stizostedion vitreum*	*	28343	26	2743	1090.12
Sauger	*Stizostedion canadense*	*	4908	26	324	188.77
Rainbow smelt	*Osmerus mordax*	*	3670	26	573	141.15
Threespine stickleback	*Gasterosteus aculeatus*	*	132	17	36	5.08
Lake sturgeon	*Acipenser fulvescens*	*	665	26	61	25.58
Atlantic sturgeon	*Acipenser oxyrhynchus*		10	5	6	0.38
Logperch	*Percina caprodes*		65	14	16	2.50
Alewife	*Alosa pseudoharengus*	*	2688	25	1399	103.38
Round goby	*Neogobius melanostomus*		1	1	1	0.04
Northern pike	*Esox lucius*	*	3232	26	353	124.31
Lake whitefish	*Coregonus clupeaformis*	*	8607	26	749	331.04
Silver lamprey	*Ichthyomyzon unicuspis*		28	3	18	1.08
Northern brook lamprey	*Ichthyomyzon fossor*	*	1254	23	170	48.23
Sea lamprey	*Petromyzon marinus*	*	1341	26	140	51.58
Mooneye	*Hiodon tergisus*	*	723	26	63	27.81
Longnose gar	*Lepisosteus osseus*	*	299	26	22	11.50
Burbot	*Lota lota*	*	4241	26	353	163.12
Freshwater drum	*Aplodinotus grunniens*	*	214	26	59	8.23
Black crappie	*Pomoxis nigromaculatus*	*	7078	26	1896	272.23
Muskellunge	*Esox masquinongy*	*	216	24	23	8.31
Common shiner	*Luxilus cornutus*		28	7	17	1.08
Golden shiner	*Notemigonus crysoleucas*		43	20	12	1.65
White sucker	*Catostomus commersoni*	*	10990	26	920	422.69
Longnose sucker	*Catostomus catostomus*	*	79890	26	7335	3072.69
Pearl dace	*Margariscus margarita*		6	2	4	0.23
Brook trout	*Salvelinus fontinalis*	*	214	23	20	8.23
Fallfish	*Semotilus corporalis*	*	333	23	47	12.81
Yellow perch	*Perca flavescens*	*	57879	26	5345	2226.12
Bowfin	*Amia calva*	*	110	22	45	4.23
Atlantic tomcod	*Microgadus tomcod*	*	18503	25	2331	711.65
Atlantic salmon	*Salmo salar*	*	171	19	33	6.58
Chinook salmon	*Oncorhynchus tshawytscha*		9	6	2	0.35
Coho salmon	*Oncorhynchus kisutch*		1	1	1	0.04
Lake trout	*Salvelinus namaycush*		11	6	5	0.42
Rainbow trout	*Oncorhynchus mykiss*	*	848	26	66	32.62
Brown trout	*Salmo trutta*	*	230	26	24	8.85

Table 2. Classification of fish species accordingly to their seasonal occurrence at the experimental trap, over the 26 years period.

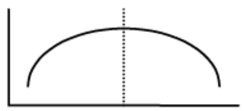
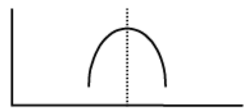
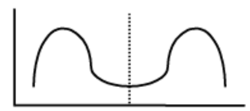
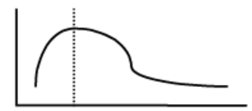
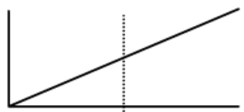
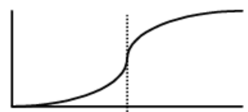
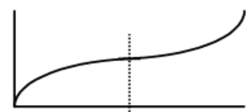
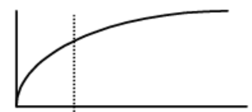
Fish abundance from May to October (Dotted line = 50%)					
Cumulative percent abundance (Dotted line = 50%)					
Classification	- Resident species	- Summer species	- Spring and fall species	- Spring species	- Fall species
Mean variation of the median date	140.1 ± 29 days	118.5 ± 19 days	Spring: 44 ± 15 days Fall: 47 ± 17days	47.5 ± 11 days	35.6 ± 17 days
Species	*Micropterus dolomieu* *Lepomis gibbosus* *Hiodon tergisus* *Pomoxis nigromaculatus* *Esox masquinongy* *Noturus flavus* *Carpiodes cyprinus* *Salmo trutta*	*Alosa sapidissima* *Alosa pseudoharengus*	*Ambloplites rupestris* *Stizostedion vitreum* *Stizostedion canadense* *Osmerus mordax* *Coregonus clupeaformis* *Petromyzon marinus* *Aplodinotus grunniens* *Catostomus commersoni* *Salvelinus fontinalis* *Perca flavescens* *Cyprinus carpio* *Amia calva*	*Esox lucius* *Ictalurus punctatus* *Ameiurus nebulosus* *Morone americana* *Moxostoma anisurum* *Moxostoma macrolepidotum* *Gasterosteus aculeatus* *Semotilus corporalis* *Oncorhynchus mykiss* *Salmo salar*	*Catostomus catostomus* *Microgadus tomcod* *Lota lota* *Lepisosteus osseus* *Ichthyomyzon fossor* *Acipenser fulvescens* *Dorosoma cepedianum* *Anguilla rostrata*

Table 3. Predictive model between annual fish abundance of all species and water flow characteristics. The estimates, the probability (*P*) associated with each independent factors, the standard error of the coefficients (SE), the R^2 associated with the model, the adjusted R^2, and the standard error of the estimate (S_{xy}) are also given (N = 26).

Dependent variable	Independent variables	Estimates	$p > t$	SE	R^2	Adj. R^2	S_{xy}
Annual abundance of all fish species	Intercept	+ 5597.7			0.41	0.35	2503
	Spring maximum flow (m^3/sec)	+ 0.50	0.015	0.19			
	Mean rate of daily decrease in flow (%)	- 3074.93	0.008	1071.7			

Table 4. Best predictive model of annual abundance of Yellow perch (*Perca flavescens*), from water flow attributes (e.g. Maximum flow, minimum flow and annual skewness). The estimates, the probability (*P*) associated with each independent factors, the standard error of the coefficients (SE), the R^2 associated with the model, the adjusted R^2, and the standard error of the estimate (S_{xy}) are also given (N = 25).

Dependent variable	Independent variables	Estimates	$p > t$	SE	R^2	Adj. R^2	S_{xy}
Annual abundance of Yellow perch	Intercept	- 9776.4			0.72	0.64	829.6
	Spring minimum flow (1 year ago)	+ 0.45	0.006	0.14			
	Spring maximum flow (3 years ago)	+ 0.22	0.005	0.069			
	Annual skewness (1 year ago)	+ 15828.6	0.009	5491.5			
	Annual skewness (2 years ago)	+ 14623.8	0.01	5587.1			
	Annual skewness (current year)	+ 13177.0	0.03	5738.2			

Table 5. Best predictive model of annual abundance of Northern pike (*Esox lucius*), from water flow attributes (e.g. Maximum flow, minimum flow and annual skewness). The estimates, the probability (*P*) associated with each independent factors, the standard error of the coefficients (SE), the R^2 associated with the model, the adjusted R^2, and the standard error of the estimate (S_{xy}) are also given (N = 26).

Dependent variable	Independent variables	Estimates	$p > t$	SE	R^2	Adj. R^2	S_{xy}
Annual abundance of Northern pike	Intercept	- 235.2			0.40	0.35	86.5
	Spring minimum flow (1 year ago)	+ 0.054	0.001	0.01			
	CV of annual flow (current year)	- 10.85	0.04	5.19			

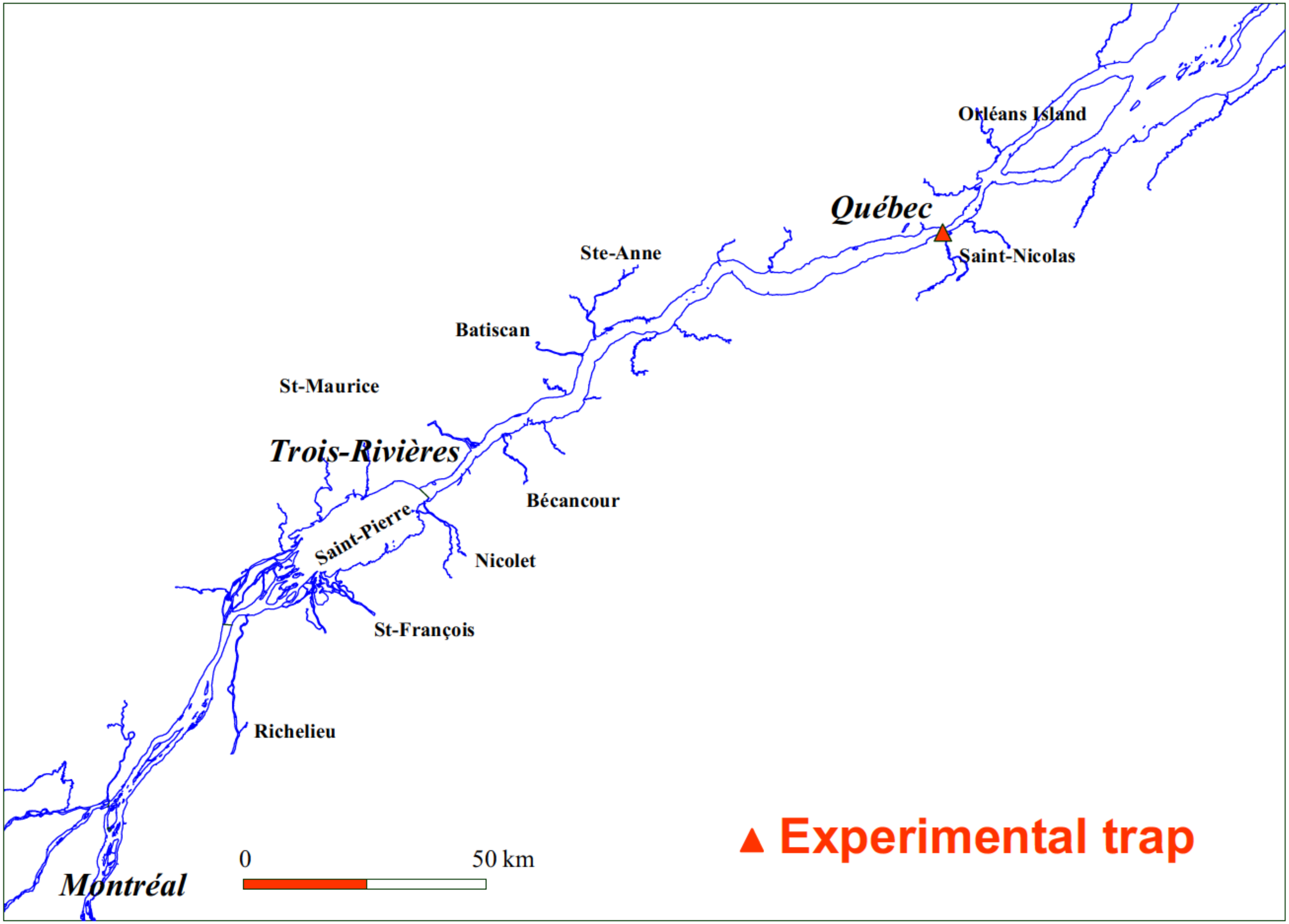


Figure 1. Localization of the experimental trap fishery, in Saint-Nicolas, Québec, Canada.

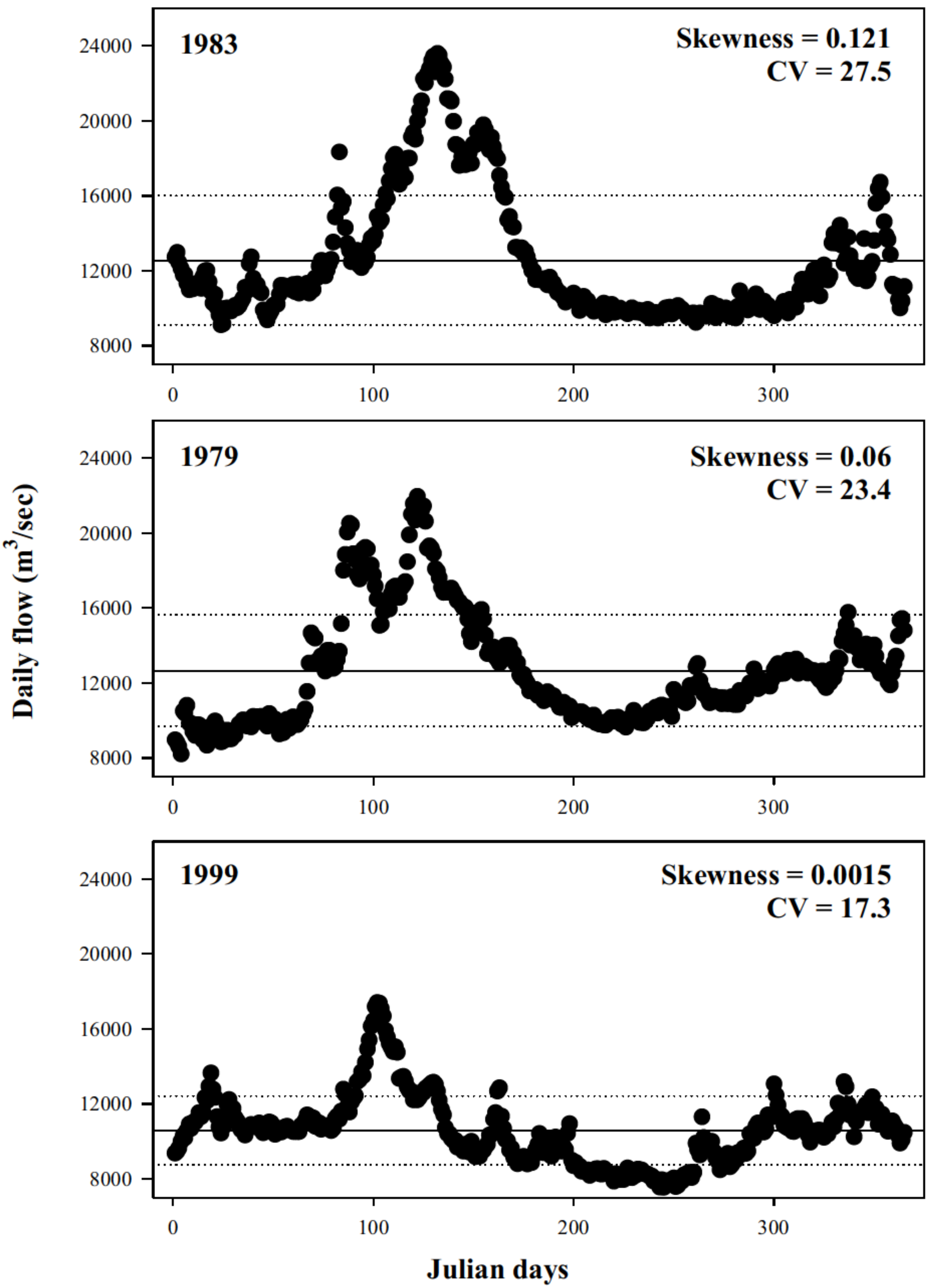


Figure 2. Examples of seasonal patterns in daily flow (m^3/sec), corresponding to three different values of skewness and CV in annual flow.

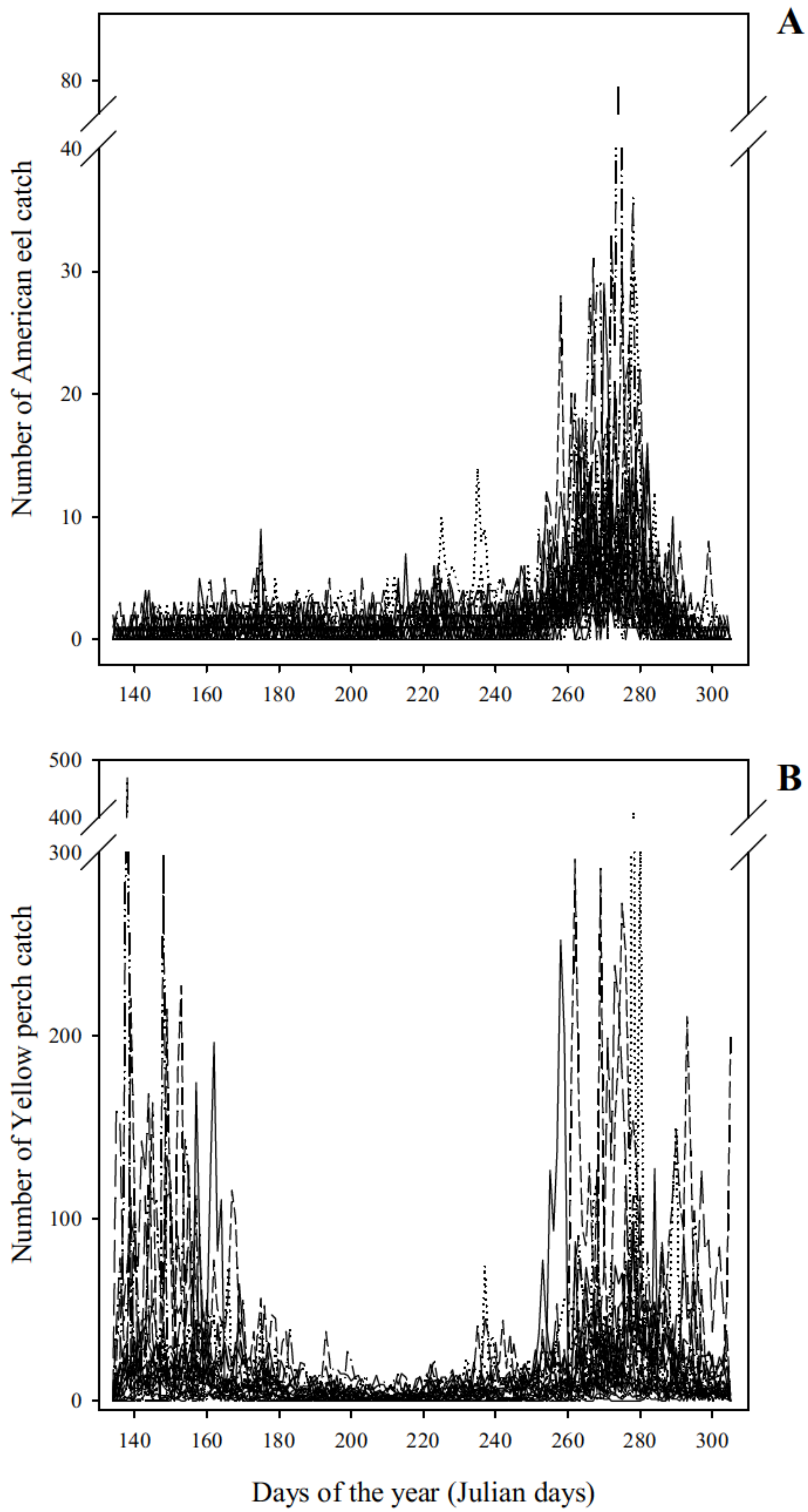


Figure 3. Daily abundance of A) American eel and B) Yellow perch at the experimental trap fishery for the fishing period each year. N= 26.

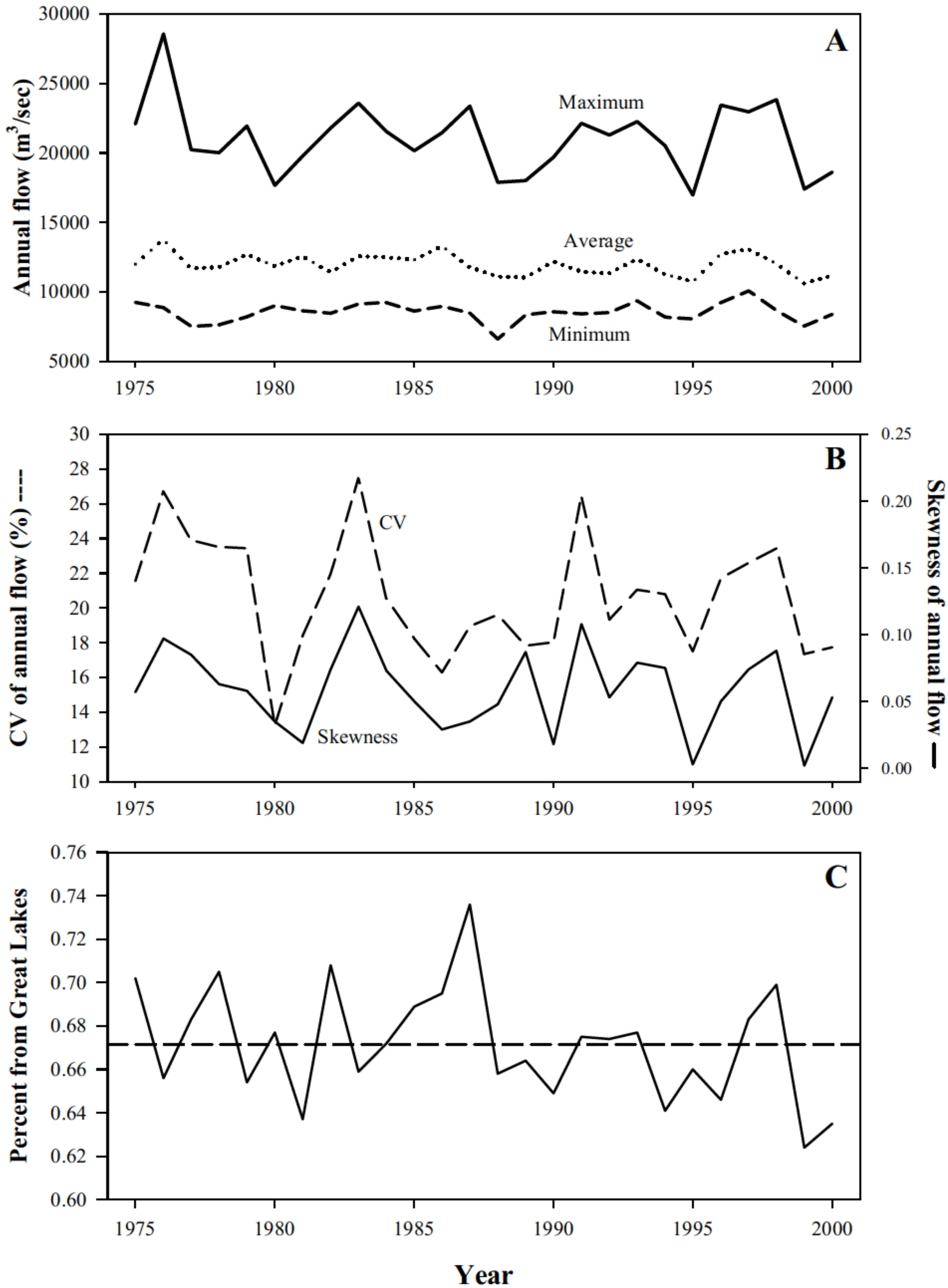


Figure 4. A) Minimum, maximum and mean values of annual flow (m^3/sec) between 1975 and 2000. B) Coefficient of variation (%) and skewness of annual flow over time. C) Percentage (%) of water flow originating from the Great Lakes as measured at Québec City between 1975 and 2000.

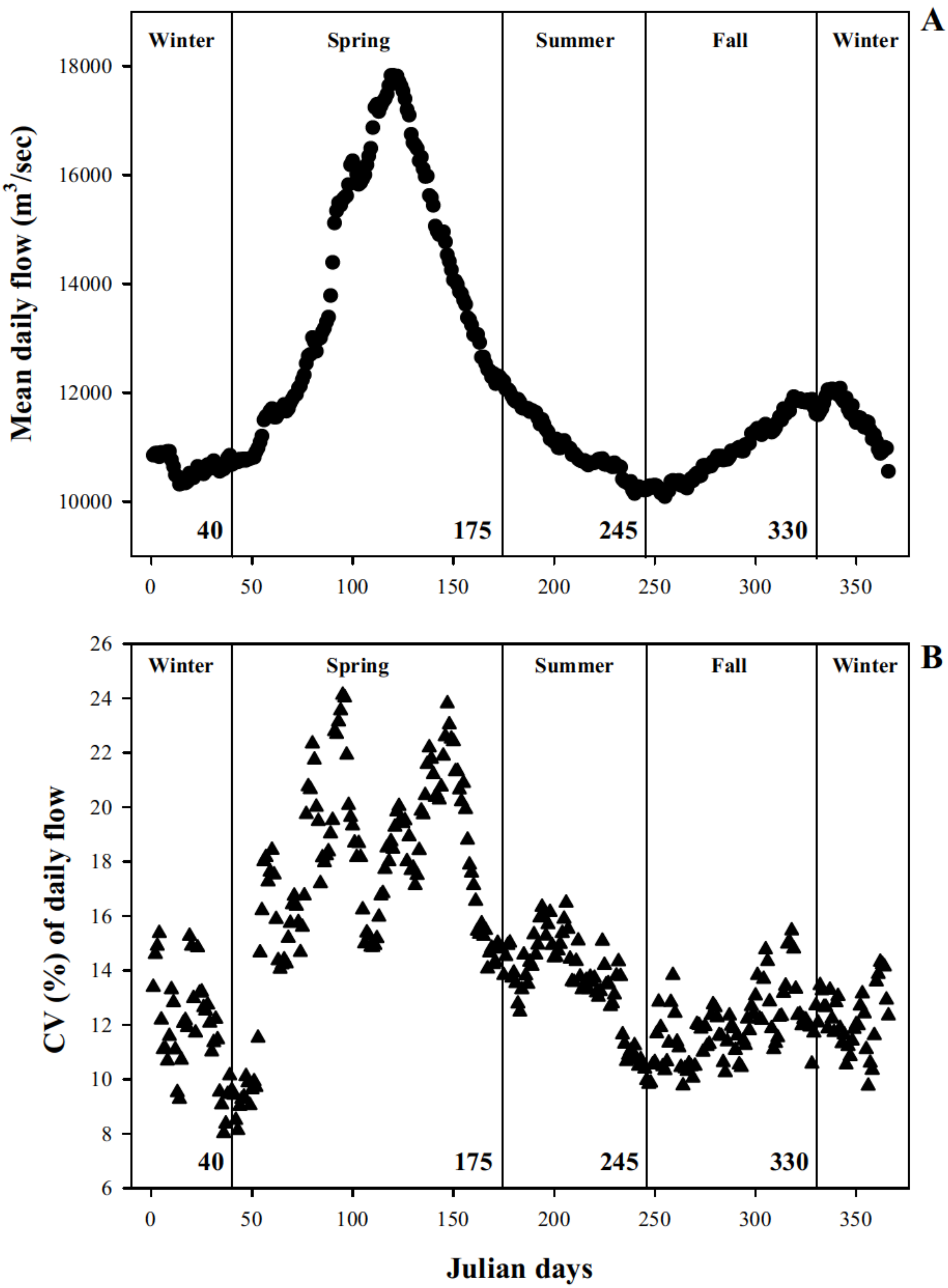


Figure 5. A) Seasonal variation of the daily flow (m^3/sec) averaged over 26 years (1975-2000). B) Coefficient of variation (%) in mean daily flow. N = 26.

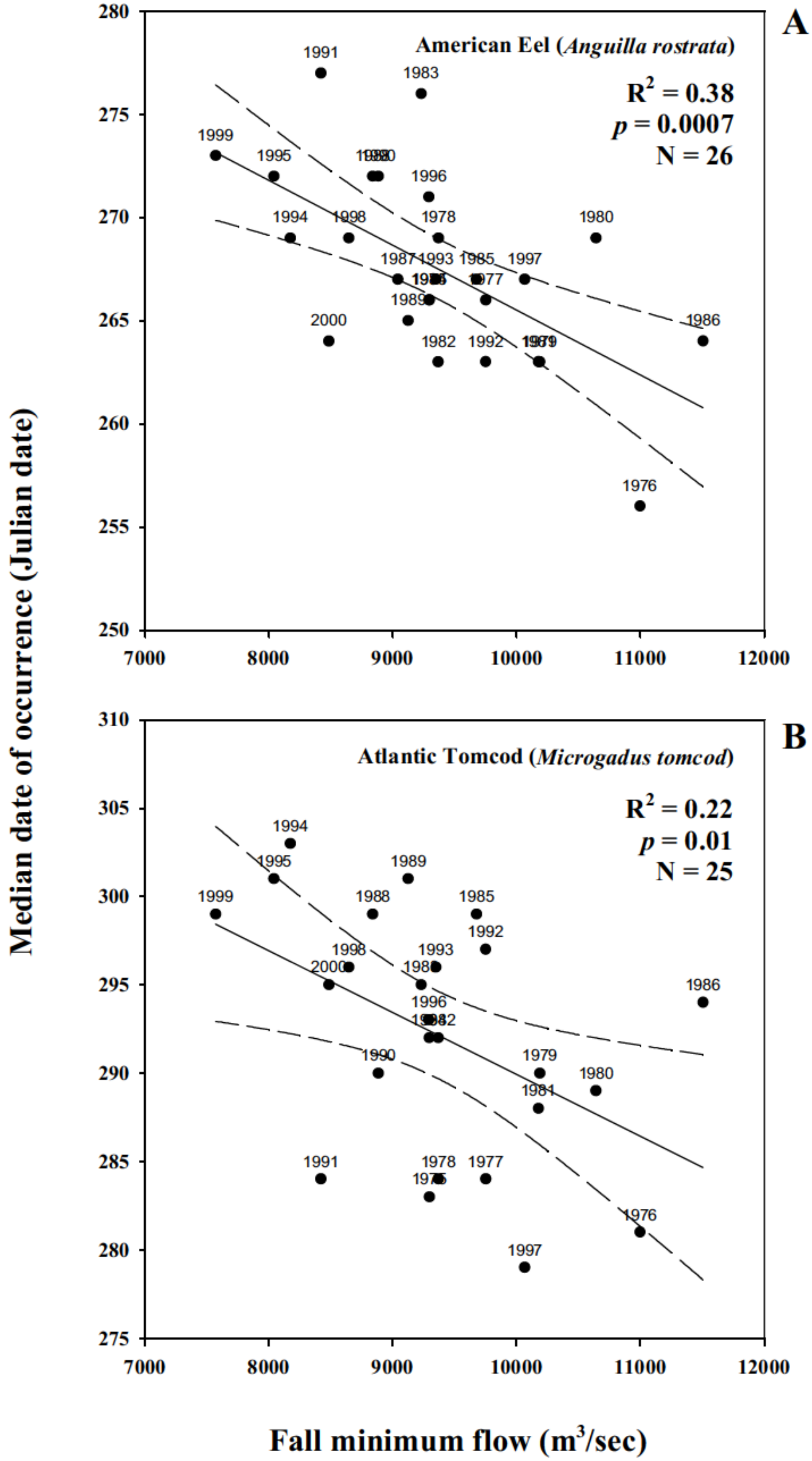


Figure 6. Linear regression between fall minimum flow (m^3/sec) and median date of occurrence for A) American eel and B) Atlantic tomcod.

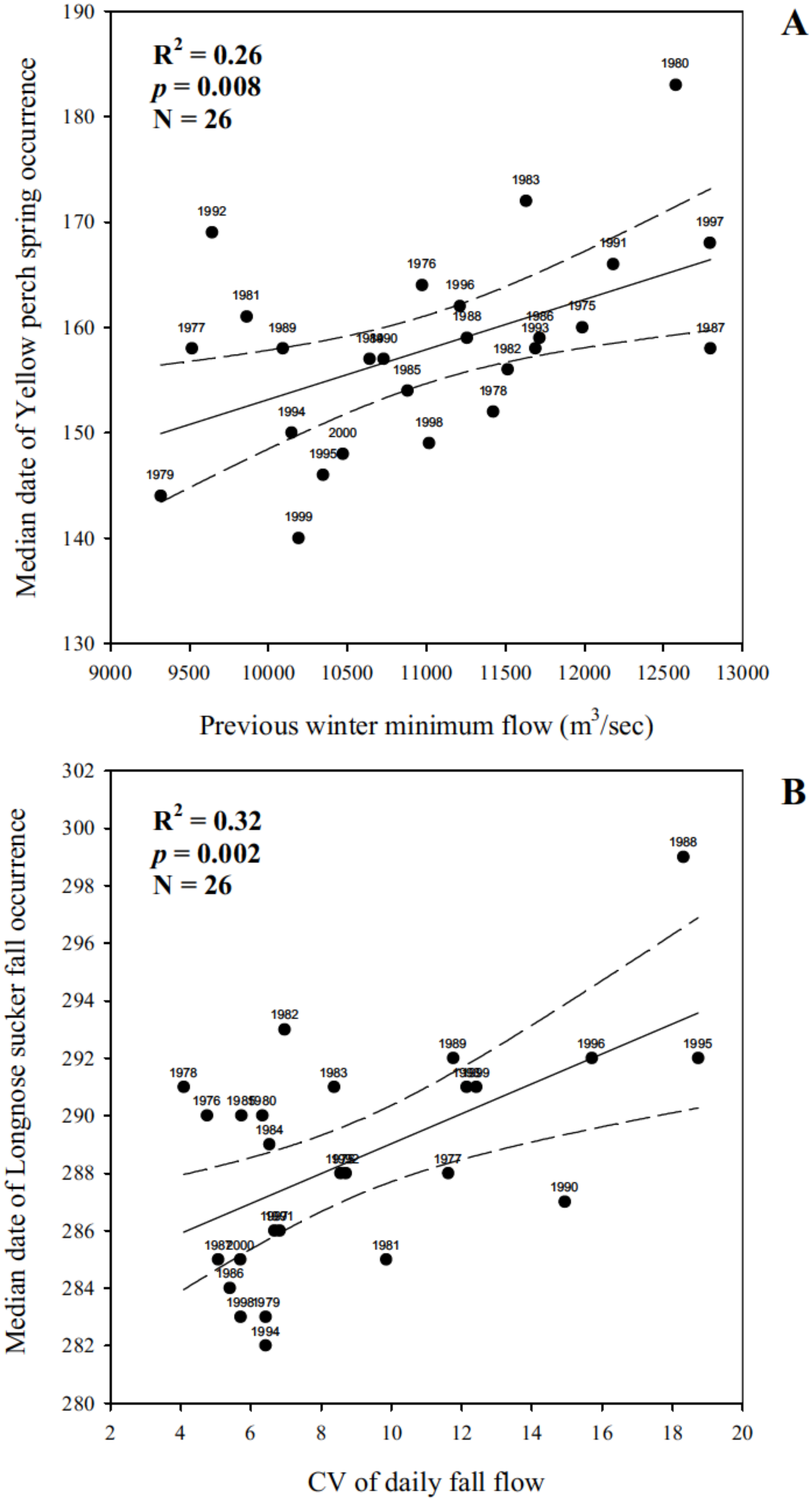


Figure 7. A) Median date of yellow perch occurrence in spring as a function of the previous winter minimum flow (m^3/sec) and B) median date of Longnose sucker fall occurrence as a function of CV of daily fall flow (%).

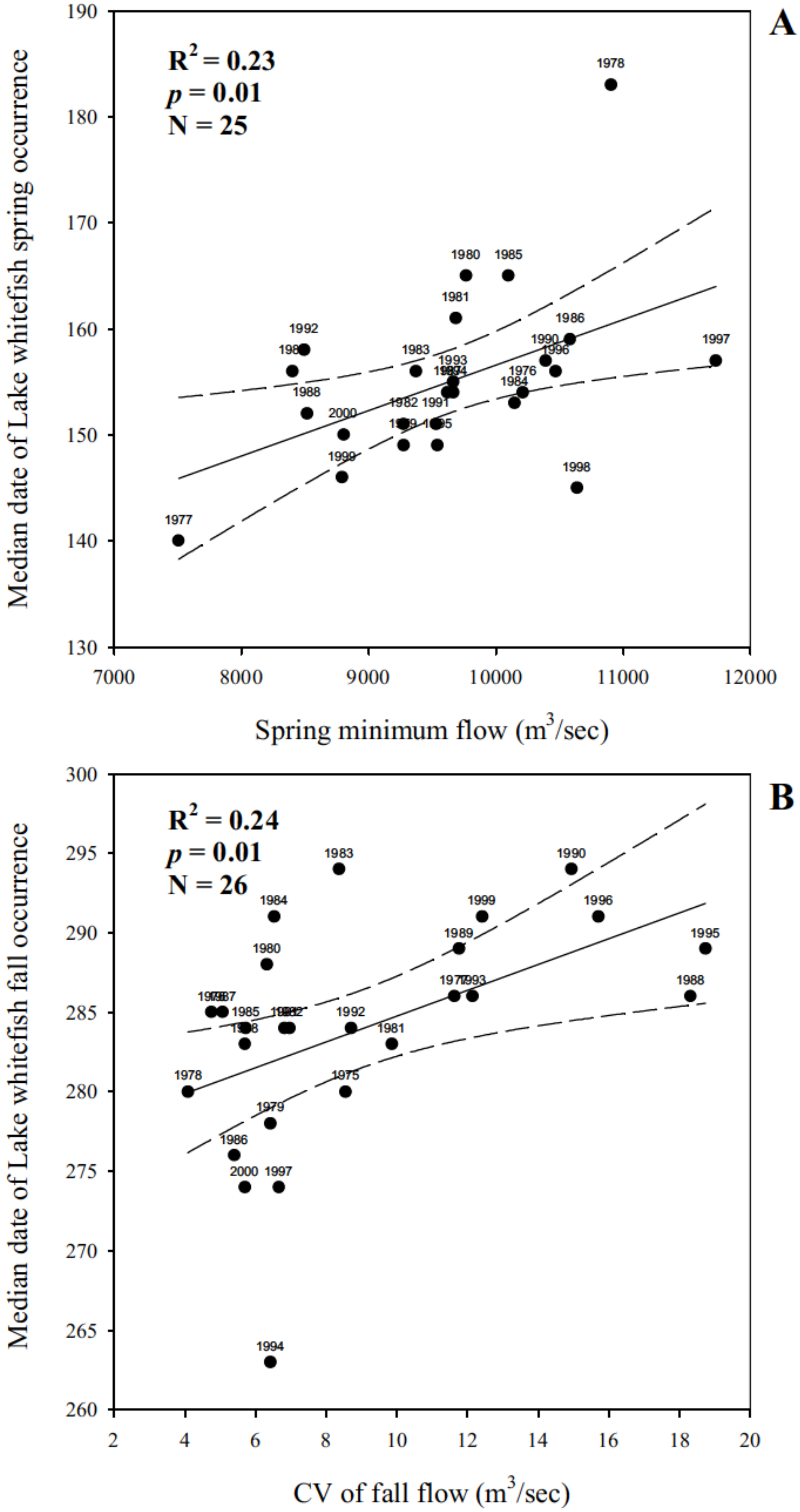


Figure 8. A) Median date of Lake whitefish spring occurrence as a function of spring minimum flow (m^3/sec) and B) median date of fall occurrence as a function of CV of daily fall flow (%).

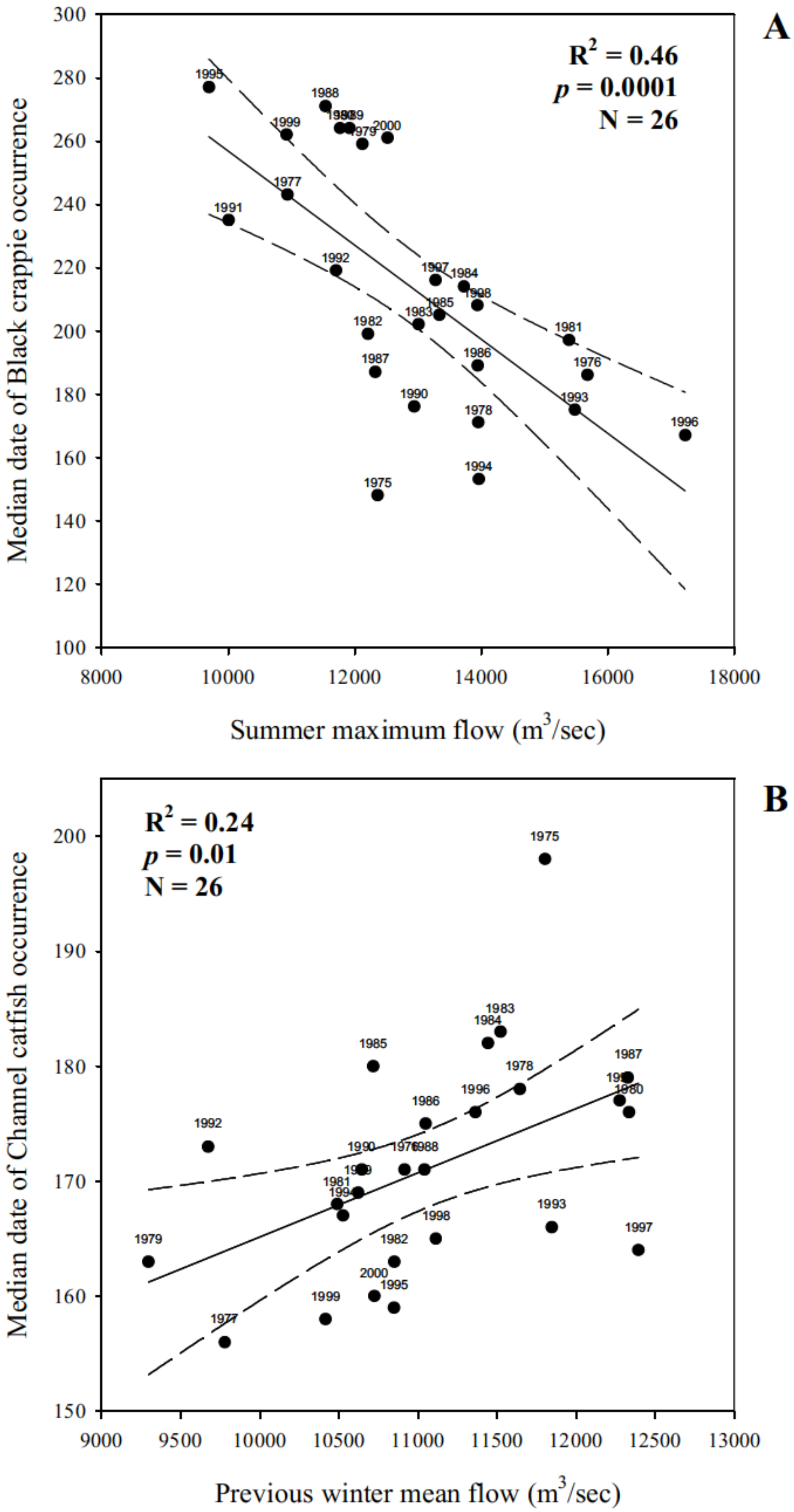


Figure 9. A) Median date of Black crappie occurrence as a function of summer maximum flow (m^3/sec) and B) median date of Channel catfish occurrence as a function of the previous winter mean flow (m^3/sec).

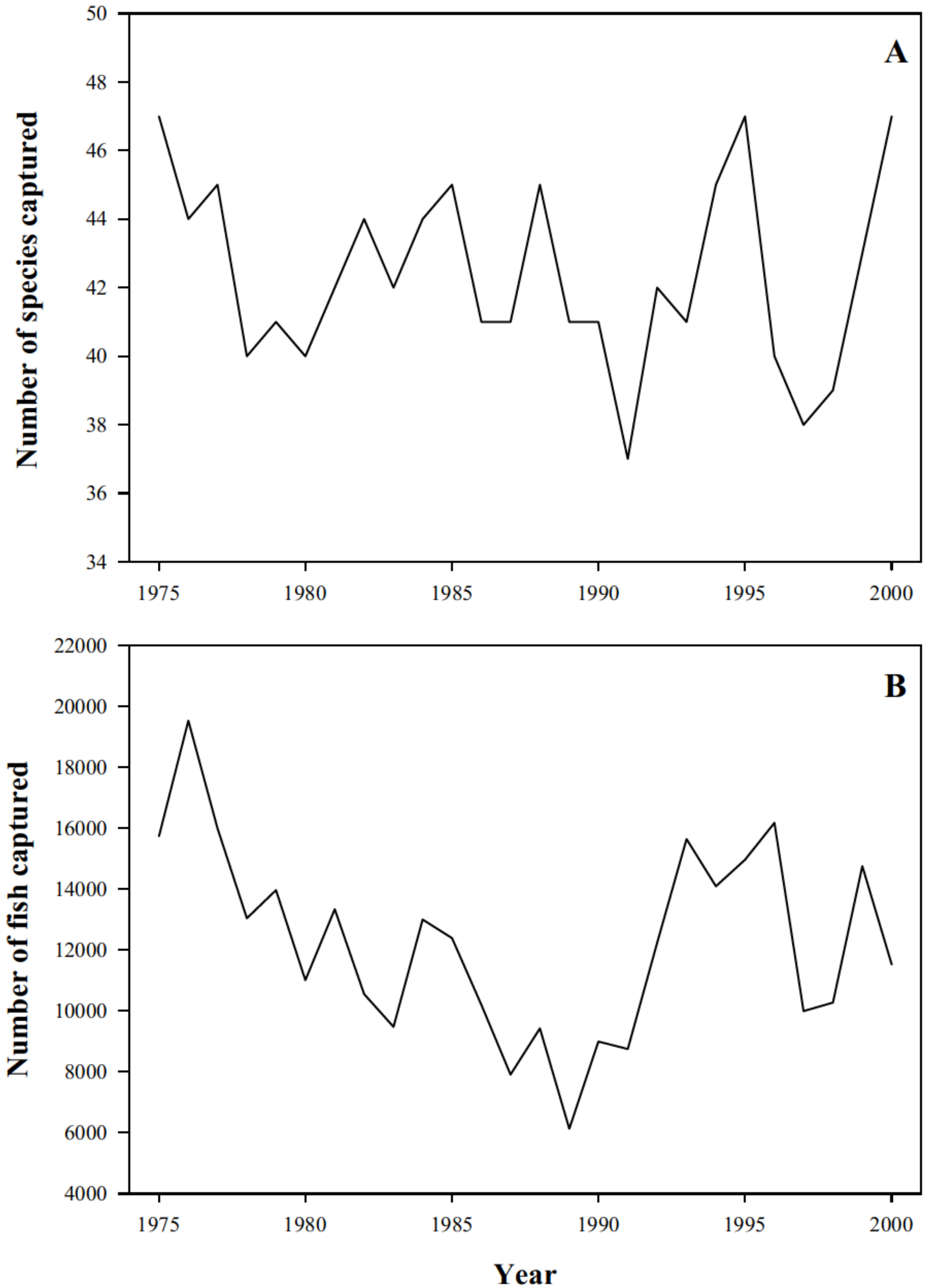


Figure 10. Total number of species (A) and total number of fish (B) captured at the experimental trap fishery in Saint-Nicolas between 1975 and 2000.

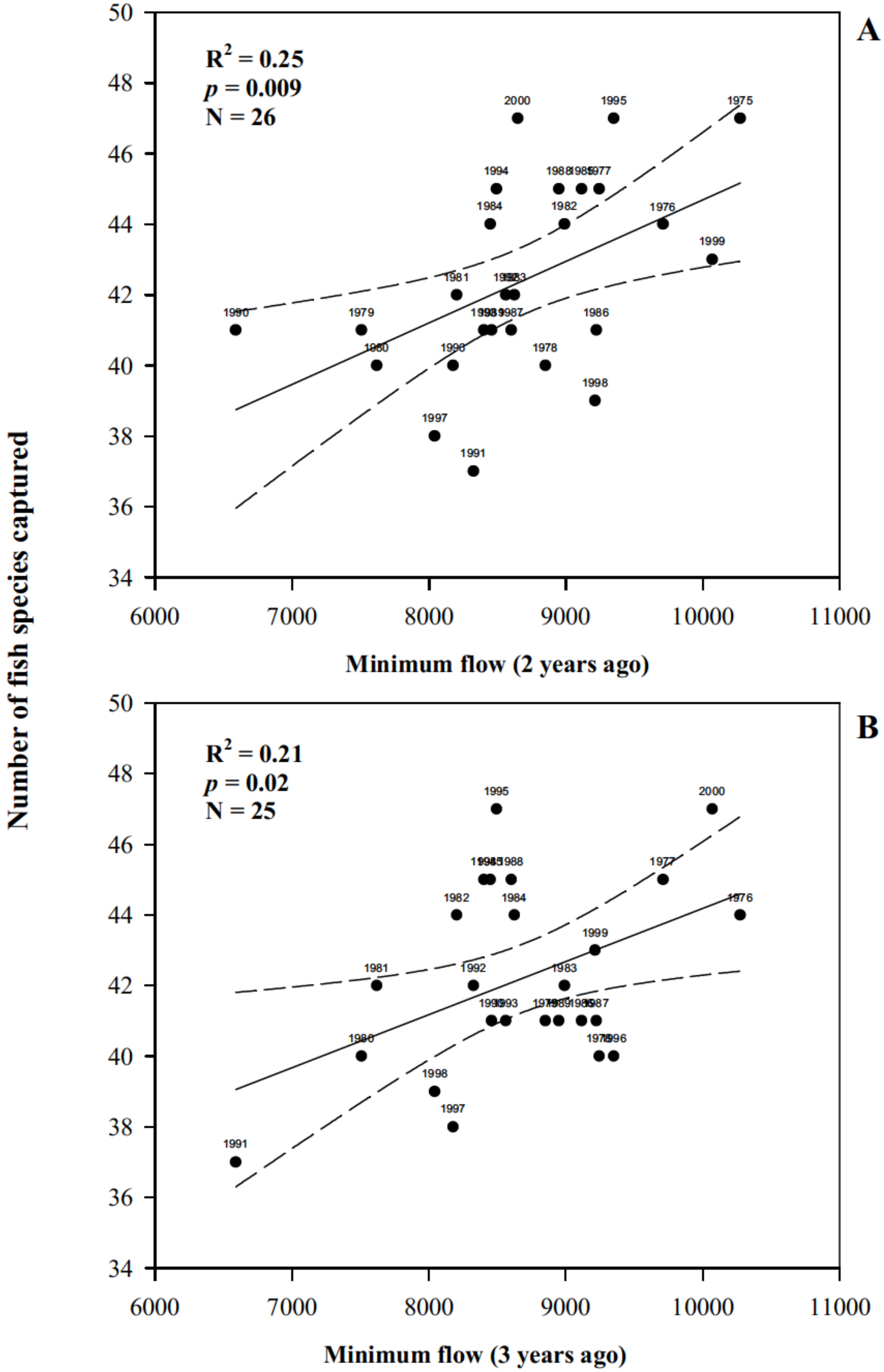


Figure 11. Linear regressions between the number of fish species captured and A) the minimum flow (m^3/sec) from 2 years ago, and B) 3 years ago. Dotted lines represents 95% confidence intervals.

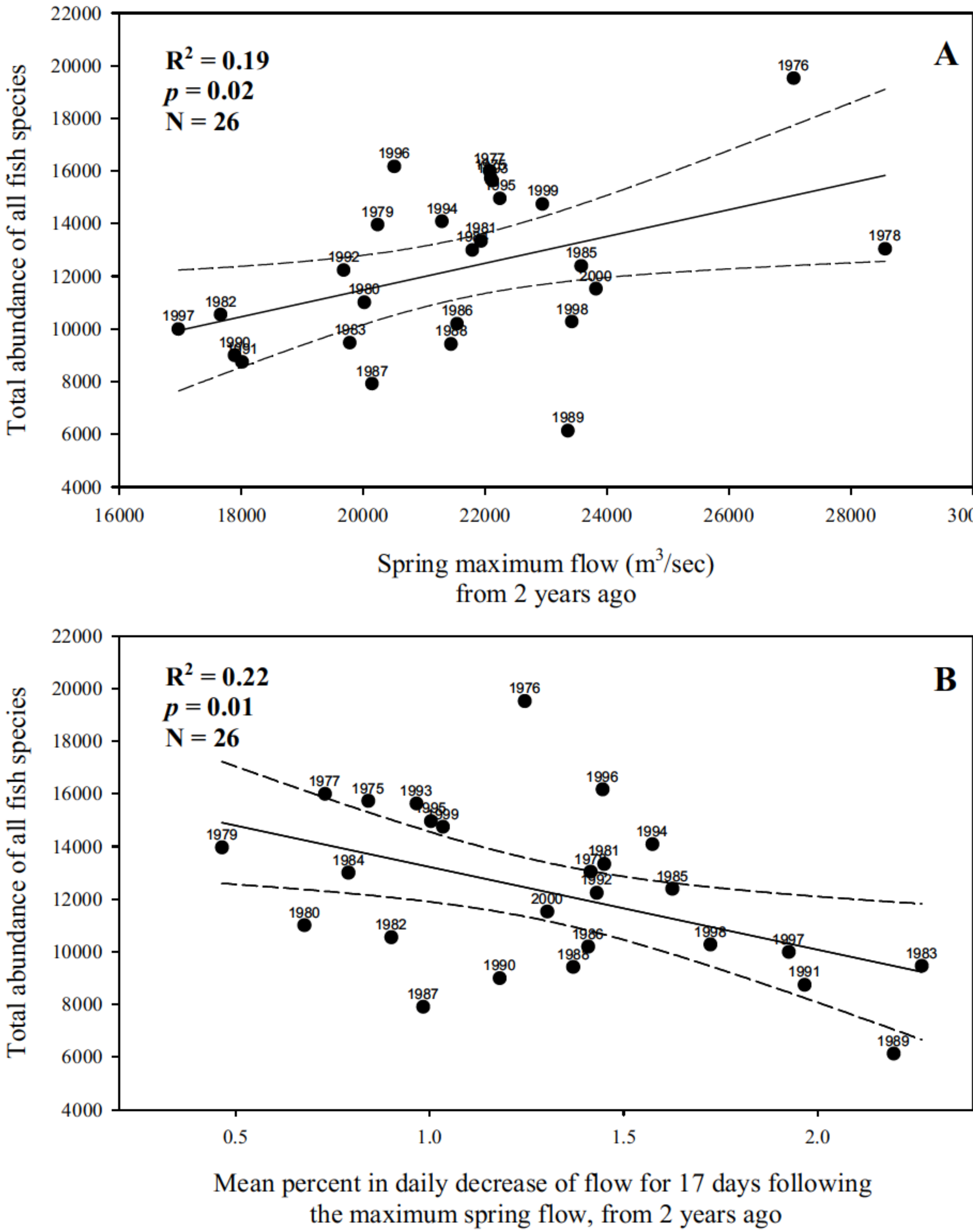


Figure 12. Total abundance of all fish species as a function of A) spring maximum flow two years before and B) water recession rate, also from two years before.

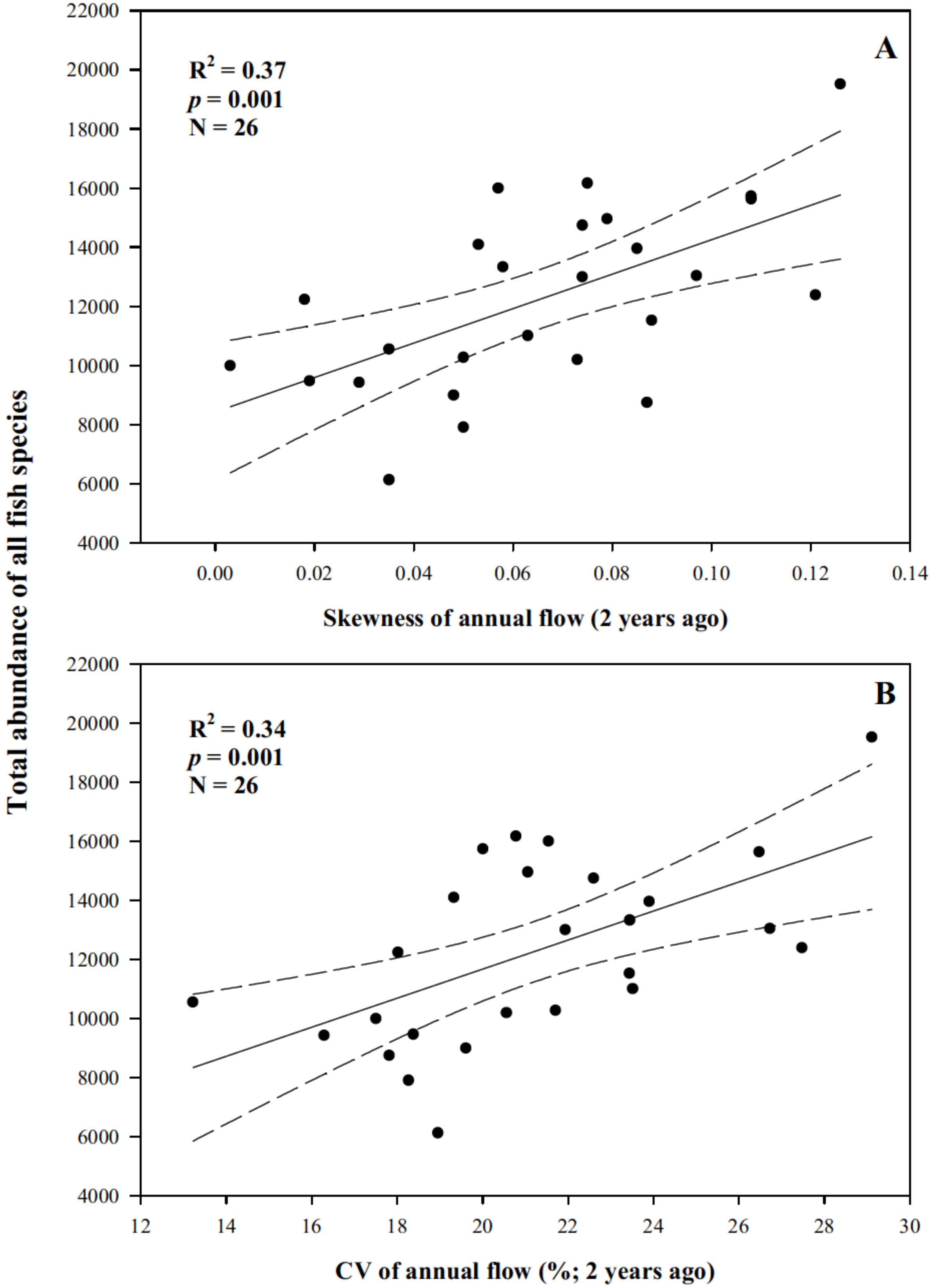


Figure 13. Linear regressions between the number of fish captured and A) the skewness of annual flow from 2 years ago and, B) the coefficient of variation of annual flow from 2 years ago. Dotted lines represent 95% confidence intervals.

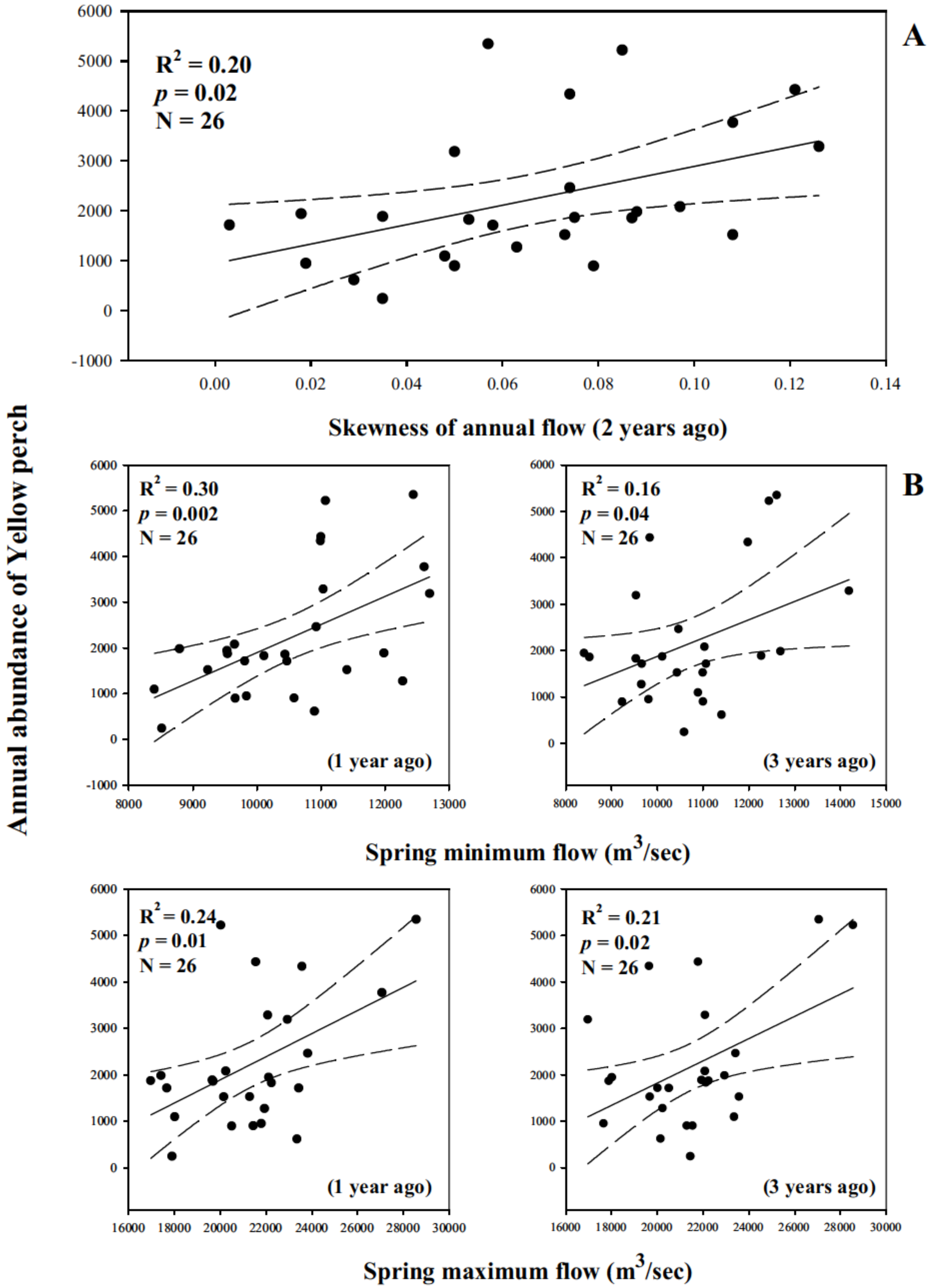


Figure 14. Linear regression between the number of Yellow perch captured and A) the skewness of annual flow 2 years ago and, B) the spring minimum and maximum flow from 1 and 3 years before. Dotted lines represents 95% confidence intervals.

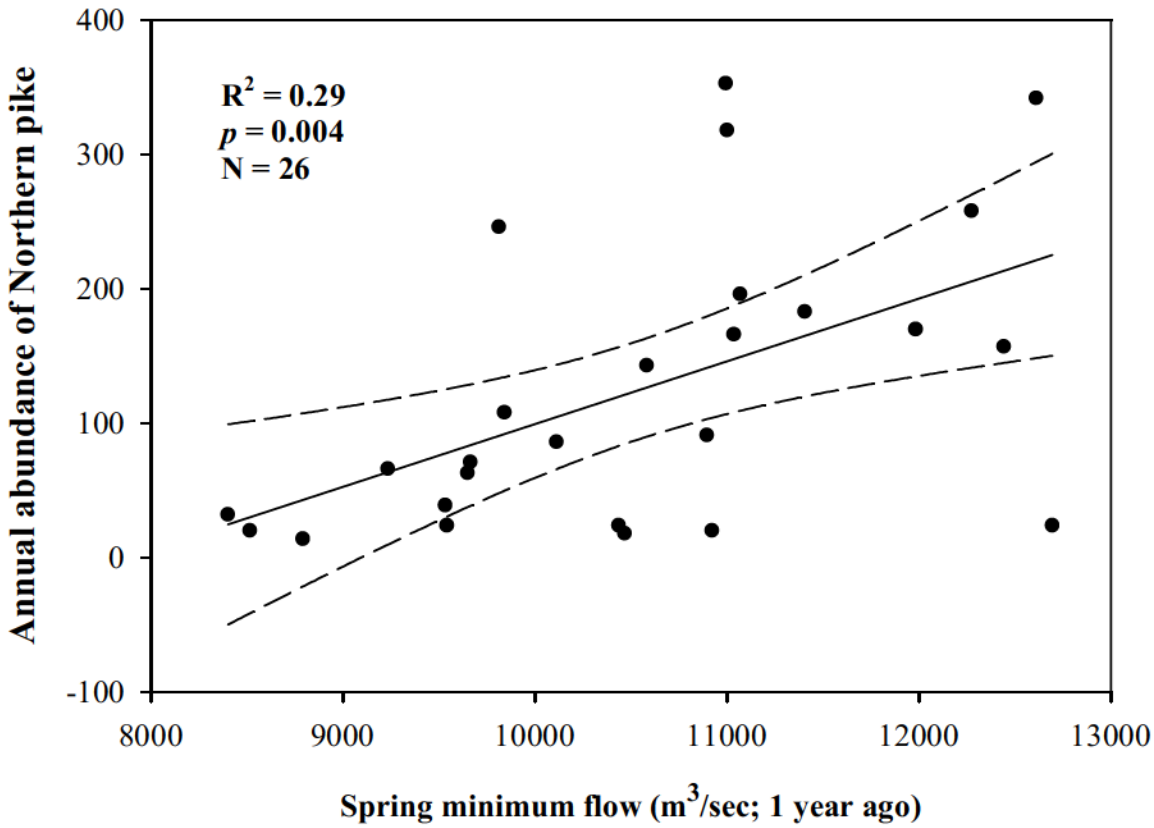


Figure 15. Linear regression between the number of northern pike captured and the spring minimum flow from the previous year. Dotted lines represents 95% confidence intervals.

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