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Diel activity patterns of the fish community in a temperate stream, Catamaran Brook, New Brunswick

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Abstract:	The diel activity patterns of fishes in Catamaran Brook and the Little Southwest Miramichi River, New Brunswick were studied during the summer over 5 years. Young-of-the year Salmo salar and blacknose dace Rhinichthys atratulus were more active during the day than at night, whereas lake chub Couesius plumbeus, brook trout Salvelinus fontinalis, and adult white suckers Catostomus commersonii were more active at night than during the day; Salmo salar parr were equally active during the day and night. Because fishes in Catamaran Brook were as likely to be nocturnal as diurnal, our data suggest that more night-time sampling is needed to provide an unbiased view of fish community structure in temperate streams.

Ethics questionnaire for JFB

This questionnaire relates to the Editorial published in JFB **68**, 1-2, which you have been asked to read. Please note that submitted manuscripts will only be considered if the experimental methods employed are ethically justified. PLEASE SUBMIT THE COMPLETED QUESTIONNAIRE WITH YOUR MANUSCRIPT ONLINE THROUGH EDITORIAL MANAGER.

Corresponding author's name: ____Asra Toobaie____

Question 1: If the fishes have been collected as part of faunal surveys, have the fishes, where feasible, been killed rapidly or returned to the wild after being held in aquaria?

N/A: Animals in our experiment were observed in their natural habitats and were not manipulated in the field or in laboratory.

Yes ☐

No ☐

Question 2: What method was used if they were killed?

Question 3: If you have undertaken experimental work, has the care and use of experimental animals complied with local and or national animal welfare laws, guidelines and policies?

N/A: Animals in our experiment were observed in their natural habitats and were not manipulated in the field or in laboratory.

Yes ☐

No ☐

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Please read the exceptions below (Questions 4 to 7). If any of these exceptions apply to your study, complete the appropriate section. Otherwise leave blank.

If 'No', because these laws do not exist in your country, please state this.

Please read the exceptions below (Questions 4 to 7). If any of these exceptions apply to your study, complete the appropriate section. Otherwise leave blank.

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Yes ☐

No ☐X

If 'Yes', state the conditions and how they can be justified.

Question 5: Did you use humane endpoints that minimized adverse effects?

Yes ☐X

No ☐

Question 6: Have you performed surgical procedures?

Yes ☐

No ☐X

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Question 7: If the procedures caused more than slight pain or distress, did you use appropriate sedation, analgesia and anaesthesia, with appropriate post-operative care?

N/A: Animals in our experiment were observed in their natural habitats and were not manipulated in the field or in laboratory.

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If 'No', did any of your procedures involve sentient, un-anaesthetized animals paralysed by chemical agents such as muscle relaxants?

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Yes ☐

No ☐X

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Diel activity patterns of the fish community in a temperate stream

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Running title: DIEL ACTIVITY OF TEMPERATE STREAM FISHES

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The diel activity patterns of fishes in a temperate New Brunswick stream were studied during the summer over 5 years. Young-of-the year Atlantic salmon *Salmo salar* and blacknose dace *Rhinichthys atratulus* were more active during the day than at night, whereas lake chub *Couesius plumbeus*, brook trout *Salvelinus fontinalis* and adult white suckers *Catostomus commersonii* were more active at night than during the day. Because fishes were as likely to be nocturnal as diurnal, the data suggest that more night-time sampling is needed to provide an unbiased view of fish community structure in temperate streams.

Keywords: diurnal; nocturnal; sampling gear; stream fish community.

The diel activity patterns of fishes have been best studied in coral reefs and temperate lakes (Helfman, 1981, 1993), typically *via* direct observation by divers. Except for a few well known species, such as American eel *Anguilla rostrata* (Lesueur 1817) and juvenile salmonids (Reebs, 2002), relatively little is known about the diel activity patterns of most temperate stream fishes. In Atlantic salmon *Salmo salar* L.1758, for example, young-of-the-year (YOY) are primarily diurnal during the summer (Breau *et al*., 2007) and nocturnal during the autumn (Johnston *et al*. 2004), whereas age 1+ and 2+ year parr are more active at night during both seasons (Gries *et al*., 1997; Imre & Boisclair, 2004; Johnston *et al*., 2004; Breau *et al*., 2007). Little is known, however, about the diel activity patterns of a complete community of stream fishes (Helfman, 1993; Roussel & Bardonnet, 1997; Reebs, 2002).

Knowledge about fish community structure will depend on both the type of sampling gear used and the diel behaviour of the fish species present. Passive gear, such as minnow traps, gillnets and fyke nets, will only catch fishes that are active and moving during the sampling period (Hardie *et al*., 2006). Hence, passive gear can potentially provide excellent information about diel activity patterns, but only if the sampling effort is spread evenly over the diel cycle. To provide an unbiased estimate of community structure from daytime sampling only, an active gear that is effective at catching active and inactive fishes is required, such as electrofishing (Hardie *et al*., 2006; Copp, 2010). Direct observations by divers are intermediate between active and passive gear. Because most inactive fishes in streams, lakes and oceans hide in or under some sort of physical structure (Reebs, 2002), they will be invisible to direct observation. Divers, however, typically sample by moving through the environment and will encounter active, but sedentary fishes, such as those that adopt a sit-and-wait foraging tactic (Grant & Noakes, 1987). Hence, juvenile *S. salar* will be invisible to most passive gear (Reebs *et al*., 1995). Because electrofishing during the day is the primary method of sampling stream fish communities (Copp, 2010), it is not surprising that little is known about diel activity patterns.

The goals of this study were to describe the diel activity patterns for the entire fish community of a temperate stream during the summer and to determine whether sampling in the daytime only would bias understanding of fish community structure. Reebs *et al*. (1995) conducted a preliminary analysis of the diel activity patterns of four of the 13 species of fishes in Catamaran Brook and the Little Southwest Miramichi River; their data indicated that three of four species were diurnal. Their study, however, was limited by the use of passive gear (minnow traps), which could not sample juvenile salmonids or large fishes, such as adult white suckers *Catostomus commersonii* (Lacépède 1803). To describe the activity patterns of the complete fish community, Reebs *et al*.'s (1995) preliminary observations were expanded in four important ways: (1) snorkelling observations were used to sample a greater variety of species, including the most abundant species, juvenile salmonids; (2) the area sampled was increased from *c.* 100 to 540 m^2; (3) the temporal scale of the study was increased from 1 to 5 years; (4) estimates of species richness were compared from sampling during the day, during the night and during both the day and night.

Data were collected in Catamaran Brook and the Little Southwest Miramichi River (46° 52´N; 66° 06´W), located in central New Brunswick, Canada. Catamaran Brook is a third-order tributary (Hynes, 1970) of the fifth-order Little Southwest Miramichi River. During the summer

(17 June – 22 August) of 5 years (2002, 2003 and 2006-2008), a mean of 6.0 daytime (range = 2-10) and 2.4 night-time (range = 2-4) surveys of fishes were completed per year between 1100 and 1900 hours and between 2200 and 0300 hours, respectively, in each of seven to eight sites. Also, temperature, depth and velocity of water at each study site were measured (Table I). The study sites varied in size among years (mean area ± S.D. = 72.60 ± 54.02 m^2) and included riffles, pools and intermediate habitats (Cunjak *et al.*, 1993). Fishes were considered active if they were swimming, feeding or holding position on or near the substratum, whereas inactive fishes were under cover and invisible to the snorkeller (Emery, 1973; Helfman, 1993). The number of active fish was counted in each site while snorkelling slowly upstream; inactive fishes were typically not seen and hence could not be counted. For all surveys, the snorkeller moved slowly upstream, completing each 1 m subsection of the site by moving from the left bank to right bank, taking *c.* 30-40 min to complete one 15 m site during either the day or night. During the night surveys, fishes were located by a snorkeller using a 20 W flashlight that was held underwater and directed at the surface of the water to reduce the possibility of disturbance (Johnston *et al*., 2004). While the visibility of fishes was poorer at night, this was partly compensated for by their sluggish behaviour, so that the detection probability was probably similar during the day and night. Furthermore, fish behaviour was the most important factor influencing detection probability; a fish hiding under cover will not be detected even under optimal lighting conditions.

For each species, site and year, the mean daytime and night-time densities (per 100 m^2) were calculated. No statistical analysis was performed on data from species that were only rarely observed: northern redbelly dace *Phoxinus eos* (Cope 1861), slimy sculpin *Cottus cognatus* Richardson 1836, sea lamprey *Petromyzon marinus* L. 1758 and brown bullhead *Ameiurus nebulosus* (Lesueur 1819). For the most abundant species [*S. salar*, blacknose dace *Rhinichthys atratulus* (Hermann 1804), lake chub *Couesius plumbeus* (Agassiz 1850), brook trout *Salvelinus fontinalis* (Mitchill 1814) and *C. commersonii*] a two-factor (within subject effect = mean day *v*. mean night density; between subject effect = year) repeated-measures ANOVA was used to compare the relative daytime *v*. night-time densities of each species over the 5 year study. Such a paired analysis allowed for correction for the difference between day and night sampling effort in each year. Also, environmental variability among years could be detected by a significant interaction between day *v*. night densities and year. For visual purposes on figures, paired *t*-tests ($\alpha = 0.01$; Dunn-Šidák method to correct for multiple comparisons; Sokal & Rohlf, 1995) were used to illustrate when yearly comparisons between daytime and night-time densities differed significantly. To meet the assumptions for parametric analyses, mean daytime and night-time densities were $\log_{10}$ transformed [$\log_{10}(x+0.1)$].

In each year, the species richness of each site was calculated in three different ways: from the two night-time samples; from the two daytime samples that corresponded most closely in time with the night-time samples; and from one randomly chosen daytime and night-time sample. In 2006, four surveys were used rather than two for the calculations. A two-way ANOVA was used to compare the mean daytime, night-time and combined daytime and night-time species richness over the 5 year survey. SPSS version12.0.1 (www-

01.ibm.com/software/analytics/spss/products/statistics/)was used for all statistical tests ($\alpha = 0.05$).

Over the 5 year study, a total of 9396 fishes of 10 different species were counted, including two age groups for *S. salar*. YOY *S. salar* were counted most frequently (53.8% of all observed fishes), followed by age 1+ and 2+ year *S. salar* parr (23.4%), *R. atratulus* (16.6%), *C. plumbeus* (3.5%), *S. fontinalis* (1.4%), *C. commersonii* (1.1%), *A. rostrata* (0.1%), *P. eos* (0.05%), *C. cognatus* (0.02%), *P. marinus* (0.01%) and *A. nebulosus* (0.01%). YOY *S. salar* was the most common fish in all years except for 2008. With the exception of *C. commersonii* and *S. salar*, all observed species were of adult size (Scott & Crossman, 1973), with no obvious size differences between day and night samples. Most *C. commersonii* were of adult size and were observed primarily at night, whereas the few juveniles were observed primarily during the day. All *S. salar* were of age classes 0+, 1+ and 2+years.

The density of YOY *S. salar* was significantly higher during the day than at night [repeated measures ANOVA, $F_{1, 32} = 89.91$, $P < 0.001$; Fig. 1(a)], whereas the density of parr did not differ significantly between day and night [repeated measures ANOVA, $F_{1, 32} = 0.256$, $P > 0.05$ Fig. 1(b)]. The density of *R. atratulus* was higher during the day than at night in all 5 years [repeated measures ANOVA, $F_{1, 32} = 85.88$, $P < 0.001$; Fig. 1(c)]. Although there was a significant interaction between the relative day *v*. night densities and year for *R. atratulus* (repeated measures ANOVA, $F_{4, 32} = 5.32$, $P < 0.01$), the magnitude of this significant interaction was considerably smaller than the main effect of day vs. night density.

The density of *C. plumbeus* [repeated measures ANOVA, $F_{1, 32} = 43.45$, $P < 0.001$; Fig. 1(d)], *S. fontinalis* [repeated measures ANOVA, $F_{1, 32} = 6.75$, $P < 0.05$; Fig. 1(e)] and *C. commersonii* [repeated measures ANOVA, $F_{1, 32} = 11.22$, $P < 0.01$; Fig. 1(f)] were all significantly higher at night than during the day. *Anguilla rostrata* were not observed regularly enough to warrant a full statistical analysis; however, they were significantly more active at night than during the day (total counts 7 *v*. 1; Sign test, $P < 0.05$), despite more sampling effort during the day.

On average, between one and five species of fish were counted in a snorkelling survey of a site (Fig. 2). Species richness differed significantly across the 5 years (two-way ANOVA, $F_{4, 96} = 5.99$, $P < 0.001$) and between the three types of surveys (two-way ANOVA, $F_{2, 96} = 15.96$, $P < 0.001$). There was no significant interaction between the time of survey and the year (two-way ANOVA, $F_{8, 96} = 1.73$, $P > 0.05$). Over the 5 years, daytime estimates of species richness were significantly lower than either the night-time estimates (Tukey *post hoc* test: P <0.001; Fig. 2) or the combined daytime and night-time estimate of species richness (Tukey *post hoc* test: $P < 0.001$; Fig. 2). The night-time estimate, however, did not differ significantly from the combined daytime and night-time estimate of species richness (Tukey *post hoc* test: $P > 0.05$).

The diel patterns of activity noted in this study were largely consistent with what is known in the literature. As expected, YOY *S. salar* were primarily diurnal in the summer (Breau *et al.*, 2007), whereas parr were equally active during the day and night (Gries *et al*., 1997; Imre & Boisclair, 2004; Breau *et al*., 2007). Primarily nocturnal species included *S. fontinalis* (Gries *et al*., 2007; Rader *et al*., 2007), *C. plumbeus* [Emery, 1973; Reebs *et al*. (1995), however, suggested that *C. plumbeus* were crepuscular or nocturnal] and *A. rostrata* (Tesch, 1977; Scott & Crossman, 1973), whereas *R. atratulus* were primarily diurnal (Reebs *et al*., 1995). In contrast to the results of Reebs *et al*. (1995), *C. commersonii* were primarily nocturnal in the present study (Emery, 1973). This discrepancy is probably because Reebs *et al*. (1995) sampled juveniles with minnow traps, whereas observations here were primarily of adults. The few juveniles observed in this study, however, were diurnal.

Reebs *et al*. (1995) concluded that three species were diurnal (*R. atratulus*, three-spined stickleback *Gasterosteus aculeatus* L. 1758 and juvenile *C. commersonii*), whereas *C. plumbeus* were crepuscular or nocturnal. The results of the present study described the diel behaviour of the six most common fish species, including two age groups for *S. salar*. Putting the two data sets together, the diel activity pattern of seven species of fishes, including two age groups of *S. salar* and *C. commersonii*, in Catamaran Brook and the Little Southwest Miramichi River can be described. Of these fishes, four were primarily diurnal (YOY *S. salar*, *R. atratulus*, *G. aculeatus* and juvenile *C. commersonii*), four were primarily nocturnal (*S. fontinalis*, *C. plumbeus*, adult *C. commersonii* and *A. rostrata*) and one was equally active during the day and night (*S. salar* parr).

Of the other fish species counted in the present study *C. cognatus*, *P. marinus* and *A. nebulosus* all tended to be nocturnal, whereas *P. eos* tended to be diurnal.

Four important results emerge from this study. First, fishes in Catamaran Brook were as likely to be nocturnal as diurnal, so biologists will have to increase their relative sampling effort at night to better describe the entire community. Second, ontogenetic shifts from diurnal behaviour as juveniles to nocturnal behaviour as older individuals were evident in *C. commersonii* and juvenile *S. salar* [consistent with the findings of Bradford & Higgins 2001, for juvenile Pacific salmon *Oncorhynchus tshawytscha* (Walbaum 1792)]. While more study is needed to verify if this is a general trend for stream fishes, biologists should be cautious about classifying species as either diurnal or nocturnal (Reebs, 2002). Third, estimates of species richness from daytime samples were lower than for night-time or day and night samples. Fourth, more night-time sampling is probably needed to provide an unbiased view of fish population and community structure. Electrofishing is the most widely used and effective sampling gear for stream fishes (Copp, 2010). Because it is an active sampling method, electrofishing will capture both diurnal and nocturnal species during daytime sampling (Hardie *et al.*, 2006) to provide reliable estimates of species richness (Copp, 2010). Nevertheless, the catch per unit of effort during the day is lower than at night for nocturnal species (Roussel & Bardonnet, 1997; Hardie *et al.*, 2006; Copp, 2010). Hence, more night-time sampling is required, even when electrofishing, particularly when accurate monitoring of threatened freshwater fish populations is required to implement management practices or to assess the success of recovery programmes.

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Table

TABLE I. Mean ± S.D. of five habitat variables at the study sites over 5 years

Variable	Year				
	2002	2003	2006	2007	2008
Depth (m)	0.23±0.08	0.51±0.08	0.41±0.15	0.37±0.13	0.30±0.18
Width (m)	3	3	5	5	8.48±2.75
Water velocity (ms^{-1})	0.14±0.13	0.43±0.18	0.44±0.27	0.24±0.16	0.35±0.23
Day water temperature (° C)	20.02±1.60	19.47±2.00	17.25±2.46	17.30±2.42	16.00±1.78
Night water temperature (° C)	18.43±1.43	19.82±0.24	17.31±3.50	13.75±0.72	13.80±0.84

FIG 1. Mean ±S.E. day density minus night density of the most common species observed in Catamaran Brook over 5 years: (a) Young-of-the-year *Salmo salar*, (b) *S. salar* parr, (c) *Rhinichthys atratulus*, (d) *Coueslus plumbeus*, (e) *Salvelinus fontinalis* and (f) *Catostomus commersonii*. *, Significant yearly differences (paired *t*-tests, $P < 0.01$). Note the logarithmic scale on the *y*-axis.

Remove fish names (YOY Salmo salar, etc.). Change y-axis to Mean ± S. E. and x-axis remove one Year and centre the other.

FIG 2. Comparison of the mean ±S.E. species richness estimated from samples taken during the day (○), night (●) and both day and night (■) in Catamaran Brook over 5 years.

Change y-axis to Mean ± S. E.

Figure

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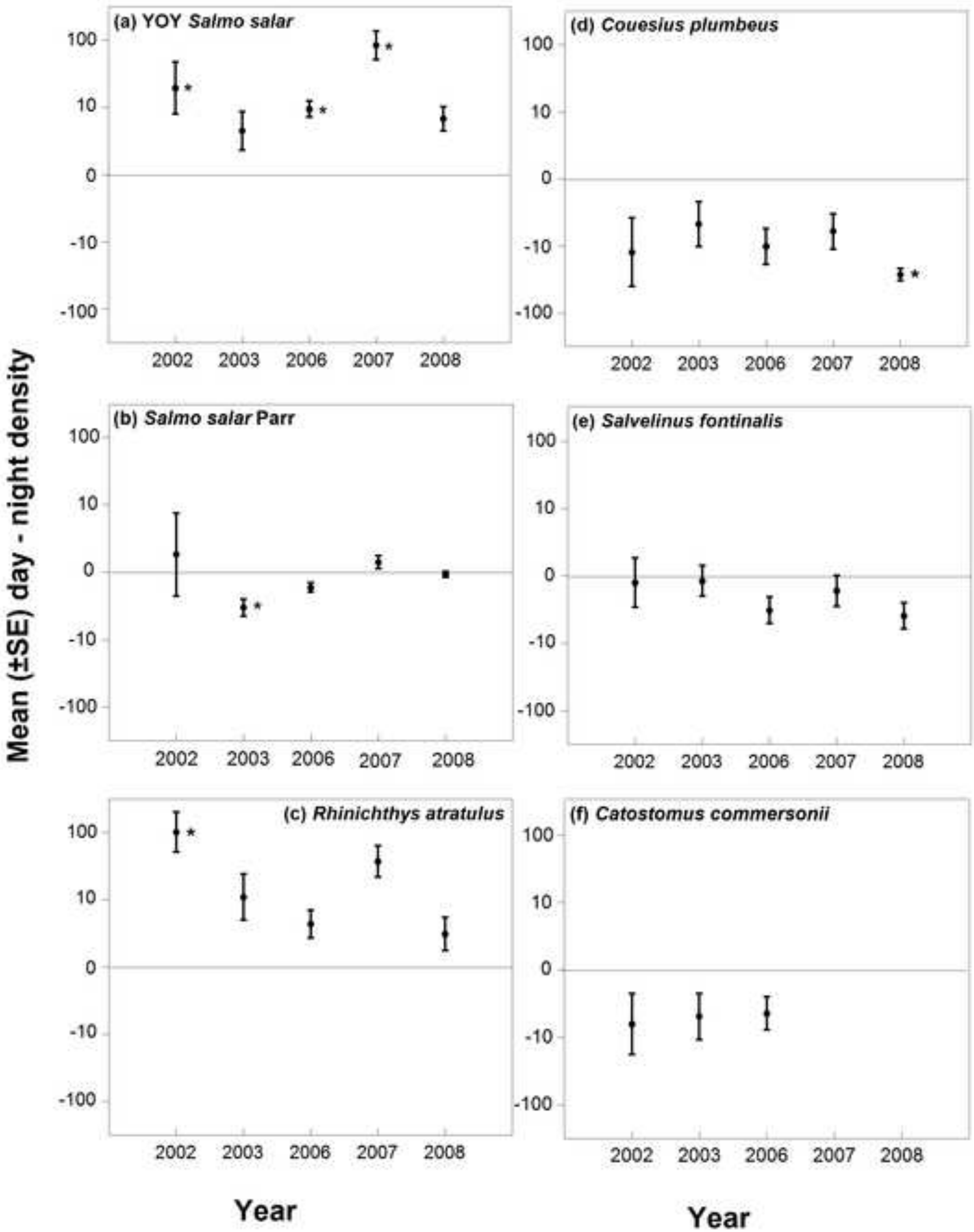

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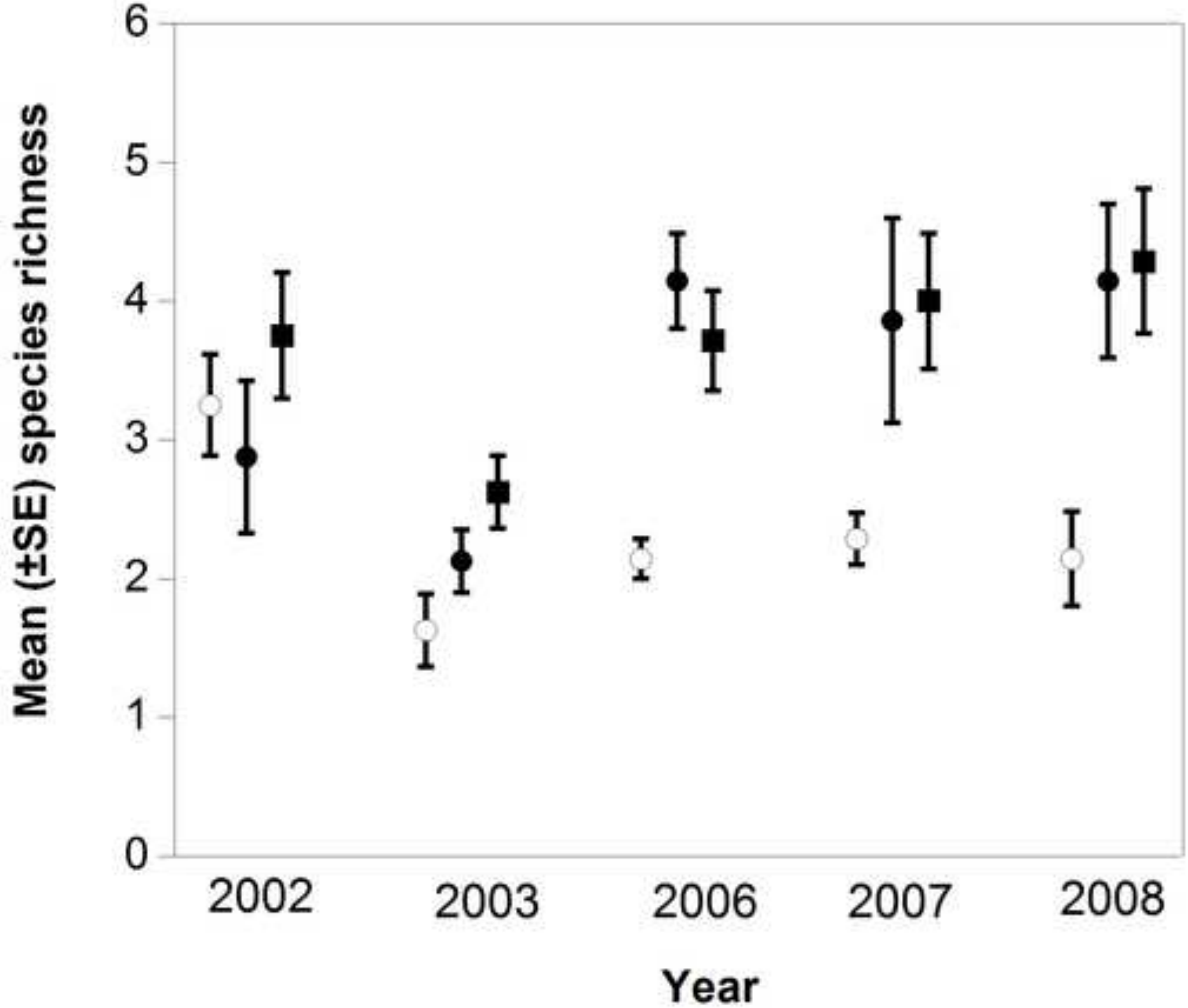

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