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Emergence pattern, site selection, and seasonal regulation of *Onychogomphus costae* Selys, 1885 (Odonata: Gomphidae) in northeastern Algeria

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Emergence and seasonal regulation of the dragonfly *Onychogomphus costae* Selys, 1885, were surveyed thoroughly during two consecutive years from two nearby stretches upstream the Seybouse River, northeastern Algeria. The emergence season started in mid-May and lasted 68 and 58 days showing a peak in late May and early June in 2011 and 2012, respectively. During the two years 2011 and 2012, 50% of annual emergence occurred after 25 and 22 days, respectively. Sex ratio was slightly but not significantly male biased. Female exuviae were recorded at higher height than males. Height of the exuviae fixation was positively correlated to support height and head width. Percentage mortality at emergence was mainly due to deformity and predation counting from 7.9% to 9.15% of the total emergent population. The species seasonal regulation is inferred and discussed based on the emergence temporal pattern and larval development.

Keywords: Odonata; Gomphidae; *Onychogomphus costae*; emergence; exuviae seasonal regulation; larva; Algeria

Introduction

Odonate emergence has well been studied in the temperate zone leading to characterise two main types of patterns resulting from variations in seasonal regulation (Corbet 1954). On one hand, 'spring species' possess a diapause in the final instar larvae and emerge synchronously; on the other hand, 'summer species' do not have a larval diapause and emerge asynchronously. Both temperature and photoperiod were shown to determine species seasonal regulation within that region (Norling 1984).

Corbet, Suhling, and Soendgerath (2006) stated that voltinism of odonates was controlled by both exogenous (habitat and latitude) and endogenous factors (phylogeny). Odonates of lotic water like Gomphidae have a slow development and usually take a long time to complete their embryonic development compared to species of lentic water (Johnson 1991; Johansson 2000; Suhling 2001). In Europe, *Paragomphus genei* Selys, 1841, is the only species of gomphid that is univoltine (Testard 1975) and all the others are semi-voltine or even partivoltine (Corbet et al. 2006). Moreover, latitude is negatively related to voltinism. For instance, larval development of some Gomphidae requires four years in Germany (Münchberg 1932; Kern 1992; Foidl, Buchwald, Heitz, and Heitz 1993), three

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years in southern France (Schütte 1992; Suhling 1995), and two years in southern Spain (Ferrerias-Romero and García-Rojas 1995). Furthermore, the effect of phylogeny has been shown on taxons like Lestidae whose voltinism is restricted to one generation per year at any given latitude (Corbet et al. 2006).

The Mediterranean basin harbours a diverse odonata fauna that has recently been assessed presenting a high degree of endemism (Riservato et al. 2009). Three species of Gomphidae (*Gomphus davidi* Selys, 1887, *Gomphus lucasii* Selys, 1849, and *Onychogomphus costae* Selys, 1885) are endemic to that region. *Gomphus davidi* is limited to the eastern Mediterranean (Middle East). However, *G. lucasii* is restricted to the western Mediterranean and present a partial geographical overlap with *O. costae*. Both of them exist in Tunisia and Algeria but *O. costae* extends to Morocco, Portugal, and Spain (Dijkstra and Lewington 2007).

Onychogomphus costae is ranked vulnerable in the IUCN Red list (Boudot 2010). Regardless of several citations in different inventories showing a large altitudinal range (0–2000 m) across its geographical distribution (Dumont 1972; Jacquemin and Boudot 1999; Khelifa et al. 2011), species life history and ecology have been little studied (Cano-Villegas and Ferreras-Romero 2005). Its congeneric species *O. uncatatus* Charpentier, 1840, on the other hand, has well been documented in Europe where it showed a ‘summer species’ pattern in some parts (Schütte 1992) and both ‘spring and summer species’ pattern in other parts (Ferrerias-Romero, Atienzar, and Corbet 1999) with a larval development lasting two to four years (Schütte 1992). Since the species has a wide distribution over the Palearctics, southern populations were shown to have a rapid development than northern ones (Ferrerias-Romero et al. 1999). In addition, variations in emergence pattern and temporal synchronisation of larvae as a result of variations in water temperature, larvae density, and drying up of water course were noted (Suhling 1995).

This study provides the first detailed description of the species emergence pattern, microhabitat choice, and larval development in the Seybouse River (northeastern Algeria).

Material and methods

The Seybouse River watershed is situated in northeastern Algeria covering an area of 6471 km² including the main water course as well as its two principal affluents oued Bouhamdane (36°26′30.84″N, 7°18′30.91″E) and oued Cherf (36°26′33.96″N, 7°18′39.20″E). The Seybouse River is 225 km long starting from Medjez Amar Province and flows into the Mediterranean Sea near Sidi Salem. Two stretches (A and B), each 1 m wide and 20 m long separated by 1.5 km, were chosen upstream of the river characterised by large, shallow, and fast flowing water. Bank vegetation of the stretch A (36°28′22.55″N, 7°22′44.81″E, 209 m a.s.l.) was dominated by *Typha angustifolia* Linnaeus, 1753, while that of the stretch B (36°28′33.91″N, 7°22′1.77″E, 212 m a.s.l.) consisted of *Cyperus longus* Linnaeus, 1753, *Typha angustifolia*, *Tamarix gallica* Linnaeus, 1753, and *Paspallum distichum* Linnaeus, 1753. Daily visits to the study stretches started on mid-April 2011 and 2012 and ended when no exuviae was collected after seven consecutive visits. We collected exuviae daily in late afternoon (at 04:00 pm) at two stretches of 20 × 5 m near the water edge. All potential supports within stretches were intensively checked. We noted the support type and height, height of the exuviae fixation (He) (distance from the water surface to the tip of exuviae abdomen), and distance from the water of each exuviae to the nearest 1 cm using a 5 m decametre. Sources of mortality were noted in order to determine the percentage mortality at emergence. In the laboratory, the sex was

determined and the body length and the head width were measured to the nearest 0.01 mm using a digital calliper.

From September 2011 to 2013, we monthly collected larvae with a rectangular hand net (40 × 25 cm, 0.5 mm mesh) from the stretch A. We followed Seidenbusch (2010) to identify the species. In the laboratory, larvae were counted and measured (body length, head width, and length of wing sheath) to the nearest 0.01 mm using a digital calliper and a dissecting microscope. The number of abdominal segments covered with wing sheath was noted. Both size of organs and external features were used to separate larvae into different instars (Ferrerias-Romero et al. 1999) according to Lutz's (1968) nomination, i.e., F = final, F-1 = penultimate, F-2 = antepenultimate, etc.

Statistical analyses were carried out using SPSS 17.0. Chi-square test was used to determine if the sex ratio at emergence significantly deviated from equilibrium. Mann–Whitney *U* tests were used to test if there was significant difference in head width, body length, height of the exuviae fixation (He), support height (Hs), and ratio He/Hs between sexes. Spearman correlations were conducted between these variables in order to test for possible significant relationship between them.

Results

Emergence pattern

Onychogomphus costae coexisted within high population densities of *Gomphus lucasii*, *Calopteryx exul* Selys, 1853, and *Platycnemis subdilatata* Selys, 1849. Temporal pattern of *O. costae* emergence during both years of study is presented in Figure 1.

In 2011, 329 exuviae were collected during the entire emergence season which lasted 68 days from 11 May to 17 July showing a peak on 30 May. In 2012, a total of 437 exuviae were collected during 58 days of emergence from 13 May to 9 July with a first peak on 30 May and a second one on 2 June. The peak of emergence counted for 9.11% of the total emergent population in 2011 and 5.72% in 2012. Figure 2 presents cumulative percentage of annual emergence of *O. costae* in both years of the study. EM50 was 25 and 22 days in 2011 and 2012, respectively.

Sex ratio was not significantly biased in both years of study (χ^2 -test: $P > 0.05$). It was 55.32% males and 52.17% males in 2011 and 2012, respectively. Females reached EM50 earlier than males with 23 and 21 days vs. 26 and 25 days in 2011 and 2012, respectively.

Vertical stratification

Head width and body length of females (4.53 ± 0.22 mm; 22.53 ± 0.80 mm, respectively) were significantly greater than that of males (4.35 ± 0.25 mm; 21.79 ± 0.86 mm, respectively) (*U*-test: $P < 0.0001$; both variables). Exuviae found on the water surface (2%–4%) were not considered in vertical stratification analyses. Final instar larvae used emergent plants (59%–55%), stones (29%–34%), and the soil (8%–7%) to emerge. Plant species used at emergence were commonly *Cyperus longus* Linnaeus, 1753, *Typha angustifolia* Linnaeus, 1753, and *Paspallum distichum* Linnaeus, 1753. A fraction of 2% and 3% of exuviae emerged out of the water at a mean distance of 18 ± 3.4 cm and 15.6 ± 2.4 cm in 2011 and 2012, respectively.

Table 1 presents vertical stratification of *O. costae* in both study years. Females chose higher heights than males during emergence in both years of study. There were significant differences in height of the exuviae fixation, support height, and head width between

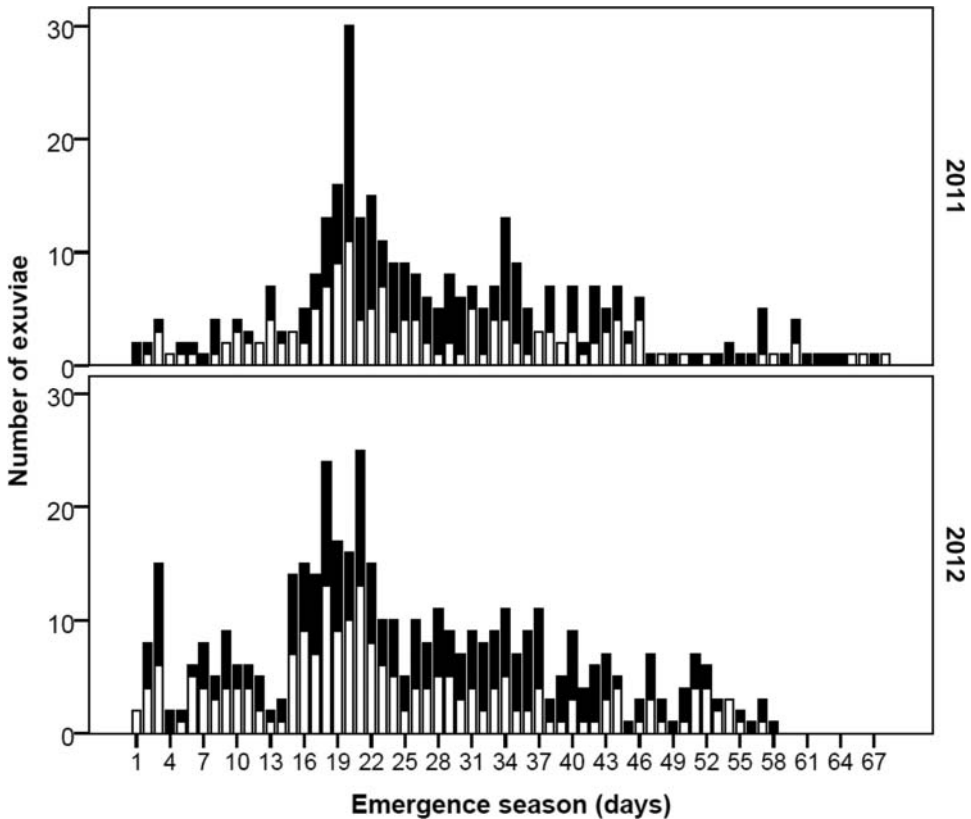


Figure 1. Temporal pattern of emergence of *Onychogomphus costae* Selys, 1885, in the Seybouse River during two emergence seasons. Black and open bars represent males and females, respectively.

study years (U -test: $P = 0.0001$; $P = 0.0001$; $P = 0.006$, respectively) but no marked difference was noted in body length and ratio He/Hs (U -test: $P = 0.85$; $P = 0.27$, respectively).

There was a positive significant correlation between height of the exuviae fixation and support height and a negative relationship between ratio He/Hs and support height in both study years (Table 2). Height of the exuviae fixation was positively related to head width only in 2011 but not to body length in both years (Table 2).

Mortality at emergence

The observed percentage mortality of *O. costae* was 7.9% in 2011 and 9.15% in 2012 (mean = 8.52%). A total of 15 and 22 teneral were recorded deformed in 2011 and 2012, respectively. Predation by asilids was observed 6 and 11 times in the respective years. Three and seven cases of ant predation killing individuals before the end of the ecdysis process were noted in 2011 and 2012, respectively. Two cases of predation by orb-spiders were noted in 2011. Potential avian predators were the barn swallow (*Hirundo rustica* Linnaeus, 1758) and the european bee-eater (*Merops apiaster* Linnaeus, 1758) which tried to capture individuals during their maiden flight: however, no successful predation was observed.

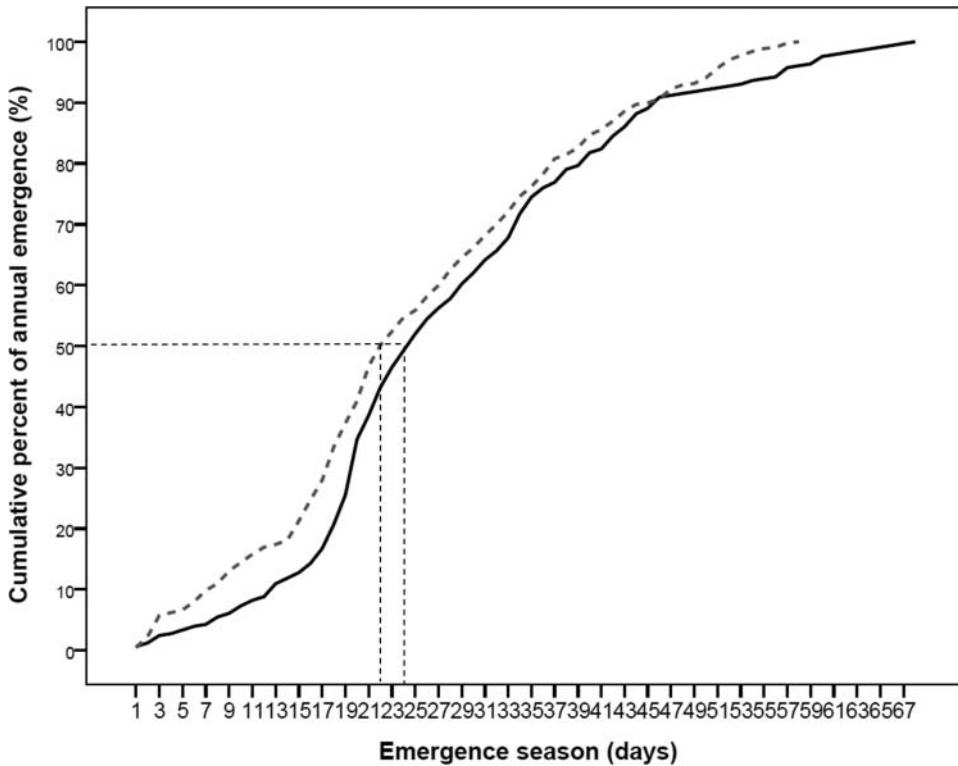


Figure 2. Cumulative percentage of annual emergence of *Onychogomphus costae* Selys, 1885, in the Seybouse River during two emergence seasons. Continuous and dotted curves represent 2011 and 2012 emergence seasons, respectively.

Population structure

A total of 123 larvae of *O. costae* were collected in both years of study. Figure 3 presents frequency of distribution of larval instars based on monthly larvae collecting during two years. Flood impeded us to collect any larva in September. F-0 larvae first appeared in

Table 1. Body size and vertical stratification of males and females of *Onychogomphus costae* Selys, 1885, in 2011–2012.

		Head width (mm)	Body length (mm)	Height of the exuviae fixation (cm)	Support height (cm)	Ratio He/Hs
2011	Male	4.33 ± 0.25	21.79 ± 0.77	5.04 ± 3.19	17.72 ± 21.12	0.45 ± 0.51
	Female	4.51 ± 0.21	22.61 ± 0.68	6.91 ± 4.24	14.68 ± 8.86	0.48 ± 0.43
	U-test <i>P</i> value	0.0001	0.0001	0.03	0.6	0.02
2012	Male	4.41 ± 0.24	21.90 ± 0.76	8.35 ± 6.58	28.62 ± 36.06	0.53 ± 0.46
	Female	4.60 ± 0.19	22.65 ± 0.77	10.66 ± 8.79	50.33 ± 41.59	0.43 ± 0.27
	U-test <i>P</i> value	0.002	0.001	0.01	0.07	0.01
Mean	Male	4.35 ± 0.25	21.79 ± 0.86	6.08 ± 4.71	21.03 ± 26.75	0.47 ± 0.50
	Female	4.53 ± 0.22	22.53 ± 0.80	8.48 ± 6.88	26.90 ± 30.87	0.48 ± 0.38
	U-test <i>P</i> value	0.0001	0.0001	0.001	0.01	0.13

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Table 2. Spearman correlations between body size and vertical stratification parameters in 2011–2012. * <math>P < 0.05</math>, ** <math>P < 0.01</math>, *** <math>P < 0.001</math>.

2011 2012	Head width	Body length	Height of the exuviae fixation	Support height	Ratio He/Hs
Head width	1	0.45***	0.08	0.04	0.02
Body length	0.44***	1	0.06	0.06	0.11
Height of the exuviae fixation	0.25*	0.15	1	0.60***	0.53***
Support height	0.22	0.12	0.66***	1	-0.24**
Ratio He/Hs	0.14	0.09	0.03	-0.61***	1

November. A small proportion of individuals entered the winter in the final instar larva but most of them presented substantial variation in size (F-7 to F-1). During the period prior to emergence (March–April), two cohorts could be identified: one consisted mainly of F-0 to F-1 larval instar and the other consisted of smaller individuals from F-3 to F-8. In July, the three last instar larvae were not collected.

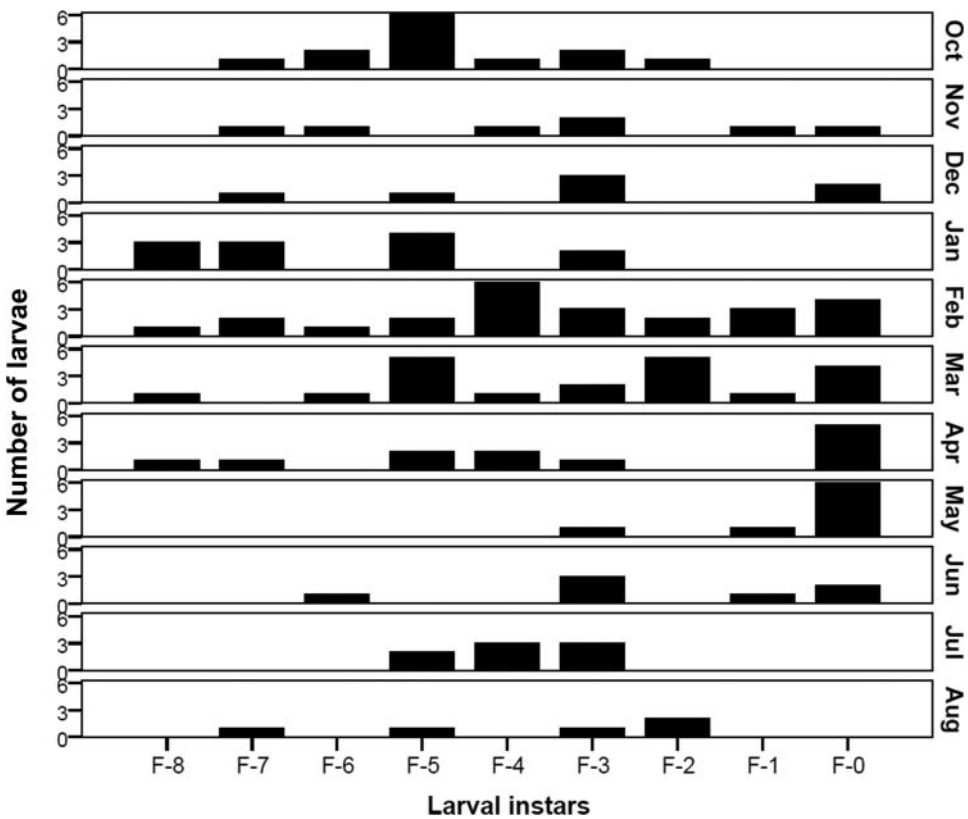


Figure 3. Frequency distribution of *Onychogomphus costae* Selys, 1885, larval instars from the Seybouse River collected monthly in 2011 and 2012. No larva was collected in September.

Discussion

Our two years of surveys on larvae and exuviae of the Mediterranean endemic *O. costae* highlighted important information on its seasonal regulation and temporal pattern of emergence in northeastern Algeria. Emergence pattern of *O. costae* was typical of a 'summer species' according to Corbet's (1954) classification. EM50 was not markedly different between the two study years (22 and 25 days) and it was similar to that of *O. uncatus* in Canal de Vergière (25 days) in southern France (Suhling 1995), *Gomphus flavipes* Charpentier, 1825 (23 days) in northeastern Hungary (Anna, Tibor, and György 2009), and *Coenagrion mercuriale* Charpentier, 1840 (22 days) in southeastern Britain (Purse and Thompson 2003). The whole emergence period lasted approximately two months (68 and 58 days) but it was 10 days shorter in the second year of study probably because of inter-annual variation in water temperature (Suhling 1995). Species with comparable emergence duration are *O. uncatus* (62–74 days, Suhling 1995), *G. flavipes* (72 days, Anna et al. 2009), and *C. mercuriale* (63 days, Purse and Thompson 2003).

A small sexual difference in emergence rhythm (1–2 days) was noted in both years. In fact, females reached EM50 earlier than males. The opposite trend was observed in *Gomphus lucasii* in the same site (Zebsa, Khelifa, and Kahlerras submitted for publication) and *G. flavipes* and *Ophiogomphus cecilia* (Fourcroy, 1785) in Hungary (Anna et al. 2009). Sex ratio of *O. costae* at emergence was slightly male biased, similar to that of *Gomphus lucasii* (Zebsa et al. submitted for publication) but not consistent with most studies on gomphids (Corbet 1962; Miller 1964; Lutz and McMahan 1973; Testard 1975; Beutler 1986; Suhling 1995). Differences in mortality and/or microhabitat use of larvae might be the reason of the biased sex ratio (Purse and Thompson 2003).

Studies have shown that mortality at emergence was usually small (<5%) with respect to the entire emerging population (Bennett and Mill 1993; Corbet 1999) but could also exceed 25% in some cases (Gribbin and Thompson 1991). In the current study, 8.5% of emerging individuals died by predation and deformity and this was higher than percentage mortality of *O. uncatus* (5.2%) in France noting that most mortality was due to heavy wind killing individuals before completing ecdysis (Jakob and Suhling 1999).

During emergence, odonates choose suitable microhabitat which encompasses a set of components including support type and height, position on the support, and vicinity to the water before undergoing their ecdysis (Ubukata 1973; Corbet 1999) to minimise the likelihood of mortality (Jakob and Suhling 1999). Vertical stratification of *O. costae* varied between years showing higher stratification in the second year when bank vegetation was denser and higher. Such significant difference in vertical stratification between years could be explained by the positive correlation of height of the exuviae fixation and support height. Height of the exuviae fixation of *O. costae* had a mean of 7.19 ± 5.93 cm which was smaller than that of *O. uncatus* (17.40 ± 4.27 cm, $N = 5$) in Spain (Cordero 1995). In addition, females climbed higher on the support than males probably because of their larger size. Similar sexual variation in vertical stratification was observed in *G. lucasii* (Zebsa et al. submitted for publication).

It is not clear whether the species life cycle is exclusively or partially semivoltine because the cohorts of consecutive years are not well defined in the pre-wintering period. However, considering the high variability in size before the winter as well as the species direct embryonic development (R. Zebsa, unpublished data), the species could have a partial semivoltine life cycle which is relatively different from the completely semivoltine population of southern Spain (Cano-Villegas and Ferreras-Romero 2005). The proportion of final instar larvae increased gradually from November to May which suggests that some larvae (F-2 and F-1) slowly continued to develop in the winter and early spring until

emergence, probably because they have lower temperature threshold for development than F-0 (Suhling 1995). This assumption explains the long emergence season followed by a long flight period extending up to September (R. Khelifa, personal observation). On the other hand, smaller larvae (F-8 to F-3) continue their growth until their second autumn when they reach F-0 larval stage which overwinter and emerge in late spring.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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