Aquatic Invasions (2011) Volume 6, Issue 3: 339–345
doi: 10.3391/ai.2011.6.3.10

Research Article

The Iraqi crab, *Elamenopsis kempi* in the Panama Canal: distribution, abundance and interactions with the exotic North American crab, *Rhithropanopeus harrisii*

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Received: 8 February 2011 / Accepted: 13 April 2011 / Published online: 13 May 2011

Abstract

We report on the distribution and abundance of the Iraqi crab *Elamenopsis kempi* in the Panama Canal and investigate possible interactions of this species with another invader, the North American mud crab, *Rhithropanopeus harrisii*. While more widespread than *R. harrisii, E. kempi* is currently limited to four locations within the Canal area: the Miraflores Lake, the Miraflores Spillway, the Southern Lagoon and the Northern Lagoon. Crabs reached peak abundances November through February. Where the two crab species overlap, the abundance of *E. kempi* was negatively associated with that of *R. harrisii*. Average *E. kempi* densities were significantly higher in cores with vegetation than those without vegetation. Laboratory experiments indicated that *R. harrisii* readily eats *E. kempi*, but that the presence of aquatic vegetation reduces predation rates. After four days, all *E. kempi* in treatments without vegetation were eaten, whereas only 53% of crabs were eaten in treatments with vegetation. *Elamenopsis kempi* is a small cryptic crab that can be easily overlooked even when abundant, suggesting that it may be more widespread than is currently reported.

Key words: *Elamenopsis kempi*, *Rhithropanopeus harrisii*, Panama Canal, introduced species, biological invasions, predation

Introduction

The Isthmus of Panama has been a hub for global commerce since the fifteenth century and its significance has expanded greatly since the opening of the Panama Canal in 1914 (Ruiz et al. 2009). Shipping is an important vector for aquatic invasions and the Panama Canal is considered to be a focal point for the dispersal of species around the globe (Cohen 2006; Kaluza et al. 2010). Currently, despite exceedingly high levels of shipping activity in this region (over 13,000 ships annually), relatively little is known about potential aquatic and coastal invasions in the area (Cohen 2006; Ruiz et al. 2009). The Canal, therefore, provides an ideal location to examine potential aquatic invasions and evaluate possible interactions between introduced species.

Recently, populations of the introduced North American Harris mud crab, *Rhithropanopeus harrisii* (Gould, 1841) were discovered in two brackish water lagoons adjacent to the Panama Canal near the Pacific Ocean (Roche and Torchin 2007; Roche et al. 2009). Concurrent with the discovery of *R. harrisii*, we also encountered reproducing populations of the cryptic Iraqi crab, *Elamenopsis kempi* (Chopra and Das, 1930) (Figure 1), in and around the Panama Canal.

Elamenopsis kempi is a false spider crab in the family Hymenosomatidae - small, cryptic brachyurans which are poorly studied and often overlooked although they can reach very high abundances (Lucas and Davie 1982; Chuang and Ng 1994). Abele (1972) first reported the presence of this crab in the Pedro Miguel Locks of the Panama Canal in 1969 and considered it to be introduced. Later, in the mid 1970's Abele and Kim (1989) found individuals of *E. kempi* in the Miraflores and Pedro Miguel Locks. Previously, *E. kempi* had only been reported from the brackish Shatt Al-Arab river system at the confluence of the Tigris and Euphrates rivers in Iraq, its native range (Chuang and Ng 1994; Ali et al. 1995; Cohen 2006). Interestingly, subsequent biological surveys in the Panama Canal do not report the presence of this crab, although it could easily have been overlooked

Figure 1. *Elamenopsis kempi* from the Northern Lagoon. Scale bar = 1 mm (Photograph by Dominique Roche).

due to its very small size. In June 2007, we found *E. kempi* to be established at several sites in the Canal area (Figure 2), nearly forty years after Abele's (1972) initial discovery. Here, we evaluate both the distribution and abundance of *E. kempi* in the Panama Canal area and the potential for interactions with the introduced mud crab, *R. harrisii*.

Materials and methods

The Panama Canal serves as an aquatic corridor between the Pacific and the Atlantic Oceans, allowing ships to transit the Isthmus of Panama via three sets of locks and a man made freshwater lake, which is thought to limit the movement of marine species across the Isthmus (Cohen 2006). Located adjacent to the Miraflores Locks, near the Pacific entrance of the Canal, are two manmade lagoons, excavated during an abandoned project to expand the Canal in the 1940's: the Northern Lagoon and the Southern Lagoon (Figure 2). During the course of this study, salinities varied between 2.1 and 4.3 PSU in the Southern Lagoon and between 0.4 and 0.6 PSU in the Northern Lagoon (see also Roche et al. 2009).

Distribution and abundance

We employed three sampling procedures to evaluate the distribution and abundance of *Elamenopsis kempi.* First, we conducted a transect across the Panama Canal to determine the overall distribution of the crab in the waterway. Second, we sampled monthly in the Northern and Southern Lagoon, to examine seasonal variation in its abundance. Third, we used cores to compare crab densities in substrate with and without vegetation in the Northern Lagoon.

To evaluate the distribution and abundance of *E. kempi* across the Panama Canal, we used the same methodology employed for quantifying the abundance and distribution of *R. harrisii* (Roche et al. 2009). We used standardized collecting units (plastic mini-crates filled with bivalve shells - approximately 8L) which are not baited but provide crabs with substrate for colonization. Between July 2007 and April 2008, a total of 179 collecting units were deployed at 12 sites transecting the Canal (see Figure 2a). Ten collecting units per site were randomly deployed; sampling at some sites had to be repeated due to the loss of some of the collectors. Collecting units remained in the field for a period of four weeks and were returned to the lab for subsequent analysis. We recorded the number of crabs (catch per unit effort - CPUE), crab size (carapace length - cl) and sex. All specimens were preserved in 95% alcohol.

Using the same methodology, we sampled the Northern Lagoon and Southern Lagoon on a monthly basis from November 2007 to February 2009 by deploying one collecting unit at each of 5 accessible sites. Because of ongoing excavation work and restrictions in accessing

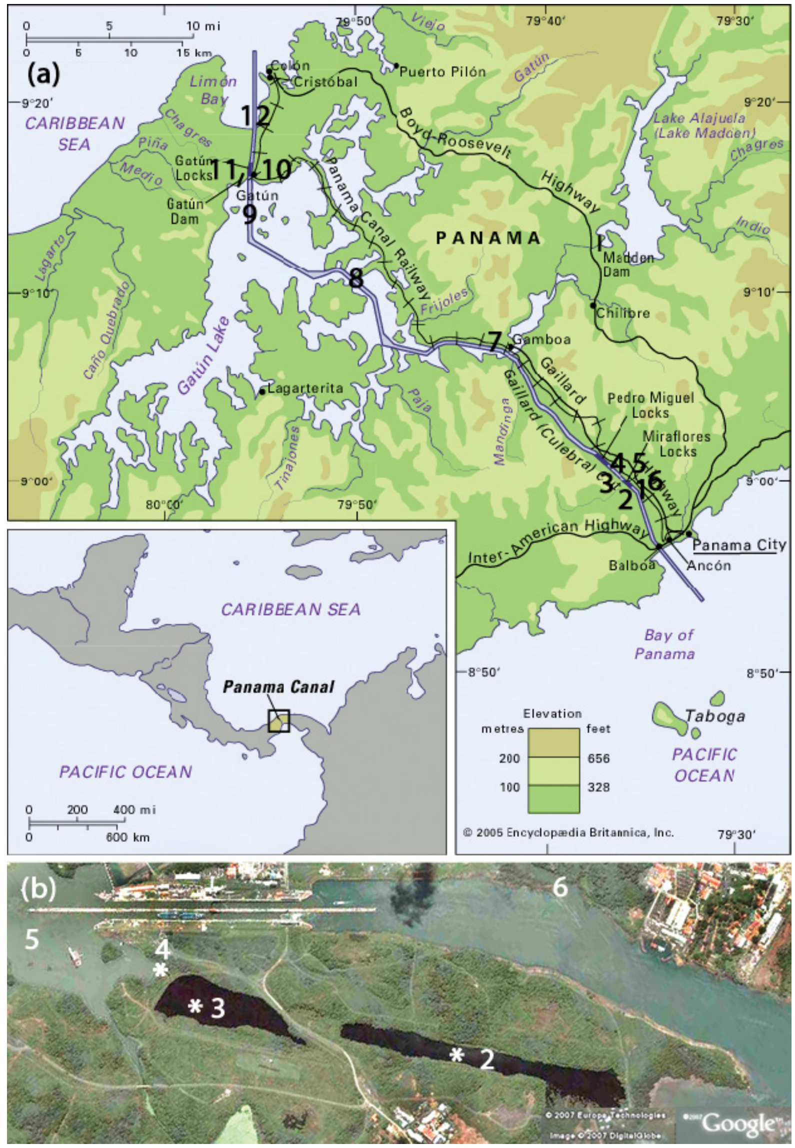

Figure 2. Map of the Panama Canal with sites surveyed for *Elamenopsis kempi* 1. Pacific approach; 2. Southern Lagoon; 3. Northern Lagoon; 4. Culverts at the Miraflores Lake; 5. Miraflores Lake; 6. Miraflores Spillway; 7. Gatun Lake – Gamboa; 8. Gatun Lake - Barro Colorado Island; 9. Gatun Lake - Gatun Locks; 10. Gatun Third Lock Lagoon; 11. Gatun Spillway and French Canal; 12. Atlantic approach. By courtesy of Encyclopaedia Britannica, Inc., copyright 2005; used with permission. (b) Inset of the Miraflores Third Lock Lagoons adjacent to the Miraflores Locks (modified from Roche et al. 2009). Numbers indicate sites with *E. kempi* presence, stars indicate sites with *Rhithropanopeus harrisii* presence.

some of our sites along the Panama Canal over the study period, we were unable to coordinate the timing of our different sampling procedures. Due to variation in the time and intensity of sampling between locations and since the data were non-normally distributed, we used a factorial generalized linear model with a Poisson distributed error term, a log link function and an overdispersion parameter estimated by Pearson's X^2 to compare catch per unit effort (CPUE) and test for differences in the relative abundance of crabs between the Northern Lagoon and the adjacent Miraflores Lake (the two locations where we encountered established populations of *E. kempi*).

To evaluate the association between the abundance of *E. kempi* and that of *R. harrisii* at the site where populations of the two species co-occur, we deployed one collecting unit at each of 10 randomly chosen sites in the Northern Lagoon. The units were deployed on 15 January 2010 and remained in the field for four weeks.

We compared the CPUE at each site within the Northern Lagoon using a least squares general linear model since the data met the assumptions of the test.

Densities

In March 2009, we sampled four sites which were accessible by land in the Northern Lagoon to compare the density of crabs in substrate with and without vegetation. Depending on the area of accessible substrate, we took a minimum of 4 and a maximum of 16 large circular cores ($0.2m^2 \times 10cm$) at each site in both vegetated and non-vegetated substrate. We collected all sediment, debris and vegetation within each core and transported the samples to the laboratory for processing. We sieved the sediment sequentially through 5 mm and 1 mm sieves. Vegetation and debris were separated and sorted to search for *Elamenopsis kempi*. Crabs were measured, sexed and preserved in 95% ethanol. To test for differences in the density of crabs between substrate with and without vegetation, we used a factorial generalized linear model as above.

Laboratory experiments

Elamenopsis kempi is common among branching water plants in its native range (Ali et al. 1995) and we suspected that the complex branching vegetation would provide refuge from predation for this cryptic crab. To examine whether the presence of vegetation reduced predation of *E. kempi* by *R. harrisii*, we conducted a laboratory experiment. We placed one crab of each species (ranging from 3.2 to 4.5 mm for *E. kempi* and 10.6 to 20.27 mm for *R. harrisii*) in 30 glass fingerbowls (10 cm in diameter) containing 1 cm of sediment and 300 ml of water from the Northern Lagoon. In 15 of the fingerbowls, we placed three 10 cm strands of *Montrichardia arborescens* (L.) Schott, the most common aquatic plant associated with *E. kempi* in the Canal; the other 15 fingerbowls were devoid of vegetation. Individual *E. kempi* stayed within the branching network of *M. arborescens* strands during the experiment, while *R. harrisii* primarily remained on the surface of the sediment. We observed crabs and recorded predation events twice a day for four consecutive days. We compared treatments with and without vegetation using a one-tailed Fisher's exact test and a logistic regression model, with vegetation treatment, *R. harrisii* sex and the size ratio of *R. harrisii* and *E. kempi* as independent variables. In trials where crabs were eaten, we used a non-parametric Kruskal-Wallis chi-square approximation to compare the time it took *R. harrisii* to eat crabs in trials with and without vegetation because the data were not normally distributed.

Results

Distribution and abundance

We recovered 370 of the 452 collecting units deployed across the Panama Canal over a period of three years. In total, 641 *Elamenopsis kempi* were captured in these units. We found *E. kempi* at four locations within the area of the Panama Canal; the Miraflores Lake (MFL), the Miraflores Spillway (MS), the Southern Lagoon (SL) and the Northern Lagoon (NL) (Table 1; Figure 2b). *E. kempi* appeared to be established solely in the Miraflores Lake and in the Northern Lagoon, as these were the only locations where we found large numbers of crabs including ovigerous females and juveniles. The mean CPUE was not significantly different between the Northern Lagoon (5.5 crabs per collector, n=91) and the Miraflores Lake (2.9 crabs per collector, n=36) (X^2 = 1.94, *df* = 1, *P* = 0. 16) but varied considerably across time (Figure 3, X^2 = 9.4, *df* = 1, *P* = 0.002). The effect of collection date on CPUE was consistent across sites (interaction non-significant, X^2 = 2.53, *df* = 1, *P* = 0.11). In general, *E. kempi* was most abundant along the shoreline, often associated with aquatic plants (*M. arborescens* and *Hydrocotyle* sp.) as well as with roots of the invasive grass, *Saccharum spontaneum* (L.). While we did encounter *R. harrisii* on the surface of mud and sediment lacking vegetation, we rarely encountered *E. kempi* in areas without vegetation.

Density

In the Northern Lagoon, the density of *E. kempi* in substrate with vegetation (*M. arborescens* and *S. spontaneum*) was significantly higher (mean 174 crabs per m^2) than in substrate without vegetation (mean 0.5 crabs per m^2) (X^2 = 61.47, *df* = 1, *P* = 0.0001). The density of crabs also varied significantly between the four sites sampled (X^2 = 10.37, *df* = 3, *P* = 0.016) but there was no interaction between site and substrate (X^2 = 0.50, *df* = 3, *P* = 0.78).

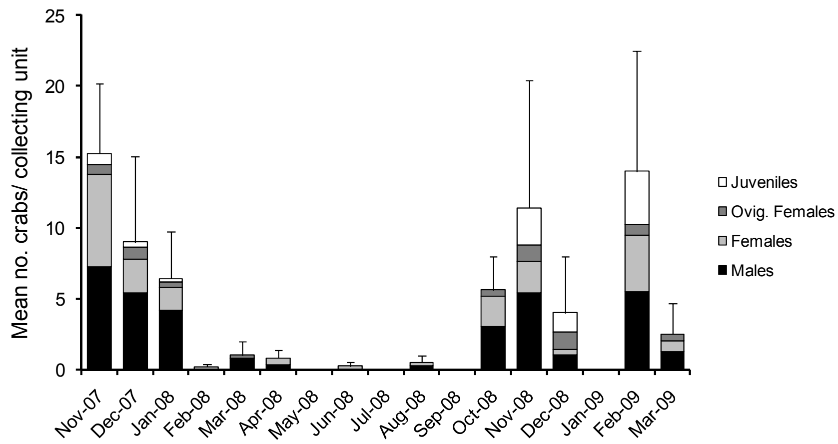

Figure 3. Mean number of *Elamenopsis kempi* per sex and life stage per collecting unit (CPUE) in the Northern Lagoon between November 2007 and March 2009. Error bars are SE for the mean number of crabs per collecting unit.

Table 1. Sites sampled and number of collecting units analyzed to assess the mean number of crabs per collector (CPUE) (and standard error SE) of *Elamenopsis kempi* (*E. k.*) in the Panama Canal.

Site	General Coordinates	Coll units	Mean *R.h.*	SE	Mean *E. k.*	SE
	Latitude, N; Longitude, W		per unit		per unit	
Pacific Approach	08º58'37" 79º35'02"	74	0	0	0	0
Southern Lagoon	08º59'03" 79º35'18"	100	27.93	3.88	0.02	0.01
Northern Lagoon	08º59'38" 79º35'41"	91	29.71	3.79	5.5	1.0
Culvert Miraflores Lake	08º59'45" 79º35'42"	28	4.76	1.85	0.72	0.23
Miraflores Lake	09º00'28" 79º36'05"	35	0.09	0.05	2.92	0.98
Miraflores Spillway	08º59'41" 79º35'06"	12	0	0	0.92	0.74
Gatun Lake – Gamboa	09º07'12" 79º42'58"	5	0	0	0	0
Gatun Lake – BCI	09º09'55" 79º50'03"	10	0	0	0	0
Gatun Lake at Gatun Locks	09º15'43" 79º55'24"	21	0	0	0	0
Gatun Third Lock Lagoon	09º16'52" 79º54'49"	7	0	0	0	0
Gatun Spillway/French Canal	09º15'51" 79º56'01"	7	0	0	0	0
Atlantic Approach	09º17'30" 79º54'54"	5	0	0	0	0

Interactions with Rhithropanopeus harrisii

In the Northern Lagoon, where populations of *E. kempi and R. harrisii* overlap, the abundance of *E. kempi* was negatively associated with that of *R. harrisii* (Figure 4, R^2 = 0.53, *F* = 8.9, *df* = 1, *P* = 0.017), however this association was driven by two data points. Additionally, our laboratory experiment revealed that *R. harrisii* readily preyed on *E. kempi*. After four days, all individual *E. kempi* in treatments without vegetation were eaten, whereas only 53% of crabs were eaten in treatments with vegetation (Figure 5, one-tailed Fisher's exact test, X^2 = 11.9, *df* = 1, *P* < 0.0032). All *R. harrisii* survived the experiment. When we examined the number of *E. kempi* eaten in more detail using a full factorial logistic regression model, accounting for *R. harrisii* sex and the size ratio between *R. harrisii* and *E. kempi*, only the vegetation treatment had a significant effect on crab survival (X^2 = 11.8, *df* = 1, *P* = 0.0006). Sex of *R. harrisii* (X^2 = 0.12, *df* = 1, *P* = 0.73) and size ratio of crabs (X^2 = 0.004, *df* = 1, *P* = 0.95) had no effect on the survivorship of *E. kempi* and none of the interaction terms were significant (all *Ps* > 0.05). There was no difference in the average time period that crabs were eaten in the treatment with (2 days) or without (1.7 days) vegetation (X^2 = 1.2, *df* = 1, *P* = 0.27).

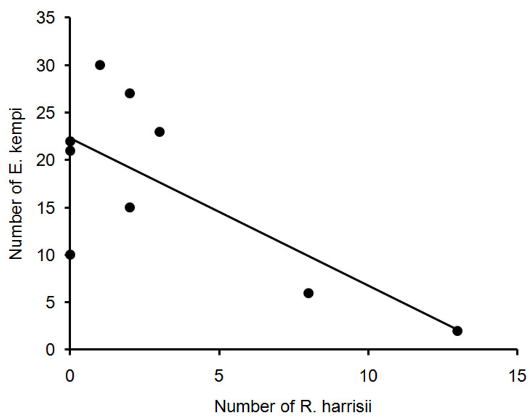

Figure 4. The association between the number of *Rhithropanopeus harrisii* and *Elamenopsis kempi* in the Northern Lagoon in March 2009 ($R^2 = 0.53$, $P = 0.017$).

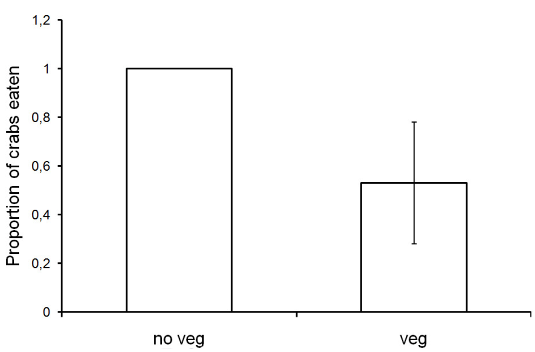

Figure 5. The proportion of *Elamenopsis kempi* eaten by *Rhithropanopeus harrisii* in experimental treatments with and without vegetation. Error bars are 95% confidence intervals.

Discussion

The Iraqi crab *Elamenopsis kempi* was common in some areas on the Pacific side of the Panama Canal. It was particularly abundant in locations with vegetation, especially on the roots of aquatic plants and in shallow water, and where the salinity was relatively low (0.4 to 0.6 PSU). In 1969, Abele (1972) first reported the presence of *E. kempi* in the Pedro Miguel Locks, and again, later, in the Miraflores and the Pedro Miguel Locks (Abele and Kim 1989). Our study confirms that reproducing populations of this species are currently established in Panama, both in the Miraflores Lake and in the Northern Lagoon. We used a standardized quantitative approach to determine whether *E. kempi* was restricted to certain regions of the Panama Canal. While we found that this species is more abundant and widespread than reported by Abele (1972) and Abele and Kim (1989) 40 years ago, established, reproducing populations appear to be restricted to the Miraflores Lake and the Northern Lagoon. Although crabs were common in the Northern Lagoon, their abundance varied considerably across time, with the highest mean CPUE recorded between October and February. This pattern is consistent with trends in *E. kempi's* native range, where the crab's abundance peaks between the months of October and December (Ali et al. 1995).

Salinity is likely to be an important factor limiting the distribution of *E. kempi* in the Panama Canal. In its native range in Iraq, the crab is found in salinities ranging from 1.29 to 2.69 PSU (Ali et al. 1995). Salinities in the Miraflores Lake (0.4–0.6 PSU) and the Northern Lagoon (0.4 PSU) appear to provide a suitable breeding habitat for this species, yet neighboring locations may not. Salinities are higher in the Pacific approach to the Canal (19.9 PSU) south of the crab's current distribution, and lower in Gatun Lake (0.1 PSU) to the north. Interestingly, however, we found relatively few crabs in the Southern Lagoon, a habitat which should be suitable for the crab given salinity levels which varied between 2.1 and 4.3 PSU. The low abundance of crabs in this lagoon could be explained by a lack of abundant aquatic vegetation and perhaps higher rates of predation by the North American mud crab, *R. harrisii*, which is very abundant in the Southern Lagoon (Roche et al. 2009). We also found *E. kempi* in the channel below the spillway of the Miraflores Locks, adjacent to the Miraflores Lake. However, we suspect that these crabs were flushed out of the lake through the opening of the spillway and that *E. kempi* is not established there.

Our findings suggest that *E. kempi* reaches higher densities in vegetated habitats relative to habitats without vegetation. In the Northern Lagoon, crabs were uncommon in mud, while they were abundant in vegetated areas. Ali et al. (1995) also report that *E. kempi* is generally associated with branches of aquatic plants in its native range, particularly *Ceratophyllum* sp., and can attain high densities, sometimes exceeding 1000 crabs per m^2 during periods of peak abundance. This number is approximately seven times the mean density recorded in the Northern Lagoon throughout the course of our study. However, we sampled crabs to obtain density measures during the month of March, a period of low abundance in Panama (Figure 3). It is also noteworthy that the maximum density observed in one of our cores was 1065 crabs/m^2, similar to peak densities observed by Ali et al. (1995) in Iraq. Interestingly, *Ceratophyllum* sp. is also introduced in the Panama Canal, but it was uncommon in our samples and never associated with *E. kempi*.

R. harrisii co-occurs with *E. kempi* in the Northern Lagoon and we found a negative relationship between the abundances of the two crabs there. We also observed that *R. harrisii* readily preys upon *E. kempi* in the laboratory. Our experiments indicated that *E. kempi* was eaten more frequently in treatments where vegetation was absent compared to treatments where it was present. Aquatic plants may therefore provide an important refuge for *E. kempi* against predation by *R. harrisii* as well as other potential predators such as native crabs and fishes. The absence of refuge could partially explain the low numbers of *E. kempi* observed in the Southern Lagoon, where suitable vegetated habitat is limited and *R. harrisii* is common (Roche et al. 2009). In contrast, in the Northern Lagoon, the presence of submerged aquatic vegetation may favor the coexistence of these two crab species.

It is unknown how long *E. kempi* may have been in Panama prior to 1969 given that it is a small, cryptic crab that can be easily overlooked even when abundant (Lucas and Davie 1982). Abele (1972) speculated that *E. kempi* may have been introduced to Panama with the aquatic weed, *Hydrilla verticillata* (L.f.) Royle, whereas Dawson (1973) and Carlton (1985) suggest it could have arrived via ballast water. The Panama Canal Authority (ACP) maritime regulations prohibit ballast discharge into Canal waters. However, to our knowledge, ballasting operations in Panama have not historically been reported or quantified. While we cannot ascertain the exact mechanism of introduction to Panama, *E. kempi* was common in some parts of the Panama Canal, including the Miraflores Lake, where ships currently transit. Its absence in other reports of biological surveys of the Panama Canal probably reflects its small size and cryptic nature which makes it easily overlooked.

Acknowledgements

We are grateful to the Autoridad del Canal de Panama for granting access to restricted sites in the Canal and to M. Calderon, F. O. Guardia, H. Broce and D. Muschett for providing comments on the manuscript, assistance in the field as well as information on the Panama Canal. We thank O. Miura, C. Mabin and M. Strader for help in the field and M. Sytsma for plant species identification. J. Carlton and two anonymous reviewers provided useful comments on the manuscript. We acknowledge the Secretaria Nacional de Ciencia, Tecnología y Innovación de Panamá (SENACYT), Smithsonian Tropical Research Institute and Smithsonian Marine Science Network for financial support. We acknowledge the Autoridad Nacional del Ambiente de Panama and the Autoridad de Recursos Acuáticos de Panama for providing applicable permits in Panama.

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