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The Asian decapod *Hemigrapsus penicillatus* (de Haan, 1835) (Grapsidae, Decapoda) introduced in European waters: status quo and future perspective

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ABSTRACT: The Asian decapod *Hemigrapsus penicillatus* (de Haan, 1835) was first recorded in European waters in 1994. The first specimens were collected in the estuary of Charente Maritime on the west coast of France close to La Rochelle. The current range in Europe covers Spanish shallow water habitats of the Bay of Biscay to areas north of La Rochelle (France). Densities of up to 20 specimens per square metre occur. This species has a high temperature and salinity tolerance and will expand its distribution in European waters. It is not clear whether this crab was introduced by shipping in ballast water or as a fouling organism. Based on a study of ship hull fouling in German dry docks this account provides evidence that hull fouling is a likely vector for the introduction of this crab. In August 1993, six juvenile specimens of *H. penicillatus* were removed from the hull of a car-carrier. After its journey from Japan into European waters this vessel docked in the port of Bremerhaven (Germany) for a routine inspection and coating with antifouling paint.

INTRODUCTION

More than 100 non-indigenous species occur in European waters and many of these document the introduction of species by anthropogenic support. Shipping has been indicated as a major vector of introduction. Two principle means that enable effective transport of exotic species with ships are known: ballast water and hull fouling (Carlton & Geller, 1993). The first non-indigenous species which is believed to have been introduced with ballast water into the North Sea, the diatom *Biddulphia* (*Odontella*) *sinensis*, bloomed in 1903 (Ostenfeld, 1908). Ballasting ships with water at sea is general practice today. The technique was developed in the late nineteenth century as a more efficient way than any previous means using stones, sand or any other solid ballast material. The volumes of ballast water transported are considerable. Shortening sea journeys is likely to aid in more successful species introduction beyond their natural ranges.

Besides ballast water, hull fouling comes more and more into focus as a vector for species transportation and was considered to be the principal vector for species introduction (Hentschel, 1923; Pyefinch, 1950; Southward & Crisp, 1963; Gollasch & Riemann-Zürneck, 1996). The use of antifouling systems has reduced the number of specimens transferred, but shipping activity has increased drastically, thereby enabling larger volumes of ballast water and higher numbers of organisms to be transferred than ever before. As a consequence, probabilities of further species successfully establishing themselves in new habitats have also increased. It was generally believed that the use of organotin antifouling paints greatly reduced fouling intensity. However, fouling still remains an important vector of species transmission. *Hemigrapsus penicillatus* was found in ship hull samples taken during a German shipping study, indicating hull fouling as the possible introducing vector of the species to European waters. This is the first record of this species from a ship's hull. Due to the high temperature and salinity tolerance of the species, further spread in European waters is expected.

MATERIALS AND METHODS

During a German shipping study the ballast water, tank sediments and ship hulls of ocean-going vessels were sampled. During a period of 4 years 131 ship hulls of vessels newly docked were sampled in the German shipyards of Hamburg and Bremerhaven (Gollasch 1996; Lenz et al., in press). Among them was the car-carrier SPICA, built in 1981, which is able to transport a maximum of 5900 cars. The vessel is approx. 14 000 dead weight tonnes (DWT), nearly 190 m long and 32.2 m wide. The maximum summer draught is 8.82 m. The estimated surface covered by water is 6500 m^2. Its average cruising speed of 17 knots enables this vessel to provide a regular service, calling at European ports every 3 months. On its way from Asia to Europe the ship visits the ports of Tokyo, Osaka, Kobe (Japan), and Pusan (Korea), crosses the Indian Ocean and passes through the Suez Canal before docking at the port of Bremerhaven.

Samples were collected on 14 August 1993, 1 h after the ship had been docked in Bremerhaven. The sampling points on the vessel's surface were randomly chosen; three samples of 10 by 10 cm were scraped off from the fouled surface near the bow. The thickness of the fouling covering the hull at the sampling sites varied from 2 to 7 cm. The species found were preserved with 70% ethanol.

RESULTS

A total of six living specimens of *H. penicillatus* (Fig. 1), two males and four females, were identified from the three hull fouling samples. The specimens were obtained in two of the three samples removed from the bow area of the ship. All specimens were in a good condition despite the fact that the ship was in the dry-dock for about 1 h while also exposed to brackish water conditions (salinity at the dock site usually between 12‰ and 24‰).

None of the female specimens were ovigerous. The width of the carapace ranged from 8 to 11 mm. All species were found in empty shells of the barnacle *Balanus amphitrite* or *B. perfortatus* and on sheltered regions (with respect to currents) of the hull shown by an overgrowth of mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas*). The fouling community of macrozoobenthos species covered nearly 10% of the permanently submerged ship surface (about 650 m^2). At the sampling sites the total hull coverage with fouling ranged from 60% to 90%.

The German shipping study revealed in total 150 species non-indigenous to the North Sea and the Baltic, found either in ballast water, tank sediments or associated

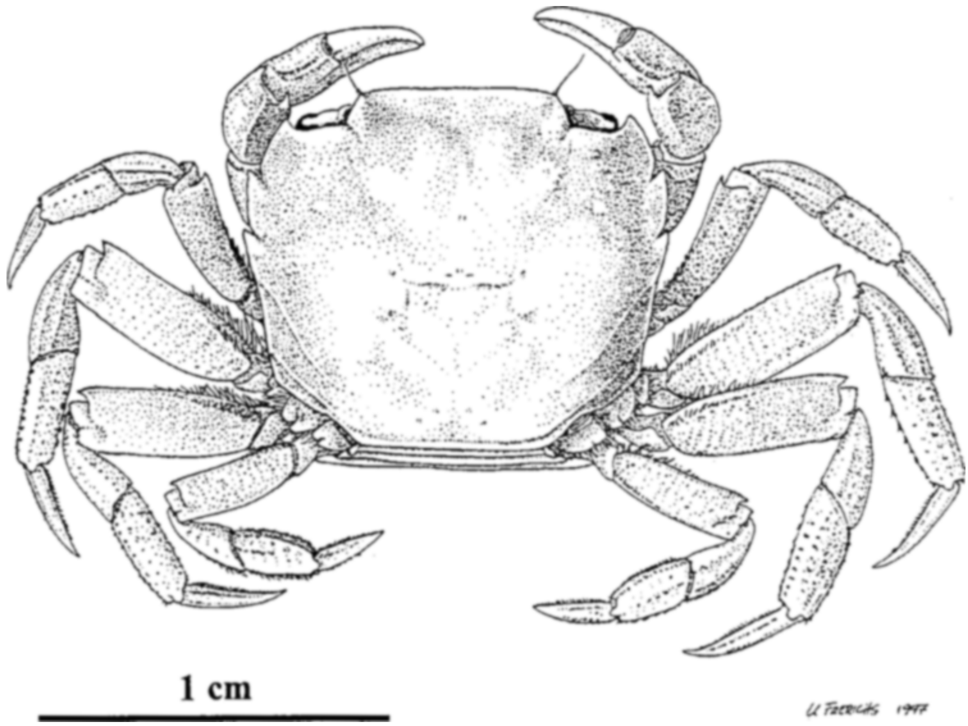

Fig. 1. *Hemigrapsus penicillatus* from the French coast. Drawn by Ursula Frerichs (Zoologisches Institut und Zoologisches Museum, Hamburg)

with hull fouling. Crustacea were the most abundant taxonomic group, followed by Mollusca. Eight decapod species were found, including three grapsid crabs: *Brachynotus sexdentatus*, *H. penicillatus* and *Pachygrapsus gracilis* in the hull samples (Gollasch, 1996; Lenz et al., in preparation).

This is the first direct observation of long-range transmission and survival of *H. penicillatus* on a ship hull of a fast ocean-going vessel.

DISCUSSION

Several decapods have been introduced by means of shipping to new localities around the world. Examples are the green crab *Carcinus maenas* (native to Europe) (Alcock, 1899; Pollard & Hutchings, 1990; McDermott, 1991; Hedgpeth, 1993; Jackson, 1993), the Chinese mitten crab *Eriocheir sinensis*, established in Europe since 1912 (Peters et al., 1936; Eno et al., 1997), and occasional findings of the blue crab *Callinectes sapidus* (den Hartog & Holthuis, 1951; Kühl, 1965; Christiansen, 1969; Holthuis, 1969) as well as other decapods, e.g. *Processa aequimana* (Walford & Wicklund, 1973) and *Rithropanopeus harrisii* (Christiansen, 1969; Walford & Wicklund, 1973; Eno et al. 1997) which are believed to have been introduced by ships (Carlton, 1985).

After the first European record of a 1-year-old specimen of *H. penicillatus* in 1994, found in the area of Charente Maritime close to La Rochelle, Noël (1997) and Noël et al. (1997) believed that the introduction of the species must have taken place in 1993.

Vectors of introduction

In 1993 the car-carrier under study passed the French coast unintentionally transporting probably several hundreds of specimens of *H. penicillatus*. It is likely that this particular vessel could have been a vector for the introduction of this species into French waters. It is assumed that specimens dropped of the bottom of the ship in sufficient numbers to generate a new population. There may be different reasons for the specimens being washed away from the ship's hull: mechanical reasons (scratched away by floating objects such as wood or plastic) or the lack of food available on the ship's hull, which made migration to another habitat necessary.

Although the hull of only one of 131 sampled vessels contained *H. penicillatus*, the finding of six specimens from 0.3 m^2 of hull surface is significant. The behaviour of *H. penicillatus* living beneath stones and rocks in its native habitat suggested that homing in empty shells of barnacles was likely. A Japanese investigation showed that *H. penicillatus* was frequently found even in beverage cans (Ogura & Kishi, 1985). The behaviour of using sheltered habitats to protect itself against predators (Kurihara & Okamoto, 1987; Okamoto & Kurihara, 1987) and probably strong water currents offered, in addition, the possibility of becoming widely distributed on the hull of ships or other floating objects. There is a need to study the conditions with regard to currents, surface structure, microturbulence and drag forces under which crab species would be able to hold on to be successfully transported. Such data would be useful to evaluate the likelihood for success of transmission and enable us to determine criteria for hull surface management to reduce the survival of unwanted species.

Another potential introducing vector could have been the transport as larvae in the ballast water of ships – which has not (yet) been confirmed by sampling ballast water or sediments in ballast tanks during several shipping studies. It is assumed that the discharge of ballast water has caused the majority of species introductions worldwide (Carlton, 1985, 1991; Gollasch, 1996). During the 6-week voyage from Japan to Western Europe, the larval development of *H. penicillatus* could have been completed in the ballast tank. According to Ogura & Kishi (1985) the zoeal stage lasts 25 days at 20–22 °C or 16 days at 24–28 °C followed by a 6-day megalopa stage. However, it should be taken into account that the survival rate of specimens during interoceanic voyages is negatively influenced by potential mechanical damage during the pumping process involved in uptake and release of ballast water. Additionally, it is known that an increasing period of time in the ballast tank decreases the survival rate of zooplankton species (Gollasch et al., in press).

Imports of living specimens for aquaculture purposes are an additional well-known vector of species introductions. The area of the Charente estuary where *H. penicillatus* was first recorded (Noël, 1997; Noël et al., 1997), is one of the most important aquaculture sites for oyster culturing in the world. Associated with imports of living oysters, more than 100 non-target species have been transported unintentionally, ranging from protozoans, phytoplankton, and macroalgae to invertebrates (Bonnot, 1935; Kincaid, 1949; Korringa, 1951; Haigler, 1969; Miller, 1969; Kornicker, 1975; Edwards, 1976; Andrews, 1980; Farnham, 1980; Christiansen & Thomsen, 1981; Carlton, 1991; Minchin et al., 1993; Reise, 1993; Minchin 1996). However, no living adult oysters or oyster seeds have been imported to the Charente estuary over the last few decades. It is believed that if this species was introduced with the most recent oyster imports in the 1970s (Goulletquer, 1997, personal communication), it would not have been overlooked for such a long period of time. Therefore, this vector can be excluded.

Nevertheless, it is believed that *H. penicillatus* was introduced by fouling of ship hulls. During the German shipping study, specimens of *H. penicillatus* were determined in samples taken at exactly the time the estimated introduction of the species into European waters took place; the lack of introducing vectors e.g., imports of oysters, makes an introduction via hull fouling most probable. Australian results showed, in the same way as the results of the German shipping study, that the highest number of non-indigenous species carried by ships was not found in ballast water but in ship hull fouling (Gollasch, 1996; Hewitt, 1998, personal communication). Surprisingly, even a previously unknown species (*Cryptostylochus hullensis*, Plathelminthes) was found on the ship's hull during the German shipping study (Faubel & Gollasch, 1997).

Impacts

Williams (1996) and Simberloff et al. (1997) concluded that all non-indigenous species are potentially harmful. Possible impacts of the introduced crab are not yet known. Non-indigenous species can have several types of impact (direct, indirect and synergistic) on native species. The feeding of *Hemigrapsus* spp. on snails such as *Littorina* spp. (Boulding & Van Alstyne, 1993; Yamada & Boulding, 1996) and egg capsules of the gastropod *Nucella* spp. (Rawlings, 1990), on algae (*Enteromorpha* spp. and diatoms) and detritus under laboratory conditions (Okamoto & Kurihara, 1989) can lead to competition with native species, especially, during mass occurrences. It is believed that any species with a density of up to 20 individuals per meter square must have an effect on trophic relationships on the shore it has invaded. If there is no predation on other species, competition for space and possibly food could be a negative impact. Burrowing activities of decapod crabs could damage riverbanks or dikes, as happened in German waters during a mass occurrence of the introduced *Eriocheir sinensis* in the 1930s (Panning & Peters, 1932, 1933; Peters et al., 1936), but in the native area of the species *H. penicillatus* is not known to burrow into sediments. Further research in this field should focus on the competition by other macro-invertebrates such as *Carcinus maenas* and in estuaries by the Chinese mitten crab *Eriocheir sinensis*.

Spread

The native habitat of *H. penicillatus* ranges from northern Japan (cold-temperate climate) to China (warm-temperate climate) (Pillay & Ono, 1978; Dai & Yang, 1991; Noël et al., 1997; Türkay 1996, personal communication). Its native range of habitats includes muddy as well as rocky shores. The preferred habitat is under stones in the mid-littoral zone. Both estuaries and port areas are colonized (Okamoto & Kurihara, 1987). Up to six broods can be produced during a breeding season within its native range (Pillay & Ono, 1978).

Three years after the first record in Europe and 4 years after its introduction, *H. penicillatus* now occurrs locally in densities of up to 20 specimens per square metre (Noël et al., 1997). Because of the matching climates in the native distribution area of *H. penicillatus* and European waters and its high salinity tolerance (Kikuchi & Matsumasa, 1991), it is assumed that this species will spread further along the European coasts (Noël et al., 1997). The combination of temperature tolerance down to freezing point, tolerance of lower salinities and the high rate of reproduction explains the development of numerous specimens in a short period of time and a high rate of spread, as shown along the Atlantic coasts of France and Spain. Due to matching climate and abiotic conditions, it is predicted that *H. penicillatus* is enabled to colonize a wide range of habitats along the North Sea and western Baltic shores.

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