5 Waterways as Invasion Highways – Impact of Climate Change and Globalization

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5.1 Introduction

The earliest civilizations flourished on the banks of navigable rivers. Indeed, their first monumental hydrological construction projects were concerned with irrigation and transport: around 2200 B.C., the first navigable canal, the Shatt-el-hai, linking the Tigris and Euphrates rivers in Mesopotamia, was excavated; in the 6th century B.C., a canal was built that joined the Nile with the northern Red Sea, and in the 4th century B.C., the Grand Canal in China connected Peking to Hangzhou, a distance of almost 1,000 km. The technological innovations of the 18th century led to an expansion of the network of navigable inland waterways, followed in the 19th century and the early part of the 20th century by the excavation of two interoceanic canals: the Suez Canal, which opened a direct route from the Mediterranean Sea to the Indo-Pacific Ocean, and the Panama Canal, which afforded passage between the Atlantic and the Eastern Pacific oceans.

Canals connecting rivers over watersheds or seas across narrow land bridges "dissolve" natural barriers to the dispersal of aquatic organisms, thereby furnishing these with many opportunities for natural dispersal as well as for shipping-mediated transport. The introduction of alien aquatic species has proven to be one of the most profound and damaging anthropogenic deeds – involving both ecological and economic costs. Globalization and climate change are projected to increase aquatic bioinvasions and reduce environmental resistance to invasion of thermophilic biota. Navigable waterways serving as major invasion corridors offer a unique opportunity to study the impact of these processes.

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5.2 The Watery Web - Inland Waterways of Europe

The complex European network of inland waterways was created over a period of more than 200 years (see Ketelaars 2004 for review; Fig. 5.1). The network comprises over 28,000 km of navigable rivers and canals, and extends from the Atlantic Ocean to the Ural mountains, connecting 37 countries in Europe and beyond. This immense aquatic web connects previously isolated watersheds and has faciliated “all-water” transport from the Caspian and Black seas to the Baltic and North seas and beyond.

Four invasion corridors have been traced between the southern and the northern European seas (Jażdżewski 1980; Panov et al. 1999; Nehring 2002;

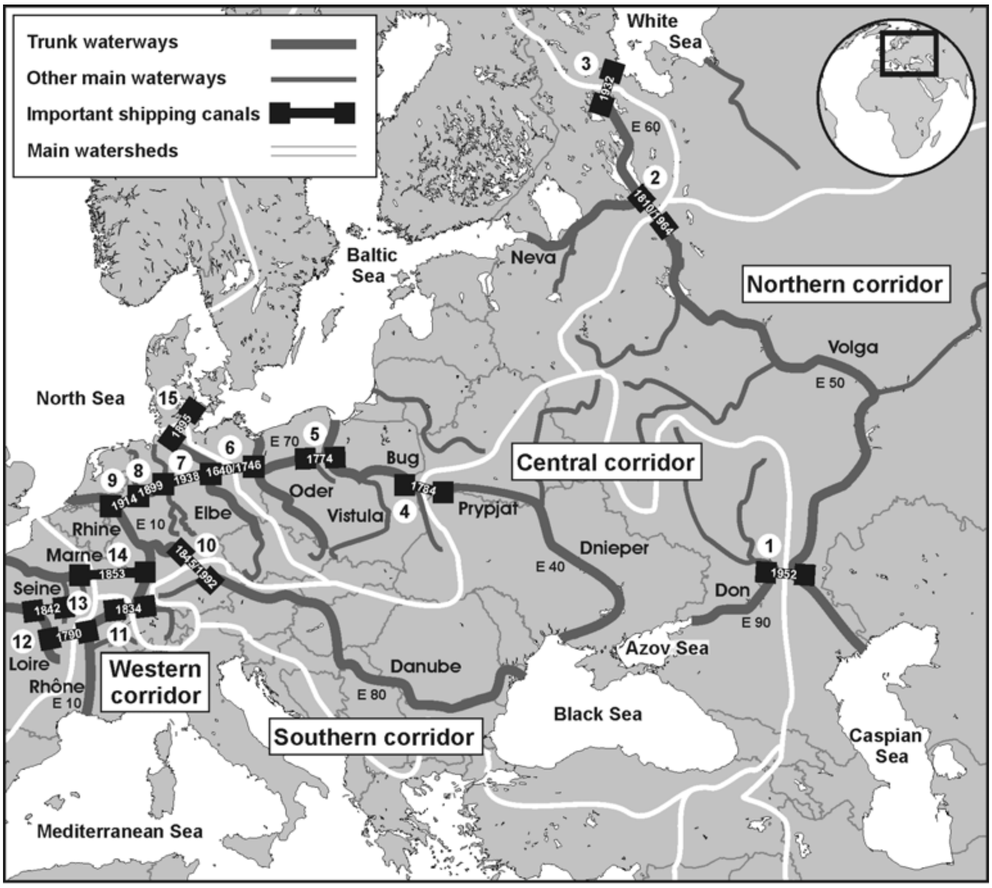

Fig. 5.1 Important European water ways and invasion corridors of aquatic species. Canal number: *1* Volga-Don Canal, *2* Volga-Baltic Canal, *3* White Sea - Baltic Sea Canal, *4* Bug-Prypjat Canal, *5* Vistula-Oder Canal, *6* Havel-Oder Canal, *7* Mittelland Canal, *8* Dortmund-Ems Canal, *9* Rhine-Herne Canal, *10* Ludwig Canal and Main-Danube Canal, *11* Rhine-Rhône Canal, *12* Canal du Centre, *13* Canal de Briar, *14* Rhine-Marne Canal, *15* Kiel Canal (dates of the openings are indicated; for further explanations, see text)

Bij de Vaate 2002; Slyn'ko et al. 2002; Van der Velde et al. 2002; Ketelaars 2004). The largest, comprising 6,500 km of main waterways and 21 inland ports of international importance, is the "northern corridor" linking the Black and Azov seas with the Caspian Sea via the Azov-Caspian waterway (E90, including the Volga-Don Canal, opened in 1952, no. 1 in Fig. 5.1), with the Baltic and White seas via the Volga-Baltic waterway (E50, the Volga-Baltic Canal, first opened in 1810, reopened after major reconstruction in 1964, no. 2 in Fig. 5.1), and the White Sea-Baltic Sea waterway (E60, White Sea-Baltic Sea Canal, opened in 1932, no. 3 in Fig. 5.1). The "central corridor" connects the Black Sea with the Baltic Sea region via Dnieper (E40) and Bug-Prypjat Canal (opened in 1784, no. 4 in Fig. 5.1). The Vistula-Oder Canal (opened in 1774, no. 5 in Fig. 5.1) and the Havel-Oder Canal (first opened in 1640, reopened after major reconstruction in 1746, no. 6 in Fig. 5.1) connect the "central corridor" with the Elbe River and the North Sea. Since 1938, the Elbe is directly connected with the Rhine via the Mittelland Canal (no. 7 in Fig. 5.1), Dortmund-Ems Canal (no. 8 in Fig. 5.1), and the Rhine-Herne Canal (no. 9 in Fig. 5.1; Jażdżewski 1980; Nehring 2002). The "southern corridor" owes its origins to Charlemagne who, in the 8th century, began digging the *Fossa Carolina* between the Rezat, a tributary of the Rhine, and the Altmühl river flowing into the Danube. Heavy rainfall thwarted his plan and over 1,000 years passed before another emperor, Louis I, constructed the Ludwig Canal with 101 locks which connects the Danube with the Main River, a tributary of the Rhine (opened in 1845, destroyed in World War II, no. 10 in Fig. 5.1). Reconstruction of the Main-Danube Canal began in 1959 and, in 1992, the Danube (E80) and the Rhine (E10) were finally connected (Nehring 2002; Bij de Vaate et al. 2002; van der Velde 2002; WSV 2005). The "western corridor" links the Mediterranean with the North Sea via the Rhône (E10) and the Rhine-Rhône Canal (opened in 1834, no. 11 in Fig. 5.1). Although of little commercial import today, numerous old navigable canals in France and the Benelux countries, including the Canal du Centre (opened in 1790, no. 12 in Fig. 5.1), the Canal de Briar (opened in 1842, no. 13 in Fig. 5.1) and the Rhine-Marne Canal (opened in 1853, no. 14 in Fig. 5.1), connected major river basins and may have served as early dispersal routes for alien species from the Mediterranean to the North Sea basin.

5.3 Aquatic Highways for Invasion

The precise number of aquatic species, primarily of Ponto-Caspian origin, that benefited from the extensive network described above and extended their ranges far and wide is as yet unknown but we estimate that 65 species may have spread through the European waterways. Some Ponto-Caspian species are considered as pests: *Dreissena polymorpha*, which spread across

Western Europe in the 19th century, exerts a significant impact upon community structure and functions, by modifying spatial and food chain resources. Alhough heavy water pollution reduced *Dreissena* populations by the mid-20th century, the improvement of water quality since the 1980s promoted their recovery (Chap. 15). *Dreissena* populations nowadays have again attained densities of up to 40,000 individuals m^{-2} in German waterways (Nehring 2005). The amphipod *Chelicorophium curvispinum*, which spread via the central and southern corridors in the 20th century, has radically altered the communities by covering hard substrates with a layer of muddy tubes up to 4 cm thick (Van der Velde et al. 2002). Since 1996, its population in the Rhine was reduced from more than 10,000 to 500 individuals m^{-2} because of the heavy predation pressure exerted by another Ponto-Caspian amphipod, *Dikerogammarus villosus* (Haas et al. 2002). After its initial introduction via the southern corridor in 1995 into the Main River, *D. villosus* has achieved wide dispersal via the Rhine (Chap. 15) and several canals in northern Germany (Fig. 5.1), and this in record time – by 2000, it was observed more than 1,000 km away in the Oder (Nehring 2005). The phenomenally successful invasive amphipod has become a major component of the macrobenthic assemblages in German waterways, and significantly impacts their ecosystem (Haas et al. 2002).

At least five Mediterranean macroinvertebrate species invaded the Rhine and neighboring basins through the "western corridor". One of these alien species, the euryhaline isopod *Proasellus coxalis*, has established populations in German inland waters as well in the North Sea estuaries (Nehring 2002). The other invasion corridors (northern, central and southern) have served as important routes for Ponto-Caspian species to disperse to the North Sea and Baltic Sea basins. At least six Ponto-Caspian macroinvertebrate species invaded western Europe waters using the central corridor, and one species, *Dreissena polymorpha,* probably dispersed also along the northern corridor (Nehring 2002; Bij de Vaate et al. 2002; Van der Velde et al. 2002). Following the opening of the new Main-Danube Canal in 1992, however, the "southern corridor" proved to be the most important dispersal route into western Europe for the Ponto-Caspian species.

To date 14 macroinvertebrate and fish species originating in the Danube have established populations in the Main and Rhine river systems, and some have spread further through the Mittelland Canal into the Ems, Weser, Elbe rivers and up to the Oder (Nehring 2005). Four species from the Rhine have been recently recorded from the Danube (e.g. the clam *Corbicula fluminalis*, Tittizer and Taxacher 1997). Twenty-five of the 44 established alien macrozoobenthic species recorded from inland waters of Germany are considered to have arrived through navigable waterways (Aet umweltplanung 2006). In the Rhine, more than 20 % of the species and more than 90 % of the biomass are represented by alien species – the Rhine is an 'international waterway' in the full sense of the word.

Organisms spread through waterways mainly through larval and postlarval drifting, active dispersal, and transport on ships' hulls. An examination of the hulls and cooling water filters of vessels plying the Danube-Main waterways revealed the presence of six alien species, underscoring the importance of that vector (Reinhold and Tittizer 1999). By contrast, we may owe the high influx of Ponto-Caspian biota through the "southern corridor" to an engineering development: to compensate for the drain deficit of the Main River, more than 100 million m^3 of Danube water are transferred annually through the Main-Danube Canal into the Main (Nehring 2002). It stands to reason that additional organisms originating in the Danube ecosystem and the Ponto-Caspian region will spread via the Main-Danube Canal, especially mobile species which have already been observed in the upper and middle Danube, such as the amphipods *Chelicorophium sowinskyi, Dikerogammarus bispinosus*, and *Obesogammarus obsesus* (Nehring 2002; Bij de Vaate et al. 2002). Recently, this was proven true – *O. obsesus* was first found in the Rhine in 2004, and further records in 2005 establish this Ponto-Caspian species as new member of the Rhine biocoenosis (Aet umweltplanung 2006).

Recent invasions of three Ponto-Caspian onychopod crustaceans – *Cercopagis pengoi*, *Evadne anonyx, Cornigerius maeoticus* – into the eastern Gulf of Finland (Baltic Sea) may indicate the increasing significance of the Volga-Baltic inland waterway in shipping-mediated long-distance intracontinental transfer of invasive species in south-north direction (Rodionova and Panov 2005; Rodionova et al. 2005). Southward dispersal via inland waterways has been shown for the northern corridor (Slyn'ko et al. 2002). Among the first invasive alien species established in the basins of the North and Baltic seas, the Chinese mitten crab, *Eriocheir sinensis,* made use of the inland waterways to spread to the basins of the Black Sea (Zaitsev and Ozturk 2001), Volga River (Slyn'ko et al. 2002) and Caspian Sea (Robbins et al. 2006). Eastwards spread of alien species via the Azov-Caspian waterway (southern part of the northern corridor) is likely the most intensive among the European waterways: since opening of the Volga-Don Canal in 1952, at least 17 alien species were introduced to the previously isolated Caspian Sea (Grigorovich et al. 2003), including the invasive Atlantic ctenophore *Mnemiopsis leidyi*, which significantly affected commercial fisheries and the whole Caspian ecosystem (Shiganova et al., 2004).

Estuaries are subjected to a two-sided invasion pressure – both through inland waterways and through coastal activities such as aquaculture – and thus represent hot spots for the occurrence of aquatic alien species (Nehring 2006). Estuarine ports servicing both inland waterways and oceanic shipping are prone to inoculations of trans-oceanic biota and may occasionally promote secondary spread of alien biota upstream. In 1985 the brackish water polychaete *Marenzelleria neglecta* (= *M.* cf. *viridis*) was introduced in ballast water to the German Baltic Sea coast. Within years, soft-bottom community structure was totally changed by this invasive species (Zettler

1997). Since 1996, it has been increasingly abundant in the German North Sea estuaries (Nehring and Leuchs, unpublished data). Its spread is attributed to the Kiel Canal (opened 1895, no. 15 in Fig. 5.1), which connects the brackish Baltic Sea (Kiel Bight) with the brackish waters of the Elbe estuary at the North Sea coast.

5.4 Hot and Hotter – the Role of Temperature in European Waterways Invasions

Increasing water temperature – in groundwater, surface runoff, streams or rivers – has a significant impact on the spread of alien species. The Asiatic clam *Corbicula fluminea* was first found in Europe in 1989 at the confluence of the Rhine and Meuse rivers near the port of Rotterdam, by 1990 it was recorded in the Rhine, in 1997 in the Danube, in 1998 in the Elbe, in 2000 from the drainage basin of the Seine River, and in 2003 in the Saône and Rhône rivers and in the Canal du Midi, clearly dispersing along the web of navigational waterways (Vincent and Brancotte 2002). It has been suggested that the successful dispersal of the Asiatic clam in European waters is correlated with winter water minima of 2 °C (Schöll 2000). Seeing that winter inland water temperatures in Germany are frequently below this value, *C. fluminea* should seldom be seen. Yet, man-induced discharge of warmer waters – industrial and residential – into the waterways raises their temperature above 2 °C and promotes the establishment of this species (Fig. 5.2). In fact, downstream from cooling water outlets of power stations, populations of *C. fluminea* reach densities of more than 3,000 individuals m^{-2} (Haas et al. 2002).

The past two decades have seen a dramatic increase in invasion rates of Ponto-Caspian species in the eastern Gulf of Finland (the northern end of the Volga-Baltic waterway): at least 50 % of established alien species were first recorded after 1986. Moreover, the number of Ponto-Caspian aliens established in the eastern Gulf of Finland in the past half century is five times as high as the number of alien species originating elsewhere. The invasions of *Cercopagis pengoi*, *Evadne anonyx* and *Cornigerius maeoticus*, introduced to the Gulf by vessels using the “northern corridor”, occurred after 1990. This period was characterized by significant declines in shipping activity via the Volga Baltic waterway due to the economic crisis in Russia; yet, environmental changes in the gulf increased its invasibility to warm-temperate Ponto-Caspian species (Panov et al. 2006). Most likely, slight changes in the temperature regime in the eastern Baltic resulted also in the recent range extension of *Dreissena polymorpha.* Distribution of this temperate species in the Baltic Sea in the century and half since its first intro-

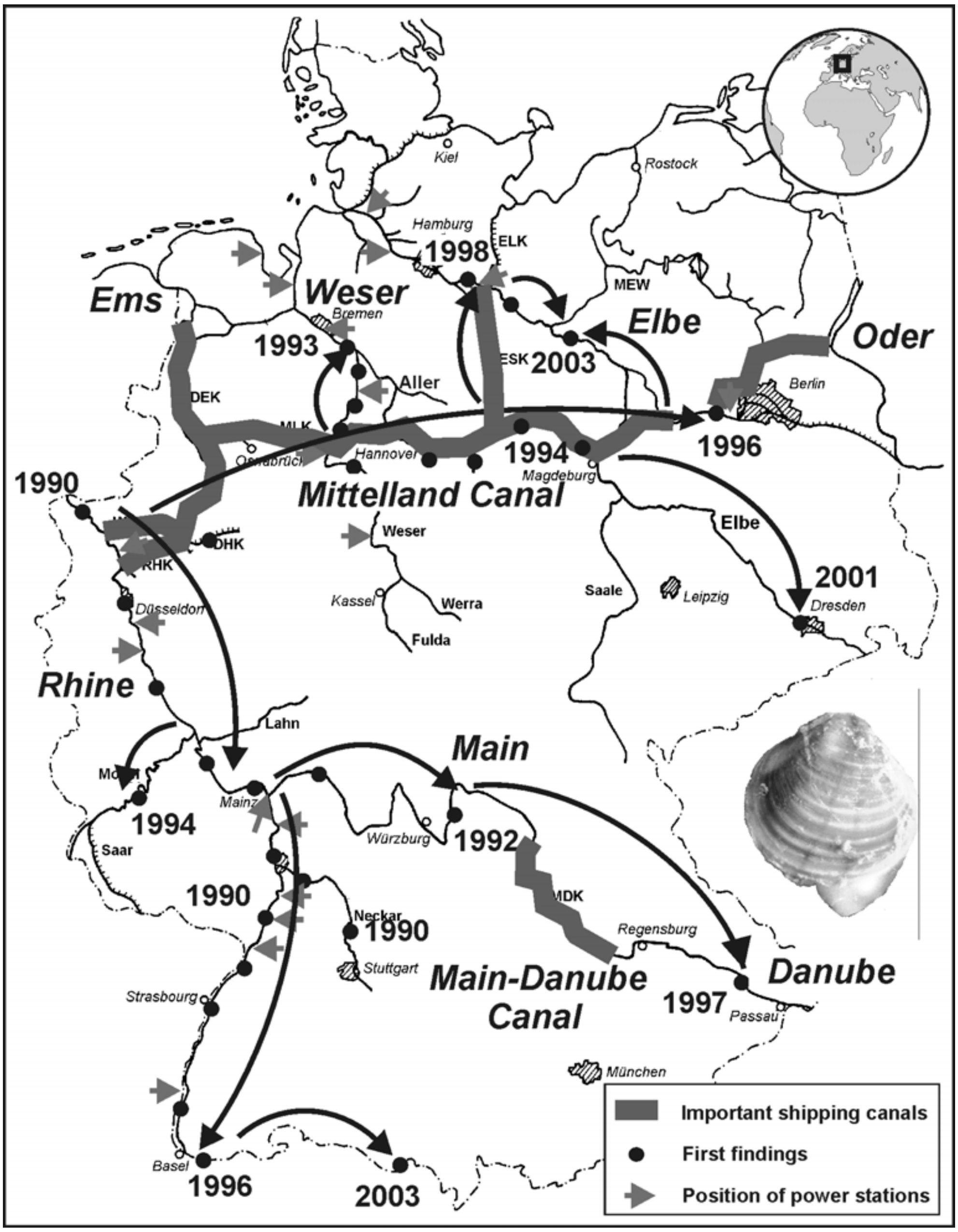

Fig. 5.2 Spread of the invasive Asiatic calm *Corbicula fluminea* in German waterways: first findings, spreading direction, and positions of power stations over 2.5 million MWh (modified after Schöll 2000)

duction was limited to latitudes below 60°N, despite available pathways (inland waterways from the Ponto-Caspian to northwest of Russia) and suitable mechanisms of introduction (intensive shipping). Recently, *D. polymorpha* has become established along the northern coast of the Gulf of Finland, reaching high densities comparable with whose reported for its native habitat. Indeed, only the higher salinity regime impedes its dispersal further westward (Orlova and Panov 2004). Global warming may be instrumental in increasing the spread of warm-temperate alien aquatic species through the inland waterways of Europe.

5.5 Future of Waterways Transport

In 1850, waterborne cargo through the Ludwig Canal amounted to 0.2 million t annually but, within a few decades, the transport of goods shifted to the railways, causing the rapid decline of the canal. We have no record of any alien species transferred between Danube and Rhine rivers via the Ludwig Canal. Since its reopening in 1992, the cargo on the Main-Danube Canal increased from 2.4 million t in 1993 to 5.2 million t in 1999 (WSV 2005), subsequently slightly declining due to political instability in the Balkans. However, the rate of invasion remains constant: since 1992, an average of one Ponto-Caspian species a year arrives through the Main-Danube Canal and establishes a population in the Rhine and neighbouring basins. With the completion of the first round of the eastern enlargement of the EU, and the improvement of the political situation in the Balkans, there are expectations for greater waterborne trade volumes of the Main-Danube Canal, which can accommodate up to 18 million t annually. It is predicted that the inland waterway transport in Germany alone will increase by 43 % by 2015 (WSV 2005) and, based on past experience, this will entail a concomitant rise in the number of alien species spreading through this waterway.

The volume of shipping along the “northern corridor” has increased to its pre-1990 level (20 million t of cargo annually, including crude oil), and is currently limited by poor upkeep of the system, including some derelict locks and waterways, and two strategic bottlenecks: the Azov-Caspian and Volga-Baltic waterways (UN 2005). Russia plans to integrate its waterway network into the European one, focusing on the Volga-Don-Danube corridor. The Russian network is due to open to international shipping by 2010. The expected increase in waterborne transport will doubtlessly be followed by a rise in the number of alien species in this cross-continental system of rivers, canals, lakes and inland seas. Policy and management should be aware that this increase in waterborne transport will facilitate the transfer of invasive species through the European web of inland waterways. Control and reduction of the dispersal of alien species may entail installation of barriers such as deterrent electrical systems as well as chloride- or pH-altered locks (Clarkson 2004; Nehring 2005).

5.6 Suez and Panama – the Interoceanic Canals

The seawater-fed Suez Canal serves as a nearly unidirectional conduit for Red Sea and Indo-Pacific biota into the Mediterranean. Despite impediments such as the canal's long length and shallowness, and strong variations in turbidity, temperature and salinity, more than 500 Red Sea species have been recorded from the Mediterranean Sea and many have become established along the Levantine coast, with some extending their range westwards to Tunis, Sicily and the Adriatic Sea (Galil 2000). The Suez Canal has provided access for over 80 % of all alien fish, decapod crustaceans and molluscs in the Mediterranean Sea (www.ciesm.org/atlas). The Red Sea aliens now dominate the community structure and function of the Levantine littoral and infralittoral zones, having replaced some local populations of native species. Some alien species are considered as pests or cause nuisance whereas other invaders are of commercial value – Red Sea prawns and fish presently constitute nearly half of the trawl catches along the Levantine coast (Goren and Galil 2005).

By contrast, the triple-locked Panama Canal is a freshwater corridor between the Atlantic and Pacific oceans. While the fresh waters of Lake Gatun connect the Rio Chagres on the Caribbean slope and the Rio Grande on the Pacific slope, facilitating the intermingling of their formerly isolated faunas (Smith et al. 2004), the lake forms an effective barrier to the dispersal of marine biota, which generally cannot tolerate hyposaline conditions. Only seven Atlantic decapod crustacean species have been collected from the Pacific drainage and a single Pacific crab from the Atlantic drainage, but none are known to have established populations outside the canal (Abele and Kim 1989). Apart from the euryhaline Atlantic tarpon, *Megalops atlanticus*, regularly reported near the Pacific terminus of the Panama Canal and around Coiba Island, no fish established populations along the Pacific coast of Panama beyond the Miraflores lagoon, although several species, predominantly blennies and gobies, have breeding populations in the canal (Hildebrand 1939; McCosker and Dawson 1975; Gunter 1979).

It has been assumed that organisms progress through canals as a result of "natural" dispersal, by autochthonous active or passive larval or adult movements, unaided either directly or indirectly by human activity (other than the construction of the canal as such). Indeed, a temporal succession of directional ("stepping stones") records from the Red Sea, the Suez Canal, and along the coasts of the Levant confirms a species status as a naturally dispersing Red Sea alien. However, dispersal could also result from anthropogenic translocation – already Fox (1926) wrote "It is, of course, well known that ships have in more than one instance dispersed marine organisms from one part of the world to another. This must apply equally to transport through the Suez Canal". Shipping has been implicated in the dispersal of numerous neritic organisms, from protists and macrophytes to fish (Carlton 1985). The transport on the hulls of ships of boring, fouling, crevicolous or adherent species is certainly the most ancient vector of aquatic species introduction. Slower-moving and frequently moored vessels, such as tugs and barges permanently employed in canal operations and maintenance, may have a larger share than other vessels in transport from one end of the canal to the other. Fouling generally concerns small-sized sedentary, burrow-dwelling or clinging species, although larger species characterized by life history which include a life stage appropriate for such dispersal may be disseminated as well (Zibrowius 1979). Ballast water is usually taken into dedicated ballast tanks or into empty cargo holds when offloading cargo, and discharged when loading cargo or bunkering (fuelling). Water and sediment carried in ballast tanks, even after voyages of several weeks' duration, have been found to contain many viable organisms. Since the volume of ballast water may be as much as a third of the vessel's deadweight tonnage, it engenders considerable concern as a key vector of introduction. However, it is seldom possible to ascertain precise means of transmission, as some organisms may conceivably be transported by several modes (Chap. 4).

In addition to serving as corridors for autochthonous or shipping-based invasion of alien species, canals facilitate aquatic invasions globally by increasing the overall volume of shipborne trade and changing the patterns of maritime transport. The opening of the Suez Canal in 1869, and the Panama Canal in 1914, had an immediate effect on shipping and trade, markedly altering global shipping routes. The Suez and Panama canals are the world's greatest shortcuts and its densest shipping lanes: about 6 and 3.4 % of total world seaborne cargo passes through these respectively (The Economist 23 July 2005). What possible effects could climate change and globalization have on marine invasions through these canals?

The Suez Canal has a tropical sea at one end and a subtropical at the other, the annual temperature range on the Mediterranean side (15-30.5 °C) being greater than that in the Gulf of Suez (23.5-28.5 °C). The Red Sea aliens, originating in tropical waters, require "temperatures high enough for the reproductive processes and development of eggs, and minimum winter temperatures above their lethal limits" to establish populations in the Mediterranean (Ben Tuvia 1966). For some of the most successful Red Sea invasive species, the initiation of the explosive population growth coincided with a rise in winter water temperatures. The abrupt rise in the populations of the Red Sea lizard fish *Saurida undosquamis*, the Red Sea goldband goatfish, *Upeneus moluccensis*, and other fish and penaeid prawns was attributed to a rise of 1-1.5 ºC in the Levantine surface seawater temperature during the winter months of 1955–1956 (Ben Yami 1955; Chervinsky 1959; Ben Yami and Glaser 1974). The appearance of six Red Sea fish species, in addition to a proliferation of previously rare thermophilic Mediterranean species, in the Adriatic Sea since the mid-1980s was correlated with a rise in eastern Adriatic surface temperatures in 1985–1987 and 1990–1995 (Dulčić and Grbec 2000; Dulčić and Lipej 2002). Similarly, a considerable increase in the number of Red Sea fish, decapods and molluscs along the south-western Anatolian coast and in the southern Aegean Sea has been attributed to a more extensive inflow of the Asia Minor Current, resulting in a westwards flow of warm, salty water from the Levantine Sea (Galil and Kevrekidis 2002; Bilecenoglu et al. 2002; Corsini et al. 2002; Kumulu et al. 2002; Yokes and Galil 2004; Yokes and Rudman 2004; Katagan et al. 2004). Global warming would likely have a significant influence on the establishment and distribution of Red Sea species entering through the Suez Canal. Rising seawater temperature may change the pool of species which could establish themselves in the Mediterranean, enable the temperature-limited Red Sea species to expand beyond their present distributions in the Mediterranean, and may impact on a suite of population characteristics (reproduction, survival) determining interspecific interactions and, therefore, the dominance and prevalence patterns of alien species, providing the Red Sea aliens with a distinct advantage over native Mediterranean biota.

The Panama Canal has a tropical sea at either end but, although the annual temperature range on the Pacific side is greater than on the Atlantic side, due to seasonal upwelling and episodic El Niño events, the “rigorous physical perturbations” on the Caribbean side mean that the former is “characterized by the presence of rich stenothermal biotic communities” (Glynn, 1972). A shift in weather patterns may have incalculable biotic consequences across the isthmus.

5.7 Globalization and Shipping – “Size Matters”

Expanding global trade engenders greater volume of shipping, and economic development of new markets brings about changes to shipping routes. The world’s seaborne trade amounted to more than 6.7 billion t in 2004. Almost 40 % of the cargo originated in Asia, and much of it was destined for Europe and North America (The Economist, 26 November 2005).

The Suez Canal benefited from the development of the Middle Eastern oilfields, being closely associated with the oil trade from the Gulf – oil shipments constituting over 70 % of total treaffic volume in 1966 (Quéguiner 1978). The closure of the Canal in 1967–1975 launched a rapid increase in tanker sizes and the emergence of the VLCC (very large crude carrier, carrying 150,000–300,000 t) and ULCC (ultra large crude carrier, carrying over 300,000 t) vessels specifically designed for long-haul routes.

Alhough recent tanker traffic has been competing with the SUMED pipeline for the transmission of oil from the Gulf of Suez to the Mediterranean and the alternate route around the Cape of Good Hope, thousands of laden and partly laden oil tankers transit the canal annually, transporting about 1.3 million barrels d^{-1} (= 174,200 t d^{-1}; www.eia.doe.gov/emeu/cabs,). At present, the Suez Canal accommodates Suezmax class tankers with 200,000 t maximum cargo. In order to attract larger vessels to use the waterway, the Suez Canal Authority has been expanding the channel to accommodate ULCC with oil cargos of up to 350,000 t by 2010.

Whereas earlier progress through the Suez Canal might have been restricted to euryhaline and generally hardy species, it is now mainly depth-restricted. Formerly, most Red Sea aliens occupied the Mediterranean littoral and infralittoral to depth of 60 m and, with few exceptions, were not found in deeper waters (Galil 1989; Golani 1996; Bilecenoglu and Taskavak 1999). However, recent records of the typically deepwater Red Sea molluscs *Ergalatex contracta* Huart 1996 and *Mactrinula tryphera* Melvill 1899 off the Levantine coast conceivably indicate the general entry of deepwater invaders (Mienis 2004). The increase in canal depth to accommodate larger vessels not only facilitates the invasion of species showing upper depth range (as adults or larvae) which otherwise would not permit passage but, in addition, the enlargement of the canal increases current velocities (Soliman 1995). Implications of faster current on the transport of biota through the Canal are clear: “With gradually improving chances for planktonic larvae to pass the Canal a steeply increasing invasion of Red Sea animals into the Mediterranean can be expected – an immigration which in a not too far future might radically change the whole faunal composition of its eastern basin” (Thorson 1971: p. 846). The profound changes wrought on the eastern Mediterranean biota commenced with the opening of the Suez Canal. The influx of the Red Sea biota is rooted in the continuous expansion of the canal, which has altered its hydrography and hydrology and enhanced its potential as a “corridor” facilitating the passage of greater numbers of organisms.

Half of the cargo transiting the Panama Canal originates in or is destined for US ports, and China and Japan are the next-biggest users. The share of the world’s trade transiting through the Panama Canal was reduced from 5.6 % in 1970 to 3.4 % in 2004 because the 80,000 dead-weight-ton Panamax, the largest vessels able to traverse the Canal, are only half as large as newly built container ships. Vessels too big for the waterway use other routes to travel between Asia and the US coast. Alternatively, goods are either unloaded at US West Coast ports and transported by road and rail or they are trans-shipped between Panama’s Atlantic and Pacific ports. To maintain its market share, the Panama Canal Authority plans to construct a third lane and new locks to accommodate ships twice as big as Panamax vessels (The Economist, 23 July 2005).

For decades the permissible draft of the Suez Canal and the dimensions of the locks in the Panama Canal determined ship sizes, and delayed and limited the construction of more stable, larger vessels with smaller ratios of ballast water and hull surface to cargo, thus impacting on patterns of shipping-transported biota worldwide. The Suez Canal and the Panama Canal have induced profound economic, political and social changes, facilitating globalization by reducing cost of ship-borne cargo. By increasing maritime trade, contracting and altering shipping routes, and influencing vessel size, both canals have had profound impacts on the ship-borne bioinvasions. Whereas the Suez Canal has been serving as a veritable gateway for Red Sea species into the Mediterranean, the waters of Lake Gatun and the upper locks of Panama Canal have reduced its permeability for marine biota.

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