BRIDGING DIVIDES
Aims and Scope

The Monographiae Biologicae provide a forum for top-level, rounded-off monographs dealing with the biogeography of continents or major parts of continents, and the ecology of well individualized ecosystems such as islands, island groups, mountains or mountain chains. Aquatic ecosystems may include marine environments such as coastal ecosystems (mangroves, coral reefs) but also pelagic, abyssal and benthic ecosystems, and freshwater environments such as major river basins, lakes, and groups of lakes. In-depth, state-of-the-art taxonomic treatments of major groups of animals (including protists), plants and fungi are also eligible for publication, as well as studies on the comparative ecology of major biomes. Volumes in the series may include single-author monographs, but also multi-author, edited volumes.
Bridging Divides
Maritime Canals as Invasion Corridors

by

STEPHAN GOLLASCH
GoConsult, Hamburg, Germany

BELLA S. GALIL
National Institute of Oceanography,
Israel Oceanographic and Limnological Research, Haifa, Israel

and

ANDREW N. COHEN
San Francisco Estuary Institute, Oakland, CA, U.S.A.
dedicated to the scientists
whose studies on the role of canals in changing
the biota laid the foundation to our work.
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The Marine Caravan – The Suez Canal and the Erythrean Invasion

_Bella S. Galil_

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Canals, Invasion Corridors and Introductions

*Chad Hewitt, Dan Minchin, Sergej Olenin & Stephan Gollasch*

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Contributors

Ashley Arnwine
Smithsonian Environmental Research Center, P.O.Box 28, Edgewater, Maryland 21037, USA

Andrew N. Cohen
San Francisco Estuary Institute, 7770 Pardee Lane, Oakland, CA 94621-1424, USA

Matej David
University of Ljubljana, Faculty of Maritime Studies and Transportation, Pot pomorscacok 4, 6320 Portoroz, Slovenia

Bella S. Galil
National Institute of Oceanography, Israel Oceanographic and Limnological Research, P.O.B. 8030, Haifa 31081, Israel

Stephan Gollasch
GoConsult, Bahrenfelder Str. 73 a, 22765 Hamburg, Germany

Chad Hewitt
National Centre for Marine and Coastal Conservation, Private Mail Bag 10, Rosebud, Victoria 3939, Australia

Kelly Lion
Smithsonian Environmental Research Center, P.O.Box 28, Edgewater, Maryland 21037, USA

Julio Lorda
Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, California 93106, USA

Dan Minchin
Marine Organism Investigations, 3 Marina Village, Ballina, Killaloe, Co Clare, Ireland

Sergej Olenin
Coastal Research and Planning Institute, Klaipeda University, H. Manto 84, Klaipeda, Lithuania
Contributors

Harald Rosenthal
Schifferstr. 48, 21629 Neu Wulmstorf, Germany

Gregory M. Ruiz
Smithsonian Environmental Research Center, P.O.Box 28, Edgewater, Maryland 21037, USA
Preface

Navigable canals are as old as civilization – the first was constructed in the 6th century BCE and joined the Nile with the northern Red Sea. Another ancient canal, the Grand Canal in China, constructed in the 4th century BCE, connected Peking to Hangzhou, a distance of almost 1000 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 opened a direct route from the Mediterranean Sea to the Indo-Pacific Ocean, and the Panama Canal afforded passage between the Atlantic and the Eastern Pacific.

Maritime canals dissolve natural barriers to the dispersal of marine organisms, thus providing them with many opportunities for natural dispersal, as well as for shipping-mediated transport. The introduction of alien species proved to be one of the most profound and damaging anthropogenic deeds – involving both ecological and economic costs. However, until recently marine bioinvasions were perceived as isolated mishaps. This book is the first to compare the impacts of the three principal maritime canals – Kiel, Panama, Suez – as invasion corridor for alien biota. The three differ in their geographic locations, hydrological regimes, and in their permeability to alien biota.

Globalization and climate change are projected to increase marine bioinvasions and reduce environmental resistance to invasion of thermophilic biota. Inter-oceanic canals offer a unique opportunity to study these processes in “status nascendi”. With ample evidence that some maritime canals serve as major invasion corridor, environmentally-considerate engineering may construct barriers to preclude future invasions. It is hoped that this book will stimulate further investigations in this field.

Neu Wulmstorf, Germany, March 2006
Harald Rosenthal

Haifa, Israel, March 2006
Bella S. Galil
Invasive alien species are considered as one of the key causes of biodiversity changes worldwide. The impacts of aquatic invasive alien species are immense, insidious, and usually irreversible. Some invaders are re-forming the structures, dynamics or functions of aquatic communities, or are imposing significant economic costs. The global rate of new aquatic invasions increased in recent years, driving efforts to evaluate their vectors and pathways (Fig. 1).

Shipping has been implicated in the dispersal of numerous aquatic organisms, from protists and macrophytes to fish. Yet, it is seldom possible to ascertain the precise means of transmission, as one species may be transported by a variety of vectors. The transport on the hulls of ships of boring, fouling, crevicolous or adherent species is certainly the most ancient vector of aquatic species introduction. Fouling generally concerns small-sized sedentary, burrow-dwelling or clinging species, though large species whose life history includes an appropriate life stage may be disseminated as well. Ballast (formerly solid, but for the past 130 years aqueous) is usually taken into dedicated ballast tanks or into empty cargo holds when offloading cargo, and discharged when loading cargo or bunkering (re-fuelling). Ballast water therefore consists mostly of port or near port waters. Water and sediment carried in ballast tanks, even after

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**Overall Introduction**

DAN MINCHIN\(^1\), BELLA S. GALIL\(^2\), MATEJ DAVID\(^3\), STEPHAN GOLLASCH\(^4\) & SERGEJ OLENIN\(^5\)

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\(^1\) Marine Organism Investigations, 3 Marina Village, Ballina, Killaloe, Co Clare, Ireland

\(^2\) National Institute of Oceanography, Israel Oceanographic and Limnological Research, P.O.B. 8030, Haifa 31081, Israel

\(^3\) University of Ljubljana, Faculty of Maritime Studies and Transportation, Pot pomorsckakov 4, 6320 Portoroz, Slovenia

\(^4\) GoConsult, Bahrenfelder Str. 73 a, 22765 Hamburg, Germany

\(^5\) Coastal Research and Planning Institute, Klaipeda University, H. Manto 84, Klaipeda, Lithuania
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 anxiety as a vector of introduction.

Fig. 1. Possible vectors (transfer mechanisms) of aquatic species. 1. shipping, 2. canals, 3. small craft, 4. intentional stocking, 5. release from aquaria, 6. release of organisms intended for human consumption, 7. release of bait species, 8. intentional and unintentional aquaculture introductions, 9. discharges of wastes following fish processing, 10. transport of fishing gear. Drawing Vitalija Gasiunaite, Vilnius, Lithuania.


<table>
<thead>
<tr>
<th>Canal</th>
<th>Opening</th>
<th>Length [km]</th>
<th>Canal features</th>
<th>Alien species movements</th>
<th>Number of ships in transit</th>
<th>Cargo in transit [mt]</th>
</tr>
</thead>
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<tr>
<td>Kiel Canal</td>
<td>21 Jun. 1895</td>
<td>98.6</td>
<td>Locks, marine-brackish</td>
<td>rare</td>
<td>39.797</td>
<td>72.296.794</td>
</tr>
<tr>
<td>Panama Canal</td>
<td>15 Aug. 1914</td>
<td>57.0</td>
<td>Locks, marine-freshwater-marine</td>
<td>medium</td>
<td>13.154</td>
<td>191.301.069</td>
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<tr>
<td>Suez Canal</td>
<td>17 Nov. 1869</td>
<td>162.3</td>
<td>No locks, marine-saline-marine</td>
<td>extensive</td>
<td>15.667</td>
<td>457.965.000</td>
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Minchin et al.
Canals serve as the world’s greatest short cuts, nexus of major trade routes and the densest shipping lanes. The world’s three principal navigable canals provide significant savings for sea borne trade: the Panama Canal eliminates travel through the Magellan Straits (saving 8,100 nautical miles (nm) on the route from Los Angeles to Philadelphia), the Suez Canal avoids the passage around Africa (a short-cut of up to 8,500 nm), and the Kiel Canal shortens the voyage between the Baltic and North Seas by up to 450 nm (Fig. 2, Tab. 1 & 2).

Table 2. Maritime route shortcuts. Ships’ speed put at 14 knots, assuming an average passage time through the Kiel Canal as 9 hours (www.ak190x.de/Bauwerke/Bau/Nord-Ostsee-Kanal.htm), average passage time through the Panama Canal as 24 hours (www.pancanal.com/eng/maritime/routes.html) and average passage time through Suez Canal as 14 hours (www.atlas.com,eg/scg.html).

<table>
<thead>
<tr>
<th>Canal</th>
<th>Route</th>
<th>via</th>
<th>Distance [nm]</th>
<th>Distance via canal [nm]</th>
<th>Savings in distance [nm]</th>
<th>Savings in time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiel</td>
<td>Rotterdam - Klaipeda</td>
<td>Denmark</td>
<td>936</td>
<td>720</td>
<td>216</td>
<td>6.4 hours</td>
</tr>
<tr>
<td>Kiel</td>
<td>Hamburg - Rostock</td>
<td>Denmark</td>
<td>629</td>
<td>174</td>
<td>455</td>
<td>23.5 hours</td>
</tr>
<tr>
<td>Panama</td>
<td>Philadelphia - Tokyo</td>
<td>Cape Horn</td>
<td>16,298</td>
<td>9,684</td>
<td>6,614</td>
<td>18.7 days</td>
</tr>
<tr>
<td>Panama</td>
<td>Los Angeles - Philadelphia</td>
<td>Cape Horn</td>
<td>12,995</td>
<td>4,897</td>
<td>8,098</td>
<td>23.1 days</td>
</tr>
<tr>
<td>Suez</td>
<td>Mumbai - Koper</td>
<td>Cape of Good Hope</td>
<td>11,316</td>
<td>4,336</td>
<td>6,980</td>
<td>20.2 days</td>
</tr>
<tr>
<td>Suez</td>
<td>Mumbai - Haifa</td>
<td>Cape of Good Hope</td>
<td>11,672</td>
<td>3,215</td>
<td>8,457</td>
<td>24.6 days</td>
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About 6% and 3.4% of the global sea borne cargo passes through the Suez Canal and Panama Canal. Aquatic organisms progress through canals both as a result of “natural” dispersal, by autochthonous active or passive larval or adult movements, and are also transported by shipping. But in addition to serving as invasion corridors for autochthonous or shipping-transported invasion of alien species, canals facilitate aquatic invasions globally by increasing the overall volume of ship borne trade and changing the patterns of maritime transport. The accelerating globalization and greater economical interdependence between distant markets result in an increase in the volume of sea borne trade. World sea borne trade expanded in 2004 to 6.76 billion metric tons, driven by the economies of Asian countries and the USA (www.UNCTAD.org). The physical limitations of the intermodal (maritime & road/rail) cargo system have driven the success of the Kiel Canal, whereas the preference for “All-Water Routes” from Asia to Western Europe and the East Coast of the United States meant a surge in traffic through the Suez and Panama Canals. As growth outpaces capacity, authorities are under severe pressure to keep up with demand: the
Suez Canal Authority has been expanding the channel to accommodate ULCC with oil cargos of up to 350,000 dead-weight-tons by 2010, and the Panama Canal Authority plans to construct a third channel, and water-recycling new locks to accommodate ships twice as big as Panamax vessels.

This book presents an account of the impact of the three principal maritime canals as invasion corridors for aquatic species. These canals differ in their ‘permeability’ to alien species. The Kiel Canal is characterized by a salinity gradient from seawater at one end to low halinity brackish water at the other, the seawater-fed Suez Canal had, for the first half of its existence, a hypersaline barrier in the form of the Great Bitter Lakes, whereas the Panama Canal is a triple-locked freshwater corridor between two oceans. The extent and distribution of the alien biota, together with their environmental impacts, and past as well as future trends, are discussed.
The Kiel Canal

The World’s Busiest Man-made Waterway and Biological Invasions

STEPHAN GOLLASCH\textsuperscript{1} & HARALD ROSENTHAL\textsuperscript{2}

\textsuperscript{1} GoConsult, Bahrenfelder Str. 73 a, 22765 Hamburg, Germany
\textsuperscript{2} Schifferstr. 48, 21629 Neu Wulmstorf, Germany

1 Introduction

In all more than 25,000 kilometres (km) of canals exist in Europe. The longest inland waterway in Europe connects the southern North Sea at Rotterdam (the Netherlands) with the Caspian Sea, and consists of rivers linked by canal systems. This and other canal systems have been important corridors for the spread of species between previously separated regions.

The Kiel Canal in northern Germany, is Europe’s longest man-made canal for ocean-going merchant vessels. It connects the North Sea (canal entrance at the mouth of the Elbe River estuary) to the Baltic Sea at the Kiel Fjord (Fig. 1), providing a more rapid and sheltered transit than the alternative passage though the Skagerrak, which is approximately 400 nautical miles (nm) longer.

The Kiel Canal is almost 100 km long and is the world’s busiest artificial waterway: more than 40,000 merchant vessels and nearly 20,000 pleasure craft pass through it each year (Wasser- und Schifffahrtsdirektion Nord pers.com., www.ak190x.de/Bauwerke/Bau/Nord-Ostsee-Kanal.htm visited January 18\textsuperscript{th} 2005).

Figure 2 shows the elevation of land along the route of the Canal. Figure 3 shows the major creeks and rivers draining into the Canal. The drainage area to the Canal covers ca 1,580 square kilometres (km\textsuperscript{2}), with an input of ca 630
million cubic metres (m³) of freshwater per year. These inputs combined with the overall direction of water flow create a clear but seasonally and inter-annually varying decline in salinity from east to west, and a net outflow towards the North Sea.

Fig. 1. Map. Insert = northern Germany with location of the Kiel Canal (dotted line).

Fig. 2. Route of the Kiel Canal from Brunsbüttel to Kiel. Top: passing bays, bridges and tunnels. Bottom: upper line is the elevation of land along the route of the canal, the horizontal grey line is the canal water surface and the heavy black line the bottom of the canal bed, both canal entrances indicated with vertical black lines. (Modified after Hill in Wasser- und Schifffahrtsdirektion Nord, Kiel 2001).
Figure 3. Schematic overview of the principal watershed draining to the Kiel Canal, including ditches, creeks, small secondary canals and lakes. These are mainly located south of the canal, and represent a catchment area of ca 1,580 km². Scale = 20 km. Arrow gives location of Flemhuder Lake (see also Fig. 4). (Modified after Hartmann & Spratte 1995).

Figure 4 shows Flemhuder Lake, a small lake connected to the Canal at canal km 85 - 86. The volume of freshwater input into this lake results in seasonal changes in salinity. Flemhuder Lake is one example of many small water bodies connected to the Kiel Canal that provide refuges for fish and have rich benthic and planktonic communities.

The Canal is managed by the Wasser- und Schifffahrtsdirektion Nord. Other canal authorities located in Brunsbüttel and Kiel-Holtenau are responsible for traffic management, canal policing, building and maintenance as well as for running the canal facilities. Additional canal authorities in Rendsburg manage ship building and are responsible for mechanical and electrical engineering, communications, maintenance and improvement works (Wasser- und Schifffahrtsdirektion Nord 1993).

The official Kiel Canal homepage may be found at www.kiel-canal.org where two web cameras deliver real time images of the approaches to the canal locks. This homepage also provides an online canal fee calculator according to ship size.

The detailed traffic rules for the canal may be downloaded at www.kiel-canal.org/pages_english/vorschriften/regulations-KIEL-CANAL.pdf.
2 History and canal construction

Today’s Kiel Canal was not the first connection between the North Sea and the Baltic Sea. There were repeated plans for a man-made shipping canal since Viking times (Fig. 5). However, most canal plans did not become reality.

2.1 The shipping route in Viking times

The first plans to build an inland waterway between the North and Baltic Seas date back to Viking times. In early medieval times, in approximately the 7th century, the Vikings started to search for an inland connection between the North and Baltic Seas.

By the end of the 9th Century Haithabu in northern Germany became the Viking’s major trade hub. This sheltered settlement formed a strategic trade gateway between northern and southern as well as eastern and western regions of the Viking territory. At its prime, more than 1,000 inhabitants lived in Haithabu, making it one of the biggest settlements in the region.
Haithabu was located at the innermost part of the Schlei Fjord - approximately 40 km inland from the Baltic shores (Fig. 6). An overland distance of only 16 km was needed to reach the Treene River (at today’s Hollingstedt), from which Viking ships sailed to the North Sea via the Eider River (Elsner 1994). However, at these early times, the building of a canal over this distance was not possible due to lack of construction knowledge, and the Viking vessels were transported overland either on carriages or by rolling them on wooden logs.

The settlement at Haithabu declined following its pillage and destruction in 1050 and 1066. Nearby settlements developed into the city of Schleswig, and in the early 13th Century the city of Lübeck subsequently became the most important trade hub in the region (Elsner 1994).

The Viking people were adventurers and may have been responsible for the introduction of the infaunal bivalve *Mya arenaria* to Europe (Petersen et al.)
1992). Vikings returning from North America may have kept live *Mya arenaria* aboard as fresh food, or they may have imported them with the solid ballast on their ships. Excavations at Haithabu reveal enormous numbers of ballast stones at and near the landing pier, supporting the probability of an introduction with ballast. Viking ships are likely to have come from sheltered, muddy estuaries in North America, and such muddy estuaries would have had large numbers of *Mya arenaria*. However, it is also possible that there was a gradual reexpansion into Europe following the last glaciation period.

In contrast Wolff (2005) states that the transfer of *Mya* by the Vikings poses a problem. Except for an occasional vessel driven off course by gales, there was no direct transport between North America and Europe in Viking times (Marcus 1980). Greenlanders travelled to North America on a more or less frequent basis and also travelled between Greenland and Norway, but these trips were not undertaken by the same vessels. As a result *Mya* was probably first introduced

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*Fig. 6.* Map of northern Germany with the Kiel Canal as a dotted line. Black arrow identifies the Viking settlement Haithabu on the innermost shore of the Schlei Fjord. Grey arrows point to the Treene and Eider Rivers. Dotted arrow indicate the possible Viking inland route connecting Baltic and the North Sea.
from North America to Greenland and thereafter from Greenland to Europe (Ockelmann 1958, Höpner & Petersen 1978, 1999).

Legend or truth?

*Mya arenaria* was probably native to North America and introduced to Europe in Viking times which would have been the first species introduction into Europe. Viking ships used solid ballast, i.e. sand or gravel. It may well be that *Mya arenaria* was shovelled onboard together with ballast when the ships left America. Discharging the ballast in Europe may have introduced the clam to Europe. Alternatively, Vikings may have used the clam as a source of food during their voyages ... two possible scenarios, impossible to prove!

Vikings may also have been the first to move a non-native species through today’s German mainland with ships. Ships were moved between the Treene and Eider Rivers and Haithabu on logs or carriages to avoid the dangerous passage around Denmark. But it is likely that any solid ballast was removed to reduce a ship’s weight before moving it over land.

However, one never knows!

Regular shipping trade demanded a safe passage from the North Sea to the Baltic Sea to avoid the dangerous passage around Denmark. As a result, canal planning projects were commissioned.

2.2 The Stecknitzkanal project

In the following centuries and at the end of the 14th Century, the cities of Lübeck and Hamburg developed as trade hubs with salt being the most valuable cargo. Salt was transported by road from Lüneburg (near Hamburg) to Lübeck. To facilitate cargo transportation the Stecknitzkanal was built between 1391 and 1398, enabling barges to be pulled by horses between Lauenburg (near Hamburg) and Lübeck. This canal was the first man-made waterway in northern Europe (Schütt 1991).
In the beginning, 13 locks were built along the water-way (total length 94 km); another four locks were added at the end of the 17th Century to ease transportation across the height difference of 18 m. The canal, 11.5 km long and 7.5 m wide, connected the Rivers Delvenau (a tributary of the Elbe River) and Stecknitz (connected to the Trave River near Lübeck). Its shallowest sections had a depth of 85 cm.

This canal was predominantly used by non-propelled barges to ship salt to Lübeck. The maximum allowable size of the barges was 12 m in length, 2.5 m in width with a maximum draught of 40 cm. Such vessels could carry 7.5 tonnes of salt. A canal passage took more than two weeks. The first vessels reached Lübeck in July 1398. Trade peaked in 1500 to 1550 when on average more than 12,000 tonnes of salt were shipped to Lübeck annually. The canal was in use for approximately 500 years and was eventually replaced by the Elbe-Lübeck-Kanal, which opened in June 1900 (www.geschichte.schleswig-holstein.de, www.schifffahrtslexikon.de/lexikon/lemma/def/stecknitzkanal_de.htm visited February 10th 2005).

2.3 The Alster-Trave-Kanal project

Another canal connecting Lübeck and Hamburg was first planned in 1448 – the Alster-Trave-Kanal (also known as Alster-Beste-Kanal). Construction started in the same year, but the excavation encountered technical difficulties, and the project was put on hold in 1452.

Construction began again in 1526 with support from the Danish King Friedrich I (1471 - 1533). Herzog Magnus II (1527 - 1603) tried to hinder this canal project as he believed the new canal would compete with and lower the toll income from the Stecknitzkanal (see above).

The Alster-Trave-Kanal opened in August 1529 providing an alternate route between Hamburg and Lübeck via the Alster and Beste Rivers and into the Trave River. Using the canal, the total distance between Hamburg and Lübeck was 91 km of which the canal itself was 8 km. The canal width was approximately 15 m and the depth nearly 2 m. It had 23 locks and was crossed by 26 bridges. Cargo was transported through the canal in approximately seven days using non-propelled lighters moved by men on the embankments.

Financially, this canal was unsuccessful. The building costs of approximately 43,000 Marks, more than the annual budget of the City of Hamburg at that time, could not be recovered and the canal was closed in 1550 (Schütt 1991,
2.4 The Schleswig-Holsteinische Canal (Eiderkanal)

There were a number of plans to build a waterway across the Cimbrian Peninsula (northern Germany and Denmark) in the 16th century to handle the increasing trade demand and to enable a safe passage from the North Sea into the Baltic Sea for sea-going vessels.

Herzog Adolf I of Holstein (1526-1586), a brother of the Danish King Christian II (1481-1559), planned a canal between Kiel and the Eider River (Eiderkanal). He presented his plans to the German Emperor on the 10th of August 1571. However, no development took place or was considered until the end of the 18th Century (Schulz 1995).

In the 1770s, during the time of Danish rule over the Cambrian peninsula as far as the Elbe estuary, a Canal Commission was founded in Copenhagen under the control of Denmark’s King Christian VII (1749-1808) and his brother Crown Prince Friedrich (1768-1839). In 1773, King Christian VII hired General Major Wegener to plan a canal between the Baltic and North Seas. This canal was to take advantage of existing navigable waters, using the Eider River from its mouth into the North Sea up to Rendsburg, and required the construction of a channel from there to the Baltic Sea at Holtenau, the “Schleswig-Holsteinische Canal”.

The Canal Realization Commission was founded on May 11th 1774 (Schulz 1995), and the plan was changed to connect Glückstadt at the Elbe River with the Kiel Fjord using existing rivers and inland lakes, such as the Stör and Einbeck Rivers, the Einbeck and Bordesholm Lakes near Neumünster, the Eider River and Schulenberg Lake.

Some further changes resulted in the final plan (from east to west): Kiel Holtenau to Levensau River with locks to overcome the approximately 7 m height difference at Holtenau, Knoop and Rathmannsdorf; to Flemhuder and Western Lakes; to the Eider River with locks at Königsförde, Kluvensiek and Rendsburg (Schulz 1995).

Construction began in 1774 and the construction site became the largest non-military building site in continental Europe. The River Eider was deepened from...
1776 onwards. Up to 4,600 construction workers were employed, more than half of which were killed by disease. Approximately 82 million m³ of material were moved to build the canal and its six locks. The construction costs rose to approximately 2.5 million “Reichstaler”.

The 43 km long Schleswig-Holsteinischer Canal was opened in October 1784 to become part of the 175 km long waterway from Kiel at the Baltic Sea to the mouth of the Eider River at Tönning near the North Sea. It was a narrow canal only 28.7 m wide at the water surface and 18 m wide at the bottom. The water depth was 3.45 m. The canal became an important shipping route for vessels up to 300 tons. Six identical locks were built to accommodate the height difference of the canal bed. Each lock was 35 m in length, 7.8 m in width and 4 m in depth. A canal passage took approximately 3 to 4 days. This canal was renamed the Eiderkanal in 1853. More than 5,000 vessels used it in the peak year of 1872 (Schulz pers. com., Schulz 1995, www.geschichte.schleswig-holstein.de visited February 10th 2005).

2.5 History of the Kiel Canal project

The Eiderkanal’s modest size could not accommodate the emerging logistic, technical and shipping demands, particularly after 1864 when political rule passed from Denmark to Prussia and then to the German Reich. In addition, the German navy wanted a direct link between its bases in the Baltic and North Seas, so the German armada would not have to sail around Denmark. Several plans were made over some decades to built a wider canal. Construction of a new canal seemed likely when Chancellor Otto von Bismarck (1815-1898) gave the project support.

But because of political differences with field marshal Helmut Karl Bernhard von Moltke (1800-1891), the project did not proceed. Von Moltke summarized his objections to the project in a talk entitled “Rede gegen den Kanalbau” (=Speech against the canal construction). He argued that the canal would be of little value to the navy and had limited strategic importance and he recommended that financial resources should rather be used to strengthen land-based military forces. These arguments convinced the German government to not invest in building the canal, and by 1873, the new canal project seemed to have failed.

However, Bismarck returned to the idea of a new and larger canal connection. Moving the major Baltic navy port to Kiel, a strategic decision, strengthened the German province Schleswig-Holstein. Further, a commercial analysis by the
Hamburg shipowner and businessman Hermann Dahlström (1840-1922), supported by the waterworks inspector Mr. Boden, provided support for a new canal. Dahlström revised the original canal plan and financed an improvement study from his own funds.

Dahlström’s plans, taking into account both commercial and naval considerations, were published in 1878 and 1879 (“Ertragfähigkeit eines schleswig-holsteinischen Schifffahrtskanals”). Bismarck eventually convinced the German Emperor Wilhelm I (1797-1888) to approve the project. In March 1880, Dahlström was contracted to develop a first working plan of the canal.

Safety aspects were a major motivation, as approximately 200 ships sank annually in the Skagerrak region on routes to and from the Baltic Sea – a canal would provide a safer and shorter route. The canal was originally planned to link the mouth of the Elbe river to Eckernförde on the Baltic shores. Dahlström planned the canal as a public-private partnership. However, the project remained in a stalled state and did not become reality!

Emperor Wilhelm I initiated a further plan in 1883, with the aim of building a canal of sufficient width and depth to enable the passage of German naval vessels. Two years later, Bismarck finally convinced Wilhelm I that work on the canal should begin.

Private Councillor Baench, a technical assistant for construction planning of the German State Department, also supported the project. Due to his and other support it was announced in 1886 that a shipping canal suitable for the German navy would be built.

The Canal Construction Act, passed by the German government, was signed by Wilhelm I in the same year. Thus, the canal from the mouth of the Elbe river via Rendsburg to Kiel became a national project funded by the German government (www.ankieken.de/schleswigholstein/pages/nordostseekanal.htm visited May 27th, 2004) and built by the Canal Construction Commission which was established.

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The Canal Construction Commission was launched on October 1st 1886 in Kiel. Subcommittees were established to build canal locks and approaches. The canal construction itself was supervised by eight construction departments, each of them responsible for approximately eleven kilometres (Schulz 1995, www.holtenau-info.de/history/kanal2.htm visited January 18th 2005).

2.6 History of the Kiel Canal construction works

On June 3rd 1887, Emperor Wilhelm I (then over 90 years of age) laid the foundation stone for the canal in Holtenau near Kiel (Fig. 7). He died soon afterwards, in March 1888. The document embedded in the foundation stone refers to the national and international importance of the canal.3

Johann Fülscher (Fig. 8), vice-chairman of the Canal Commission, managed the construction works. Because of his success, he was later appointed as an advisor to the Panama Canal Project (Schulz 1995).

Building started in 1888 and took eight years to completion in 1895. During this time the Eiderkanal was in operation and every effort was made not to interfere with its traffic. Where the two canals met, a movable bridge was built so as to simultaneously allow (a) construction work of the Kiel Canal and (b) passage of vessels in the Eider Canal. Figure 9 shows the canal construction site with a tug boat crossing at the movable train bridge. The movable bridge allowed a navigational water surface in the Eider Canal of 18 m in width. Here, both canals were separated by a dam (Schulz 1995). For comparison today’s Kiel Canal and the Eider river are shown in Figure 10.

Up to 8,900 workers from Germany, Spain, Poland, Italy, Denmark, Austria and Russia were employed during the building phase. The minimum age for employment was 17, although younger workers could accompany their fathers.

The treatment of the workers was exceptionally up-to-date and included housing in camps organised by commissioned military officers in several locations near the canal. Food, health care, sanitary facilities and religious services were also supplied. All workers had daily meals – prepared according to strict regulations allowing an optimum nutrition. This health regime prevented disease outbreaks and almost certainly maintained the work-force in good condition, especially when in the nearby City of Hamburg, a severe cholera outbreak in 1892 resulted in approximately 8,600 deaths (Schütt 1991, Grahl & Kelm (eds.) 1992). The disease also spread among the canal workers, but due to proper treatment only three died from cholera.

The canal was completed on time and within the calculated budget of 156 million Gold-Marks.

It was built at mean sea level of the North and Baltic Seas – with a light house at each end. The tidal amplitudes are different, with the greatest tidal range in the North Sea. These level differences required the construction of locks at both canal entrances (Fig. 11 & 12). Without locks, the tides at the North Sea canal entrance would have flooded it at high tide and drained it at low tide.