

Maritime flows and networks in a multidisciplinary perspective

César Ducruet

▶ **To cite this version:**

César Ducruet. Maritime flows and networks in a multidisciplinary perspective. César Ducruet. Maritime Networks. Spatial Structures and Time Dynamics, Routledge Studies in Transport Analysis, pp.3-26, 2015, 9781138911253. halshs-01374937

HAL Id: halshs-01374937
https://shs.hal.science/halshs-01374937

Submitted on 11 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Maritime flows and networks in a multidisciplinary perspective

César DUCRUET, CNRS & UMR 7235 EconomiX, Nanterre, France

Pre-final version of the chapter published in Ducruet C. (Ed.) (2015) *Maritime Networks. Spatial Structures and Time Dynamics*. Routledge Studies in Transport Analysis, pp. 3-26.

It is almost inevitable when introducing a book about maritime networks to recall that more than 90 percent of world trade volumes are still supported by maritime transport. Seas and oceans occupy about 70 percent of the Earth's surface and coastal areas concentrated 16 and 39 percent of the world's total and urban populations respectively in the 1990s (Noin, 1999). This overwhelming importance is reflected by the great quantity of cultural, social, political, and scientific research about the sea in all its aspects. Dedicated sub-disciplines such as maritime history, geography, engineering, biology, and economics as well as institutions organise large-scale meetings to discuss the organisation and evolution of the sea as an ecosystem, a natural resource, and a vector of exchanges.

But what remains striking is that maritime transport has been much less studied than any other transport mode, especially from a network perspective. Existing research remains rather fragmented and scattered across the academic spectrum, which makes it difficult to review it exhaustively and to define any possible common framework. Five main reasons contribute to explaining such a fact: the dominance of a continental culture favouring studies of populated rather than "empty" spaces (Steinberg, 1999; Lewis and Wigen, 1999); the vague geographic distribution and morphology of maritime flows due to the absence of a track infrastructure (White and Senior, 1983; Rodrigue et al., 2013); the capture of most passenger and information flows by air transport and telecommunications since the second half of the 20th century; the continuous decline of maritime transport costs compared with other logistics costs; and the reluctance of scholars and experts to access and compile costly and hard to obtain maritime traffic statistics.

The World Seastems project No. 313847, funded by the European Research Council (ERC) over the period 2013-2018, is aimed primarily at compiling and analysing untapped historical records of global vessel movements over the contemporary period. Its international workshop held in June 2014 at the Paris Institute for Complex Systems (ISC-PIF), gathered many researchers with a similar focus, namely to provide a quantitative analysis of maritime networks in space and time. In so doing, the 20 chapters of the present book, written by 40 scholars from 12 countries and 10 academic backgrounds, offer a multidisciplinary perspective about one of the most vital pillars of world society.

The maritime network: late emergence of a multifaceted concept

A simple online search via *Science Direct* provided about 100 results for "maritime network" (as of 16 September 2014) compared with more than 10,000 results for road, global, or transport network, taking into account all scientific disciplines. Airline network scored 261, while trade, logistics, street, river, and railway ranged between 1,000 and 4,000 results each. Among maritime-related terms, "maritime network" scored less than maritime transport, trade, and traffic, shipping, port, or route, whereas "maritime transport" scored far below "road network", thereby illustrating the paramount importance of roads for daily commuting and trucking. Such a situation echoes the work of Danisch et al. (2014) who in their analysis of word co-occurrences found that "global shipping network" occupied a peculiar, peripheral situation with regard to the graph theory community. As a matter of fact, many scholarly works using the term maritime (or shipping) network make no

reference to graph theory per se, in contrast to road, railway, air, and even river transport where network analysis had become a very common approach since the 1960s in the social sciences (Ducruet and Lugo, 2013).

As pointed out by Lemarchand (2000, pp. 1-2), "the literature on networks ignores maritime places [while] port and maritime actors do not refer much to the concept of network". If the network traditionally describes technical systems made of material infrastructure, maritime routes exist on the map only so that the maritime network remains rather abstract, invisible, and decentralised, especially at the national scale where only a fragment of the network is perceived. The maritime network may refer to various realities according to different disciplines, such as trading linkages by sea organised by merchants in maritime history (Gipouloux, 2011; Tartaron, 2013), tactical or wireless communication networks between vessels in engineering, inter-firm alliances in maritime economics (Caschili et al., 2014), distribution of ocean carriers' schedules, and physical flows of vessels between ports. With reference to the European *Motorways of the Sea* initiative, Baird (2010) even proposed to treat the floating deck of vessels just like road and rail infrastructure to favour integrated policies. In geography for instance, the maritime network had long been termed «system» (Bird, 1984, p. 26): "the ultimate system of maritime transportation is a true freedom of the seas whereby every port node can theoretically be linked to every other port node" (see also Slack, 1993).

The concept of "port system", suggesting linkages between ports was found in many works, but "in their preoccupation with the development of land communications (…) the authors neglected the development of maritime space" (Rimmer, 2007, p. 76). In addition, the port system concept was used interchangeably to describe multiple realities such as port (or maritime) range, region, façade, or seaboard, and mostly at the national scale, leading to confusion. The phased model of port system evolution proposed by Rimmer (1967) initially incorporated maritime linkages contrary to earlier models (Figure 1.1), but without concrete empirical validation as subsequent works continued focusing on individual port traffics and port hinterlands. The classic distinction between a French school focusing on forelands and a Dutch school more interested in hinterlands (Weigend, 1956) led to distinct research pathways. For instance, the "port network" concept was proposed by Van Klink (1998) to describe the inland shift of port activities (Van Klink, 1998), but the same concept used in another context could also refer to a set of ports belonging to the portfolio of a given ocean carrier or terminal operator. When it comes to forelands, the French geographer André Vigarié (1979) proposed the concept of "port triptych" to think simultaneously the port itself, the hinterland (inland market area), and the foreland (overseas markets). Yet, out of 399 scientific articles published in major geography journals between 1950 and 2012, only seven mentioned foreland in their title, against 29 for hinterland; 12 mentioned "network" of which only five for maritime networks and seven for barge, hinterland, and other networks (Ng and Ducruet, 2014). Other concepts such as transport chain, logistics chain, commodity chain, and value chain became frequent to describe ports' place in networks with a qualitative approach (see Robinson, 2002).

[Figure 1.1 here]

The emergence of a dedicated network vocabulary for describing maritime patterns and traffic came long after using more imaginary semantics. The French geographers René Perpillou (1959) and André Vigarié (1968), for instance, mentioned the constellation of ports and compared sea lanes to urban streets delivering flows of life in a city like arteries in a biological organism, respectively. Other concepts taken from other fields were gradually applied to maritime transport, such as corridor, loop, cycle, and hub. Graph-related concepts such as centrality and intermediacy were used about ports (Fleming and Hayuth, 1994) alongside studies of site and situation, carrier choice and selection factors, and port competition to explain the emergence of hubs at certain locations, but without yet applying network analysis to maritime flows, so that "a connectivity index is used for

airports (…) but does not exist for seaports" (de Langen et al., 2007, p. 31). This deficit became a growing issue, especially given that "the structure of [maritime] networks evolves over time [and therefore] the position of ports as nodes in the network also changes over time (…) understanding these changes is crucial for analysing the competitive position and growth prospects of (…) ports" (de Langen et al., 2002, p. 1). The conceptualisation of maritime transport as a network gave birth to many discussions that did not necessarily lead to empirical analyses of actual maritime flows, such as about security issues (Kristiansen, 2004; Angeloudis et al., 2007) or operations research on navigation safety, ship routing and scheduling, and optimisation (Christiansen et al., 2013; Windeck, 2013). Maritime economics barely refers to either graphs or networks in its central focus on management, pricing, markets, and finance, which is also true of wider transport economics (Zwier et al., 1994; Brooks et al., 2002; Leggate et al., 2004; Stopford, 2008).

The diversity of maritime data analyses

Before analysing maritime transport as a network, graphical representations of maritime flows long remained broad estimates of amount and geographic distribution (Scarborough, 1908; Siegfried, 1943; Alexandersson and Norström, 1963; Central Intelligence Agency, 1973). Still in 2014, a geophysics paper reported "a lack of knowledge in the actual global distribution of the ships, i.e. vessel density, and its evolution over time due to economics or other causes" (Tournadre, 2014). This situation was already deplored in the 1940s when early economic geographers such as Ullmann (1949) provided an innovative cartography of maritime routes connecting the United States, claiming that maritime flows were useful to "take the pulse of world trade and movement" (see also Figure 1.2). Such a call did not, however, have many followers. Foreign trade statistics served to analyse overseas connections or maritime forelands of single ports such as Toronto (Kerr and Spelt, 1956), Genoa (Rodgers, 1958), Victoria (Britton, 1965), Clyde (Desbarats, 1971), Halifax and Saint John (Patton, 1961), Irish Sea ports (Andrews, 1955), and ports in the countries of Norway (Sommers, 1960), England (Bird, 1969; Von Schirach-Szmigiel, 1973), and Sweden (Von Schirach-Szmigiel, 1978). Such studies grew scarce until a recent revival based on the Chinese case (Wand and Ng, 2011). Accurately calculating and representing ship traffic densities on a larger scale demanded enormous data collection and extraction from printed reports on vessel movements such as on a world square grid (McKenzie, 1975). Until the 2000s, analyses of global maritime flows were bound to diagrams and simplified maps using United Nations (van den Bremen and de Jong, 1986) or other data (Fossey and Pearson, 1983; Rodrigue, 2004). Nevertheless in the 1980s, a few works mapped the nodal hierarchy of ports based on small data samples (Marti, 1981; Marti and Krausse, 1983) using trade data to/from United States ports (Figure 1.3).

[Figure 1.2 here]
[Figure 1.3 here]

It is only recently that scholars from various backgrounds, through interdisciplinary collaboration, have produced more elaborate representations of maritime flows on a larger scale, often from unexpected research domains. One of them is climatology, which made particular use of *log books* that reported weather conditions during ship voyages, as in the *Climatological Database for the World's Oceans (CLIWOC)* project for the period 1750-1850 (Herrera et al., 2003), affiliated with similar projects such as ICOADS, RECLAIM, and *Old Weather* (see Figure 1.4). The same data also was used by historians to analyse technological progress in terms of sailing speed (Ronnback, 2012). The extraction of archival records provided unprecedented knowledge of transatlantic slave voyages over the period 1500-1900 (*Transatlantic Slave Voyages* project), and trade flows across the Oresund Strait for the period 1634-1857 (*Sound Toll* project)[1]. In other fields such as

1 Other sources are worth mentioning although they have not yet been studied, such as the archives of the Suez Canal Authority, where every ship reported the precise content and value of its cargoes as well as the origin and

anthropology and archaeology, the lack of knowledge on precise maritime circulations could be overcome by looking at sailing distances to explain the spread of languages in Australasia (Coupé and Hombert, 2005), demographic migrations in the Caribbean (Friedman et al., 2009), the diffusion of techniques (Leidwanger, 2013), and sea-land accessibility in the Roman Mediterranean (Scheidel, 2013).

[Figure 1.4 here]

Other themes and issues included the effects of network centricity on maritime warfare based on the queuing theory (Fewell, 2003), geospatial analysis of maritime piracy (Leymarie et al., 2014), modelling of optimal shipping routes to prevent collisions and oil spills (Höglund and Meier, 2012), simulation of attacks on the intermodal shipping network (Earnest et al., 2012), calculation of a composite index of global urban accessibility based on raster data including maritime flows (Nelson, 2008) (see Figure 1.5), and the mapping of traffic densities based on ship detection (Tournadre, 2014), voluntary observing ships (Vettor and Guedes Soares, 2014), and Automated Identification Systems (AIS) (Le Guyader et al., 2011). Measuring the environmental impacts of shipping also provided among the most detailed and aesthetically advanced maps of global maritime flows, focusing on ship emissions (Corbett and Winebrake, 2008; Halpern et al., 2008; Leonardi and Browne, 2010). Specific commodity flows in relation to United States ports using MARAD data were mapped also using Geographical Information Systems (GIS) methods combined with Google Earth 3D visualisations (Shen et al., 2013) (see Figure 1.6). In maritime geography, scholars proposed mapping the service networks of ocean carriers based on schedule data (Robinson, 1998; Comtois and Wang, 2003; Frémont and Soppé, 2004; Rimmer and Comtois, 2005; Frémont, 2007, 2010) but still without direct engagement in network science, although some visualisations already underlined the centralisation of links around certain hubs (Figure 1.7). Another example is in maritime economics where disaggregated data of shipments served to measure the effect of maritime networks, services structure, and port infrastructure variables on maritime transport costs (Martinez-Zarzoso et al., 2011).

[Figure 1.5 here]
[Figure 1.6 here]
[Figure 1.7 here]

A recent surge in maritime network analysis: towards a convergence?

Maritime networks for many years did not fit well into the traditionally "planar culture" of graph theoretical approaches of the academic literature (Ducruet and Beauguitte, 2014). In the 1960s, the vast majority of network analyses focused on planar graphs (no crossing between links, or edges, without creating a node, or vertex) such as power grids, road networks, etc. The only exception was the PhD dissertation of Ross Robinson (1968), deeply rooted in graph theory, geography and regional science, for its application to the analysis of the maritime network within Vancouver port and with other British Columbia ports (see Figure 1.8): "it is possible to define the spatial patterns of functional relationships between ports by examining the linkages which are sustained by the inter-port shipping movements of foreign trade vessels. Such an analysis provides not only an accurate measure of the linkages themselves but also clarifies the relationships between ports, the spatial organisation of port functions and the functional status of individual ports within the total group (…) The system of ports operating interdependently may now be regarded in abstract form as a set of points or nodes in a network, a transportation network in which the lines or links in the network are in fact 'imaginary routes'" (Robinson, 1968, pp. 95-97). A port network development model was also proposed to depict four phases that may apply to other regions of the world (Figure

---

destination of its voyage (see: http://suezcanal.bibalex.org/Presentation/home/home.aspx).

1.8). Strangely enough, and even after its partial publication in a renowned journal a few years later (Robinson, 1976), that pioneering work found no followers until the 1990s, mainly due to the wider shift from quantitative to behavioural approaches in the social sciences (Ducruet and Beauguitte, 2014; Ng and Ducruet, 2014). It was only in the 1990s that scholars began to analyse maritime flows using a dedicated network methodology, just like airline or multinational firms networks; there was another unpublished PhD dissertation, this time on the North Atlantic region based on carrier schedule data (Helmick, 1994), but with no reference to Robinson's initial breakthrough.

[Figure 1.8 here]

Starting with a simple count of vessel calls at world ports (Brocard et al., 1995), and a preliminary paper on the matter (Joly, 1995), another pioneering work was the PhD dissertation of Olivier Joly (1999) who provided the first-ever network analysis of maritime container flows at the global scale, revealing the bipolar structure of the global maritime network centred upon Europe and Asia (Figure 1.9). The fast-growing field of complex networks recorded its first paper about maritime networks in 2007, which described the topological structure of container shipping networks in China (Xu et al., 2007) and later on, the world (Deng et al., 2009; Hu and Zhu, 2009; Doshi et al., 2012); these works were based on carriers' schedules and collaborations with physicists. Most of the time such works looked at the small-world and/or scale-free network structure of container flows (see also Hu and Zong, 2013), with reference to drastically different concepts and literatures than those of scholars interested in operations research and optimisation. The latter school recently provided many applications of the hub allocation model to container flows among Asian ports (Low and Tang, 2012; Asgari et al., 2013; Jiang et al., 2015). Research on marine bioinvasions benefitted from globally available AIS data tracking the real-time position of vessels through growing collaboration between biology and physics (Kaluza et al., 2010; Concepcion et al., 2010; Keller et al., 2011; Seebens et al., 2013) (see Figure 1.10).

[Figure 1.9 here]
[Figure 1.10 here]

Geographers also provided various studies of hub-and-spokes systems in liner shipping networks at the regional level using elements of graph theory and spatial analysis, such as for the Caribbean basin (Veenstra et al., 2005; McCalla, 2004), Canary Islands (Tovar et al., 2015), Mediterranean basin (Cisic et al., 2007), northeast Asia (Ducruet et al., 2010a), and southern Africa (Fraser et al., 2014). Global-level analyses also gradually became prominent about the container business to map nodal regions (Wang and Wang, 2011; Ducruet and Notteboom, 2012) and evaluate network vulnerability with reference to interoceanic canals (Ducruet, 2015), also based on multiple fleet types and the concept of multigraph or multiplex graph (Ducruet, 2013). Economists as well recently started to investigate the correlation between centrality and accessibility measures of port nodes and their broader traffic attributes (Wang and Cullinane, 2008; Lam and Yap, 2011; Li et al., 2015; Xu et al., 2015), such as macro-scale analyses of country pairs based on their maritime connectivity (Fugazza et al., 2013). In the same vein, Ducruet et al. (2014a) used a multilevel analysis to show the influence of port centrality on average ship turnaround times globally. In particular, degree centrality and hub position of ports (as measured by the clustering coefficient) speed up their cargo handling operations while the volume of container throughput has the opposite effect, but this is even truer in richer countries.

Another avenue of research has been to unravel the regionalism of maritime flows. A wide variety of network clustering methods has been used in various contexts, such as the Atlantic (Ducruet et al., 2010b) and the world (Ducruet and Zaidi, 2012; Ducruet et al., 2014b) to detect the influence of geographic proximity on the distribution of flows or the emergence of a cohesive region such as Europe. Complementary views were offered by the study of particular regions such as the Korean

Peninsula (Ducruet et al., 2009), the East Asian maritime corridor (Ducruet et al., 2011a), the Le Havre-Hamburg range (Plasschaert et al., 2011), the East-West maritime corridor (Tran and Haasis, 2014), Greece (Tsiotas and Polyzos, 2014), and North Africa (Mohamed-Chérif and Ducruet, 2015). Graph theoretical methods as well as social network analysis (SNA) revealed the backbone of maritime flows and emergent hub ports (Cullinane and Wang, 2012; Montes et al., 2012; Gonzalez-Laxe et al., 2012; Freire Seoane et al., 2013; Wang and Cullinane, 2014). The global maritime network was also analysed through its complementarity with the global airline network regarding their respective and mutual connectivities (Parshani et al., 2010; Ducruet et al., 2011b; Woolley-Meza et al., 2011) and the spread of infectious diseases (Tatem et al., 2006), and with the global road network to estimate cost effects on port and route performance (Tavasszy et al., 2011; Wang et al., 2012).

Perspectives and structure of the book

Although the late application of network analytical methods to maritime transport flows has been somewhat counterbalanced by a growing number of empirical studies, this book addresses several unresolved issues. First, most studies remain static, so that the dynamic properties of change in maritime network organisation and spatial distribution remain unclear. Second, the majority of recent works have focused on flow patterns but without explicit reference to any theoretical model, be it spatial or statistical. Third, the maritime network is not an isolated entity floating in an abstract space or defined only by its costs or benefits. It is a component of the society we live in, and as such its analysis should consider its local and regional embedding.

This first part of the book, ***Introduction to Maritime Network Analysis***, addresses the aforementioned issues in both theoretical and practical ways. Chapter 2, by Anne Bretagnolle, particularly stresses the emergence of city-systems throughout history, defined as networks of cities linked by certain transport modes, including maritime transport, although it lost its ability to move information and people in the second half of the 20th century. Chapter 3, by Antoine Frémont, complements the previous chapter in that it concerns maritime transport actors (shipping lines) and how the CMA-CGM has evolved alongside technological and managerial transformations in the container business. Chapter 4, by Marc Barthelemy, focuses on the concept of spatial network and how it is analysed in the current transdisciplinary literature. It implicitly raises a crucial question: how can maritime networks contribute to such a fast-growing, mainstream research arena?

The second part of the book, ***Modelling Past Maritime Networks***, comprises five chapters all concerned with the specific difficulties of using old data sources to map and analyse maritime networks. The lack of knowledge on actual Bronze Age maritime routes created the opportunity for Ray Rivers, Carl Knappett, and Tim Evans to simulate the distribution of inter-island maritime links in the Aegean Sea based on archaeological records and spatial models (Chapter 5). When route data does exist, problems are all but eliminated as new ones emerge, as seen in the other contributions. This was particularly well discussed and overcome by Mélanie Fournier in her visualisation experiment of Venice's maritime trade during the Middle Ages (Chapter 6); by Silvia Marzagalli when creating a new database on 18th century shipping flows allowing her to map, among other things, the distribution of French seaborne trade in the world (Chapter 7); by Liehui Wang, Theo Notteboom, and Lei Yang, who show the convergence or divergence of British and Japanese maritime colonial networks in 1920s China based on local archives (Chapter 8); and by César Ducruet, Sébastien Haule, Kamel Ait-Mohand, Bruno Marnot, Zuzanna Kosowska-Stamirowska, Laura Didier, and Marie-Anne Coche, who have extracted and mapped thousands of vessel movements from the world's biggest source of shipping information, *Lloyd's List*, to represent major shifts of maritime activity since the late 19th century to the present (Chapter 9).

The third part, composed of five chapters, is entitled ***Topology and Spatial Distribution of***

Maritime Networks. These works all apply wider statistical and spatial models of networks and trajectories to massive maritime data. The analysis by Frédéric Guinand and Yoann Pigné (Chapter 10) of daily connectivity changes in the global container shipping network is a very innovative approach that sheds new light on seasonal and cyclical dynamics in liner shipping as well as on temporal graphs, a novel approach to maritime networks with huge potential to zoom on particular events and nodes. The following work by Laurent Etienne, Erwan Alincourt and Thomas Devogele (Chapter 11) provides a critical analysis of real time vessel positioning data based on radar information or AIS to identify peculiar ship behaviour within aggregated maritime trajectories, an approach which has direct implications for port and maritime security. The identification of clusters in the global maritime network by Charles Bouveyron, Pierre Latouche, Rawya Zreik, and César Ducruet (Chapter 12) allows us to better define the functional specialisation of port nodes within a system of interlocked components connected by various fleet types, with cores, peripheries, and brokers. Another way to link maritime networks with mainstream network analytical research is shown by Serge Lhomme (Chapter 13) who measures the vulnerability of liner shipping networks to random or targeted failures of port nodes. This work sheds new light on the geographic dimension of network dereliction under certain attack scenarios, taking into account the weight of links and nodes as well as possible traffic shifts due to rerouting. Lastly, Michael Gastner and César Ducruet (Chapter 14) question the statistical structure of global cargo ship traffic with reference to well-known models such as scale-free and small-world networks. They also emphasise noticeable changes over time in the distribution of the port hierarchy that correspond to important technological breakthroughs in the industry.

The last part of the book, ***Maritime networks and regional development***, provides a closer look at the local embedding of maritime flows. Ronald Halim, Jan Kwakkel, and Lorant Tavasszy (Chapter 15) use simulation and spatial econometric methods to show direct connections between port traffic, maritime network design, trade, and economic development by choosing different parameters and scenarios in their global network model. An exploratory analysis of Pacific Rim port regions is proposed by César Ducruet and Hidekazu Itoh (Chapter 16) to seek the local socio-economic determinants of maritime connectivity in a network composed of different fleet types. Territorial factors thus play an important role as seen with the tendency for richer, more urbanised regions specialised in the tertiary sector to be more dominant in the network and to centralise higher-valued flows. At the country level, David Guerrero, Claude Grasland, and César Ducruet (Chapter 17) revisit the gravity model by comparing trade flows to maritime container flows on country pairs. They particularly highlight the facilitation of trade by shipping frequency, especially for manufactured goods, and the geographic essence of this relationship notwithstanding a number of outliers among countries. By linking spatial economics with spatial statistics, network analysis, and GIS, Igor Lugo provides a novel approach to systems of cities (Chapter 18) based on the case of Mexico, where urban nodes as well as port locations are connected via road segments. Such a combined approach has important implications for further understanding multimodal urban centrality and accessibility. The analysis by Nora Mareï and César Ducruet (Chapter 19) of the network configuration of maritime container flows in three different regions of the world discuss the respective influences of regional integration processes and carrier/port selection and competition dynamics on port hierarchies. A new measure of intra- versus extra-regional vessel circulation allows us to detect noticeable differences in the way such basins are organised and have evolved in recent decades. The last contribution to this part and to the book by César Ducruet, Sylvain Cuyala, Ali El Hosni, and Zuzanna Kosowska-Stamirowska (Chapter 20) re-explores the longstanding port-city issue by measuring the influence of urban demographic size on the spatial pattern of global maritime flows between 1950 and 1990. Larger cities maintained their overwhelming dominance in terms of centrality, but at the same time, port hierarchy and urban hierarchy gradually became less overlapped.

Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013)/ERC Grant Agreement n. [313847] 'World Seastems'.

References

Alexandersson G., Norström G. (1963) *World Shipping: An Economic Geography of Ports and Seaborne Trade*. Stockholm : Almqvist & Wiksell.
Andrews J.H. (1955) Eighteenth century port forelands in the Irish Sea. *Irish Geography*, 3(2) : 114-117.
Angeloudis P., Bichou K., Bell M.G.H. (2007) Security and reliability of the liner container-shipping network: Analysis of robustness using a complex network framework. In: Bichou K., Bell M.G.H., Evans A. (Eds), *Risk Management in Port Operations, Logistics and Supply Chain Security*, London: Informa, pp. 95-106.
Asgari N., Farahani R.Z., Goh M. (2013) Network design approach for hub ports-shipping companies competition and cooperation. *Transportation Research Part A*, 48 : 1-18.
Baird A. (2010) Redefining maritime transport infrastructure. *Proceedings of the ICE – Civil Engineering*, 163(5): 29-33.
Bird J. (1969) Traffic flows to and from British seaports. *Geography*, 54 : 284-302.
Bird J. (1984) Seaport development: Some questions of scale. In: Hoyle B.S., Hilling D. (Eds), *Seaport Systems and Spatial Change*, Chichester: Wiley, pp. 21-41.
Britton J.N.H. (1965) Coastwise external relations of the ports of Victoria. *Australian Geographer*, 9 : 269-281.
Brocard M., Joly O., Steck B. (1995) Les réseaux de circulation maritime. *Mappemonde*, 1 : 23-28.
Brooks M.R., Button K.J., Nijkamp P. (2002) *Maritime Transport.* Edward Elgar.
Caschili S., Medda F.R., Parola F., Ferrari C. (2014) An analysis of shipping agreements: The cooperative container network. *Networks and Spatial Economics*, 14(3-4) : 355-377.
Central Intelligence Agency (1973) World shipping lanes. Cited by Walbridge S. (2013) *Assessing ship movements using volunteered geographic information*. Master Thesis in Ecology, Evolution, and Marine Biology, University of California, Santa Barbara.
Christiansen M., Fagerholt K., Nygreen B., Ronen D. (2013) Ship routing and scheduling in the new millennium. *European Journal of Operational Research*, 228(3) : 467-483.
Cisic D., Komadina P., Hlaca B. (2007) Network analysis applied to Mediterranean liner transport system. Paper presented at the International Association of Maritime Economists Conference, Athens, Greece, July 4-6.
Comtois C., Wang J.J. (2003) Géopolitique et transport : Nouvelles perspectives stratégiques dans le détroit de Taïwan. *Etudes Stratégiques*, 34 (2) : 213-227.
Concepcion G.T., Kahng S.E., Crepeau M.W., Franklin E.C., Coles S.L., Toonen R.J. (2010) Resolving natural ranges and marine invasions in a globally distributed octocoral (genus Carijoa). *Marine Ecology Progress Series*, 401 : 113-127.
Corbett J.J., Winebrake J.J. (2008) *The Impacts of Globalisation on International Maritime Transport Activity*. OECD/ITF Working Paper (online).
Coupé C., Hombert J.M. (2005) Les premières traversées maritimes : une fenêtre sur les cultures et les langues dans la préhistoire. In : Hombert J.M. (Ed), *Aux origines des langues et du langage*, Paris : Fayard, pp. 118-161.
Cullinane K.P.B., Wang Y. (2012) The hierarchical configuration of the container port industry: An application of multiple linkage analysis. *Maritime Policy and Management*, 39(2) : 169-187.

Danisch M., Guillaume J.L., Le Grand B. (2014) Complétion de communautés par l'apprentissage d'une mesure de proximité. ALGOTEL 2014 – 16èmes Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, June, Le Bois-Plage-en-Ré, France, pp. 1-4.
De Langen P.W., Nijdam M.H., Van der Horst M.R. (2007) New indicators to measure port performance. *Journal of Maritime Research*, 4(1) : 23-36.
De Langen P.W., van der Lugt L.M., Eenhuizen J.H.A. (2002) A stylised container port hierarchy: A theoretical and empirical exploration. Paper presented at the International Association of Maritime Economists Conference, Panama, November 13-15.
De Sbarats JM (1971) A geographical analysis of the Clyde's forelands. *Tijdschrift voor Economische en Sociale Geografie*, 62 : 249-263.
Deng W.B., Long G., Wei L., Xu C. (2009) Worldwide marine transportation network: Efficiency and container throughput. *Chinese Physics Letters,* 26(11) : 118901.
Dick H., Rimmer P.J. (1993) The trans-Pacific economy: A network approach to spatial structure. *Asian Geographer*, 12(1-2) : 5-17.
Doshi D., Malhotra B., Bressan S., Lam J.S.L. (2012) Mining maritime schedules for 9nalyzing global shipping networks. *Business Intelligence and Data Mining*, 7(3) : 186-202.
Ducruet C. (2013) Network diversity and maritime flows. *Journal of Transport Geography*, 30 : 77-88.
Ducruet C. (2015) The polarization of global container flows by interoceanic canals: Geographic coverage and network vulnerability. *Maritime Policy and Management* (in press).
Ducruet C., Beauguitte L. (2014) Spatial science and network science: Review and outcomes of a complex relationship. *Networks and Spatial Economics*, 14(3-4) : 297-316.
Ducruet C., Ietri D., Rozenblat C. (2011b) Cities in worldwide air and sea flows: A multiple networks analysis. *Cybergeo: European Journal of Geography,* 528 (online).
Ducruet C., Itoh H., Merk O. (2014a) *Time Efficiency at World Container Ports*. OECD-ITF Discussion Paper 2014-08.
Ducruet C., Joly O., Le Cam M. (2014b) Europe in global maritime flows: Gateways, forelands, and subnetworks. In: Pain K., Van Hamme G. (Eds), *Changing Urban and Regional Relations in a Globalizing World. Europe as a Global Macro-Region*, Edward Elgar, pp.164-180.
Ducruet C., Lee S.W., Ng A.K.Y. (2011a) Port competition and network polarization at the East Asian maritime corridor. *Territoire en Mouvement*, 10 : 60-74.
Ducruet C., Lugo I. (2013) Structure and dynamics of transportation networks: Models, concepts, and applications. In: Rodrigue J.P., Notteboom T.E., Shaw J. (Eds), *The SAGE Handbook of Transport Studies*, SAGE Publications Ltd., pp. 347-364.
Ducruet C., Notteboom T.E. (2012) The worldwide maritime network of container shipping: Spatial structure and regional dynamics. *Global Networks,* 12(3) : 395-423.
Ducruet C., Roussin S., Jo J.C. (2009) Political and economic factors in the evolution of North Korea's maritime connections. *Journal of International Logistics and Trade*, 7(1) : 1-23.
Ducruet C., Rozenblat C., Zaidi F. (2010b) Ports in multi-level maritime networks: Evidence from the Atlantic (1996-2006). *Journal of Transport Geography*, 18(4) : 508-518.
Ducruet, C., Lee, S.W., Ng, A.K.Y. (2010a) Centrality and vulnerability in liner shipping networks: Revisiting the Northeast Asian port hierarchy. *Maritime Policy and Management*, 37(1) : 17-36.
Ducruet, C., Zaidi, F. (2012) Maritime constellations: A complex network approach to shipping and ports. *Maritime Policy and Management* 39(2) : 151-168.
Earnest D.C., Yetiv S., Carmel S.M. (2012) Contagion in the transpacific shipping network: International networks and vulnerability interdependence. *International Interactions*, 38(5) : 571-596.
Fewell M.P. (2003) An approach to modelling the effects of network centricity in maritime warfare. *Proceedings of the 5th International Conference on Industrial and Applied Mathematics*, Sydney, New South Wales.

Fleming D.K., Hayuth Y. (1994) Spatial characteristics of transportation hubs: Centrality and intermediacy. *Journal of Transport Geography*, 2(1) : 3-18.
Fossey R., Pearson R. (1983) *World Deep-Sea Container Shipping: A Geographical Economic & Statistical Analysis*. Gower.
Fraser D., Notteboom T.E., Ducruet C. (2014) Peripherality in the global container shipping network: the case of the Southern African container port system. *Geojournal* (in press).
Freire Seoane M.J., Gonzalez-Laxe F., Montes C.P. (2013) Foreland determination for containership and general cargo ports in Europe (2007–2011). *Journal of Transport Geography*, 30 : 56-67.
Frémont A. (2007) Global maritime networks: The case of Maersk. *Journal of Transport Geography,* 15(6) : 431-442.
Frémont A. (2010) Maritime networks: A source of competitiveness for shipping lines. In: Cullinane K. (Ed), *International Handbook of Maritime Business*, Edward Elgar, pp. 150-173.
Frémont A., Soppé M. (2004) Les stratégies des armateurs de lignes régulières en matière de dessertes maritimes. *Belgeo*, 4 : 391-406.
Friedman E., Look C., Perdikaris F. (2009) Using viewshed models in GIS to analyze island inter-connectivity and ancient maritime pathways of the Pre-Columbian people in the Caribbean. Working Paper (online).
Fugazza M., Hoffmann J., Razafinombana R. (2013) Building a dataset for bilateral maritime connectivity. United Nations Conference on Trade and Development (UNCTAD), Policy Issues in International Trade and Commodities Series No. 61 (online).
Gipouloux F. (2011) *The Asian Mediterranean: Port Cities and Trading Networks in China, Japan and Southeast Asia, 13th-21st Century*. Cheltenham and Northampton : Edward Elgar.
Gonzalez-Laxe F., Freire Seoane M.J., Montes C.P. (2012) Maritime degree, centrality and vulnerability: Port hierarchies and emerging areas in containerized transport (2008–2010). *Journal of Transport Geography*, 24 : 33-44.
Halpern B.S., Walbridge S., Selkoe K.A., Kappel C.V., Micheli F., D'Agrosa C., Bruno J.F., Casey K.S., Ebert C., Fox H.E., Fujita R., Heinemann D., Lenihan H.S., Madin E.M.P., Perry M.T., Selig E.R., Spalding M., Steneck R., Watson R. (2008) A global map of human impact on marine ecosystems. *Science*, 319(5865) : 948-952.
Helmick J.S. (1994) *Concentration and Connectivity in the North Atlantic Liner Port Network, 1970-1990*. Unpublished PhD Dissertation, Miami : University of Miami.
Herrera R.G., Wheeler D., Können G., Koek F., Jones P., Prieto M.R. (2003) *Climatological Database for the World's Oceans 1750-1850*. CLIWOC Final Report (online).
Höglund A., Meier H.E.M. (2012) Environmentally safe areas and routes in the Baltic proper using Eulerian tracers. *Marine Pollution Bulletin*, 64(7) : 1375-1385.
Hu B., Zong G. (2013) Topology analysis of China's port shipping network. *Journal of Software*, 8(10) : 2581-2586.
Hu Y., Zhu D. (2009) Empirical analysis of the worldwide maritime transportation network. *Physica A*, 388(10): 2061-2071.
Jiang J., Lee L.H., Chew E.P., Gan C.C. (2015) Port connectivity study: An analysis framework from a global container liner shipping network perspective. *Transportation Research Part E*, 73 : 47-64.
Joly O. (1995) Structuration des lignes maritimes régulières de navires porte-conteneurs. Paper presented at the 2nd Theoquant meeting, Besançon, October 4-5.
Joly O. (1999) *La structuration des réseaux de circulation maritime*. Unpublished PhD Dissertation in Territorial Planning, Le Havre University, CIRTAI.
Kaluza P., Kölzsch A., Gastner M.T., Blasius, B. (2010) The complex network of global cargo ship movements. *Journal of the Royal Society Interface*, 7(48) : 1093-1103.
Keller R.P., Drake J.M., Drew M.B., Lodge D.M. (2011) Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network. *Diversity and Distributions*, 17(1) : 93-102.

Kerr D., Spelt J. (1956) Overseas trade at the port of Toronto. *The Canadian Geographer*, 2 : 70-79.
Kristiansen S. (2004) *Maritime Transportation: Safety Management and Risk Analysis*, Routledge.
Lam J.S.L., Yap W.Y. (2011) Dynamics of liner shipping network and port connectivity in supply chain systems: Analysis on East Asia. *Journal of Transport Geography*, 19(6) : 1272-1281.
Le Guyader D., Brosset D., Gourmelon F. (2011) Exploitation de données AIS pour la cartographie du transport maritime. *Mappemonde*, 104(4) (online).
Leggate H., McConville J, Morvillo A. (2004) *International Maritime Transport : Perspectives*. Routledge.
Leidwanger J. (2013) Modeling distance with time in ancient Mediterranean seafaring: A GIS application for the interpretation of maritime connectivity. *Journal of Archaeological Science*, 40(8) : 3302-3308.
Lemarchand A. (2000) *La Dynamique des Ports : Mesures de la Valeur et des Emplois, Emplois et Valeur des Mesures*. CERENE : Le Havre University.
Leonardi J., Browne M. (2010) A method for assessing the carbon footprint of maritime freight transport: European case study and results. *International Journal of Logistics Research and Applications*, 13(5) : 349-358.
Lewis M.W., Wigen K. (1999) A maritime response to the crisis in area studies. *Geographical Review*, 89(2) : 161-168.
Leymarie P., Rekacewicz P., Stienne A. (2014) *UNOSAT Global Report on Maritime Piracy. A Geospatial Analysis 1995-2013*. United Nations Institute for Training and Research (UNITAR).
Li Z., Xu M., Shi Y. (2015) Centrality in global shipping network basing on worldwide shipping areas. *Geojournal*, 80(1) : 47-60.
Limao N., Venables A.J. (2001) Infrastructure, geographical disadvantage, transport costs, and trade. *The World Bank Economic Review*, 15(3) : 451-479.
Low J.M.W., Tang L.C. (2012) Network effects in the East Asia container ports industry. *Maritime Policy and Management*, 39(4) : 369-386.
Marti B.E. (1981) Patterns of United States–Canadian maritime container flows. *Maritime Policy and Management*, 8(4) : 253-259.
Marti B.E., Krausse G.H. (1983) Trade route 11: Methods to assess port exchanges of maritime containerized cargo flows. *Ocean Management*, 8(4) : 317-333.
Martinez-Zarzoso I., Wilmsmeier G., Perez-Garcia E., Marquez-Ramos L. (2011) Maritime networks, services structure and maritime Trade. *Networks and Spatial Economics*, 11(3): 555-576.
McCalla R.J. (2004) Hierarchical network structure as seen in container shipping liner services in the Caribbean basin. *Belgeo*, 4 : 407-417.
McKenzie F.D. (1975) *Maritime Dynamic Traffic Generator. Volume III: Density Data on World Maps*. Working Paper No. AD-A012 498, Transportation Systems Center, Cambridge, Massachusetts.
Mohamed-Chérif F.Z., Ducruet C. (2015) Regional integration and maritime connectivity across the Maghreb seaport system. *Journal of Transport Geography* (forthcoming).
Montes C.P., Freire Seoane M.J., Gonzalez-Laxe F. (2012) General cargo and containership emergent routes: A complex networks description. *Transport Policy*, 24 : 126-140.
Nelson A. (2008) *Travel time to major cities: A global map of Accessibility*. Global Environment Monitoring Unit, Joint Research Centre of the European Commission, Ispra Italy (online).
Ng A.K.Y., Ducruet C. (2014) The changing tides of port geography (1950-2012). *Progress in Human Geography*, 38(6) : 785-823.
Noin D. (1999) La population des littoraux du monde. *L'Information Géographique*, 63(2) : 65-73.
Parshani R., Rozenblat C., Ietri D., Ducruet C., Havlin S. (2010) Inter-similarity between

coupled networks. *Europhysics Letters,* 92 : 68002.
Patton DJ (1961) Railroad rate structures, ocean trade routes and the hinterland relations of Halifax and Saint John. *Tijdschrift voor Economische en Sociale Geografie*, 52(1) : 2-13.
Perpillou A. (1959) *Géographie de la Circulation.* Paris : Centre de Documentation Universitaire.
Plasschaert K., Derudder B., Dullaert W., Witlox F. (2011) Redefining the Hamburg – Le Havre range in maritime networks. *Proceedings of the BIVE-GIBET Transport Research Day 2011*. Zelzate University Press, pp. 240-244.
Rimmer P.J. (1967) The search for spatial regularities in the development of Australian seaports 1861-1961/2. *Geografiska Annaler*, 49B : 42-54.
Rimmer P.J. (2007) Port dynamics since 1965: Past patterns, current conditions and future directions. *Journal of International Logistics and Trade*, 5(1): 75-97.
Rimmer P.J., Comtois C. (2005) China's extra and intra-Asian liner shipping connections, 1990-2000. *Journal of International Logistics and Trade*, 3 : 75-97.
Robinson R. (1968) *Spatial structuring of port-linked flows: the port of Vancouver, Canada, 1965*. Unpublished PhD dissertation in Geography, Vancouver: University of British Columbia.
Robinson R. (1976) Modelling the port as an operational system: A perspective for research. *Economic Geography*, 52(1) : 71-86.
Robinson R. (1998) Asian hub/feeder nets: The dynamics of restructuring. *Maritime Policy and Management*, 25(1) : 21-40.
Robinson R. (2002) Ports as elements in value-driven chain systems: The new paradigm. *Maritime Policy and Management*, 29(3): 241-255.
Rodgers A.L. (1958) The port of Genova: External and internal relations. *Annals of the Association of American Geographers*, 48: 319-351.
Rodrigue J.P. (2004) Straits, passages and chokepoints: A maritime geostrategy of petroleum distribution. *Cahiers de Géographie du Québec*, 48(135): 357-374.
Rodrigue J.P., Comtois C., Slack B. (2013) *The Geography of Transport Systems*. New York: Routledge.
Ronnback K. (2012) The speed of ships and shipping productivity in the age of sail. *European Review of Economic History*, 16(4): 469-489.
Scarborough (1908) Carte du Monde, Europe, Asie, Afrique et Océanie. Indiquant les Pays et leurs Colonies les principaux moyens de transport. Paris: Scarborough.
Scheidel W. (2013) *The Shape of the Roman World*. Working Paper, Stanford University.
Seebens H., Gastner M.T., Blasius B. (2013) The risk of marine bioinvasion caused by global shipping. *Ecology Letters*, 16(6): 782-790.
Shen G., Wang C., Pulat P.S. (2013) An exploratory analysis and visualisation of U.S. global trade patterns through maritime freight movement between U.S. ports and world ports: 1997-2007. Paper presented at the International Forum on Shipping, Ports and Airports (IFSPA), Hong Kong, June 3-5.
Siegfried A. (1943) Les routes maritimes internationales. In: *L'Empire et la Mer*, Paris: Institut Maritime et Colonial, pp. 7-18.
Slack B. (1993) Pawns in the game: Ports in a global transportation system. *Growth and Change*, 24(4): 579-588.
Solomon R.J. (1963) External relations of the port of Hobart 1804–1961. *Australian Geographer*, 9: 43-53.
Sommers L.M. (1960) Distribution and significance of the foreign trade ports of Norway. *Economic Geography*, 36: 306-312.
Stopford M. (2008) *Maritime Economics*. Routledge.
Tartaron T.F. (2013) *Maritime Networks in the Mycenaean World*. Cambridge University Press.
Tatem A.J., Hay S.I., Rogers D.J. (2006) Global traffic and disease vector dispersal. *Proceedings of the National Academy of Sciences*, 103(16): 6242-6247.
Tavasszy L., Minderhoud M., Perrin J.F., Notteboom T.E. (2011) A strategic network choice

model for global container flows: Specification, estimation and application. *Journal of Transport Geography*, 19(6): 1163-1172.
Tournadre J. (2014) Anthropogenic pressure on the open ocean: The growth of ship traffic revealed by altimeter data analysis. *Geophysical Research Letters*, 41(22): 7924-7932.
Tovar B., Hernandez R., Rodriguez-Deniz H. (2015) Container port competitiveness and connectivity: The Canary Islands main ports case. *Transport Policy*, 38: 40-51.
Tran N.K., Haasis H.D. (2014) Empirical analysis of the container liner shipping network on the East-West corridor (1995–2011). *Netnomics* (in press).
Tsiotas D., Polyzos S. (2014) Analysing the maritime transportation system in Greece: A complex network approach. *Networks and Spatial Economics*, doi: 10.1007/s11067-014-9278-y
Ullman E.L. (1949) Mapping the world's ocean trade: A research proposal. *The Professional Geographer*, 1(2): 19-22.
van den Bremen W.J., de Jong B. (1986) The aggregate spatial patterns of maritime transport at world scale: A macro-scale approach in transport geography. *Geojournal*, 12(3): 289-303.
Van Klink H.A. (1998) The port network as a new stage in port development: the case of Rotterdam. *Environment and Planning A*, 30(1): 143-160.
Veenstra A.W., Mulder H.M., Sels R.A. (2005) Analysing container flows in the Caribbean. *Journal of Transport Geography*, 13(4): 295-305.
Vettor R., Guedes Soares C. (2014) Detection and analysis of the main routes of voluntary observing ships in the North Atlantic. *Journal of Navigation* (in press).
Vigarié A. (1968) *Géographie de la Circulation. La Circulation Maritime*. Paris: Genin.
Vigarié A. (1979) *Ports de Commerce et Vie Littorale*. Paris: Hachette.
Von Schirach-Szmigiel C. (1973) Trading areas of the United Kingdom ports. *Geografiska Annaler B*, 55: 71-82.
Von Schirach-Szmigiel C. (1978) Competition for the general cargo transports of Sweden's foreign trade. *GeoJournal*, 2: 133-146.
Wang C., Wang J. (2011) Spatial pattern of the global shipping network and its hub-and-spoke system. *Research in Transportation Economics*, 32(1): 54-63.
Wang J., Pulat P.S., Shen G. (2012) Data mining for the development of a global port-to-port freight movement database. *International Journal of Shipping and Transport Logistics*, 4(2): 137-156.
Wang J.J., Ng A.K.Y (2011) The geographical connectedness of Chinese seaports with foreland markets: A new trend? *Tijdschrift voor Economische en Sociale Geografie*, 102: 188-204.
Wang Y., Cullinane K. (2008) Measuring container port accessibility: An application of the Principal Eigenvector Method (PEM). *Maritime Economics and Logistics*, 10: 75-89.
Wang Y., Cullinane K. (2014) Traffic consolidation in East Asian container ports: A network flow analysis. *Transportation Research Part A*, 61: 152-163.
Weigend G.G. (1956) The problem of hinterland and foreland as illustrated by the port of Hamburg. *Economic Geography*, 32(1): 1-16.
White H.P., Senior M.L., 1983. *Transport Geography*. Hong Kong: Longman House Ltd.
Windeck V. (2013) *A Liner Shipping Network Design*. Springer.
Woolley-Meza O., Thiemann C., Grady D., Lee J.J., Seebens H., Blasius B., Brockmann D. (2011) Complexity in human transportation networks: A comparative analysis of worldwide air transportation and global cargo-ship movements. *The European Physical Journal B*, 84: 589-600.
Xu M., Li Z., Shi Y., Zhang X., Jiang S. (2015) Evolution of regional inequality in the global shipping network. *Journal of Transport Geography*, 44: 1-12.
Xu X., Hu J., Liu F. (2007) Empirical analysis of the ship-transport network of China. *Chaos*, 17(2): 023129.
Zwier R., Hiemstra F., Nijkamp P., van Monfort K. (1994) Connectivity and isolation in transport networks: A policy scenario experiment for the Greek island economy. Working Paper, Vrije Universiteit Amsterdam, Faculteit der Economische Wetenschappen en Econometrie.

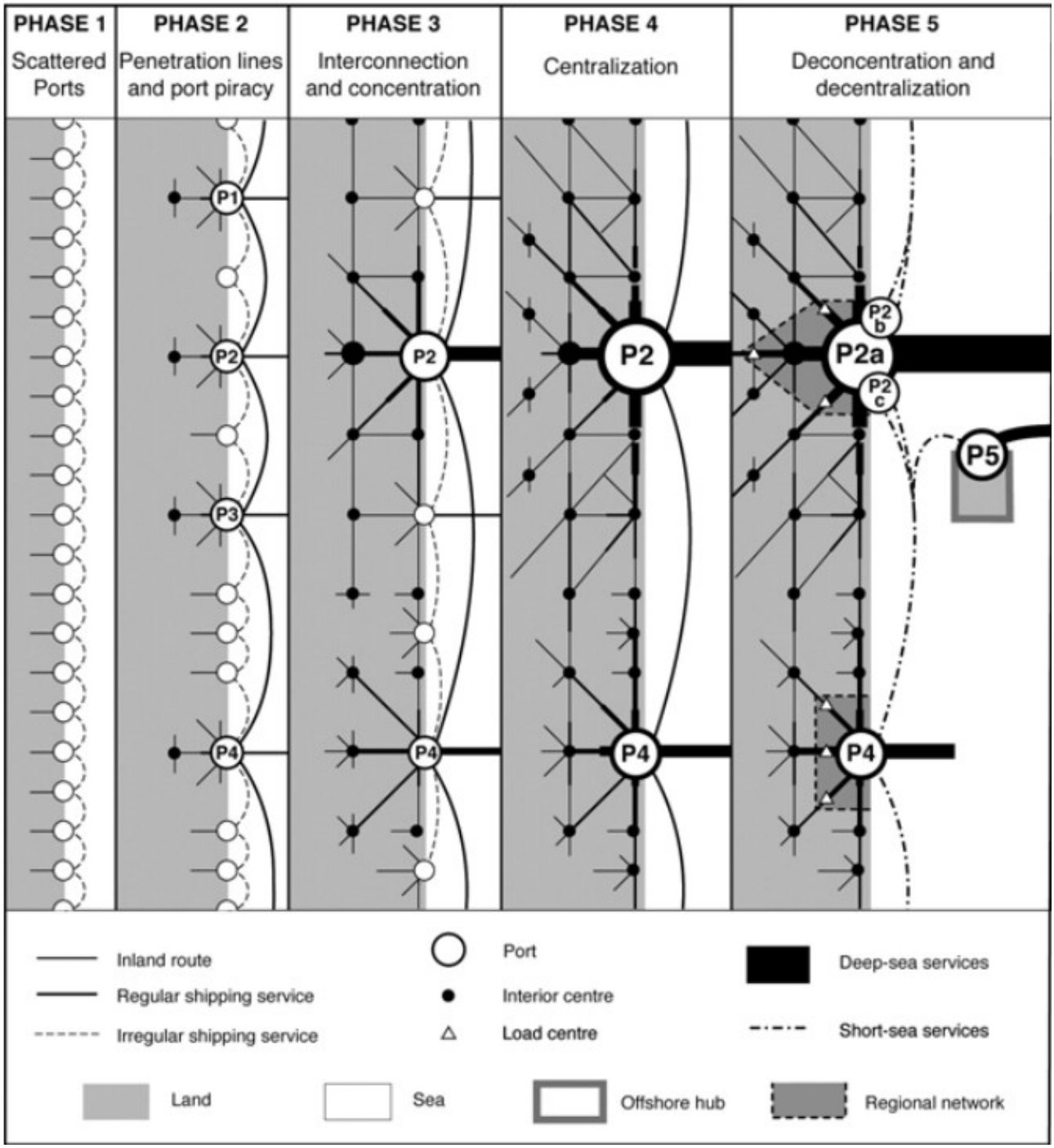


Figure 1.1 Spatial model of the evolution of a port system including maritime linkages
Source: Rimmer (2007).

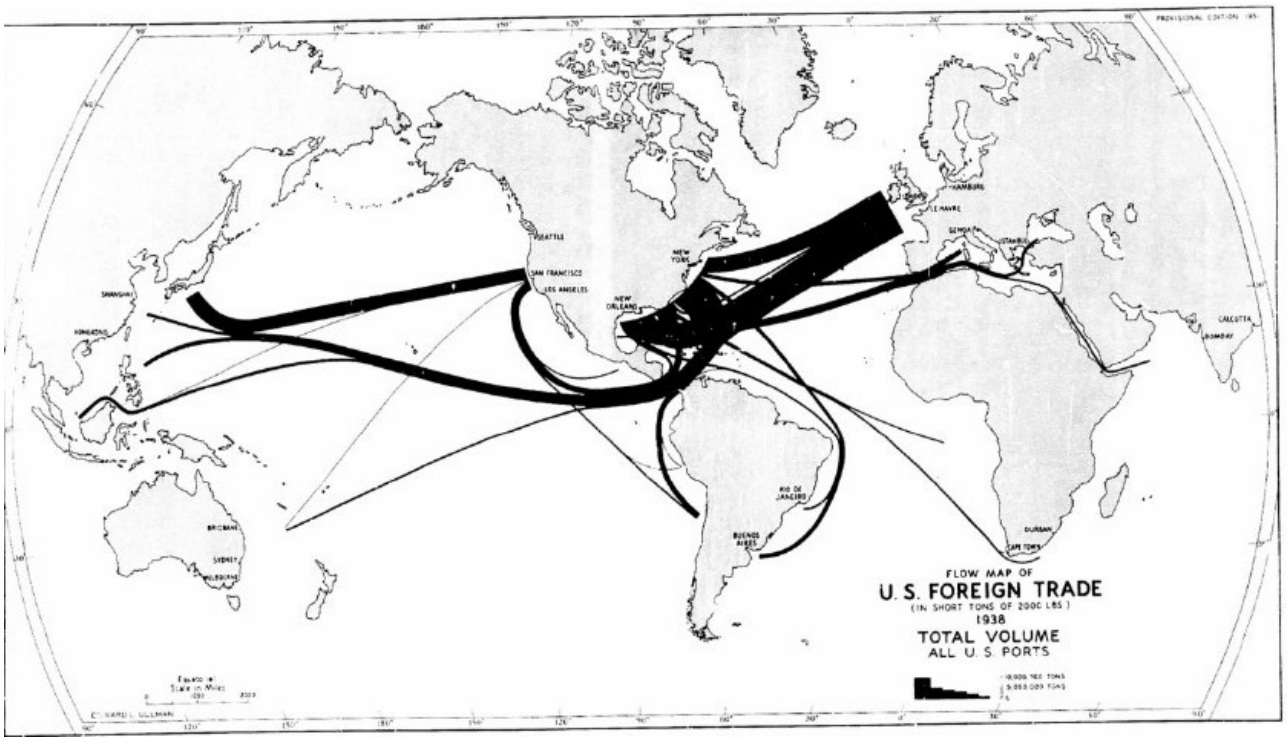


Figure 1.2 A cartography of US maritime trade, 1938.
Source: Ullman (1949).

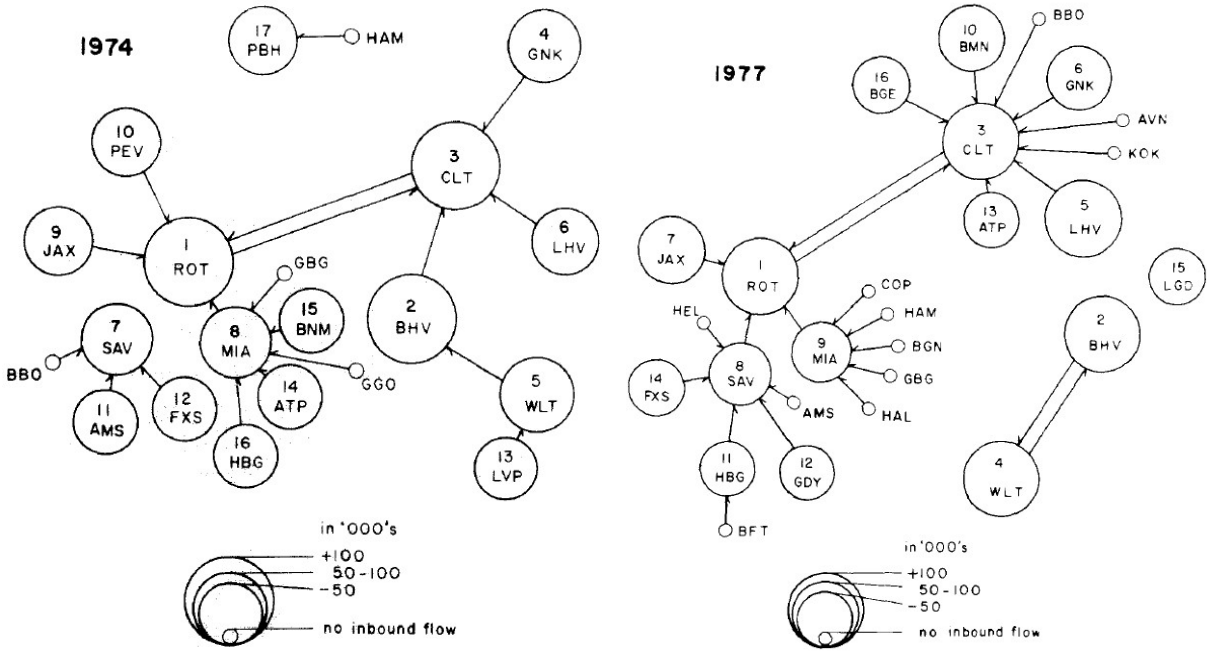


Figure 1.3 Nodal hierarchy of US-European ports in maritime container flows, 1974 and 1977.
Source: Marti and Krausse (1983).

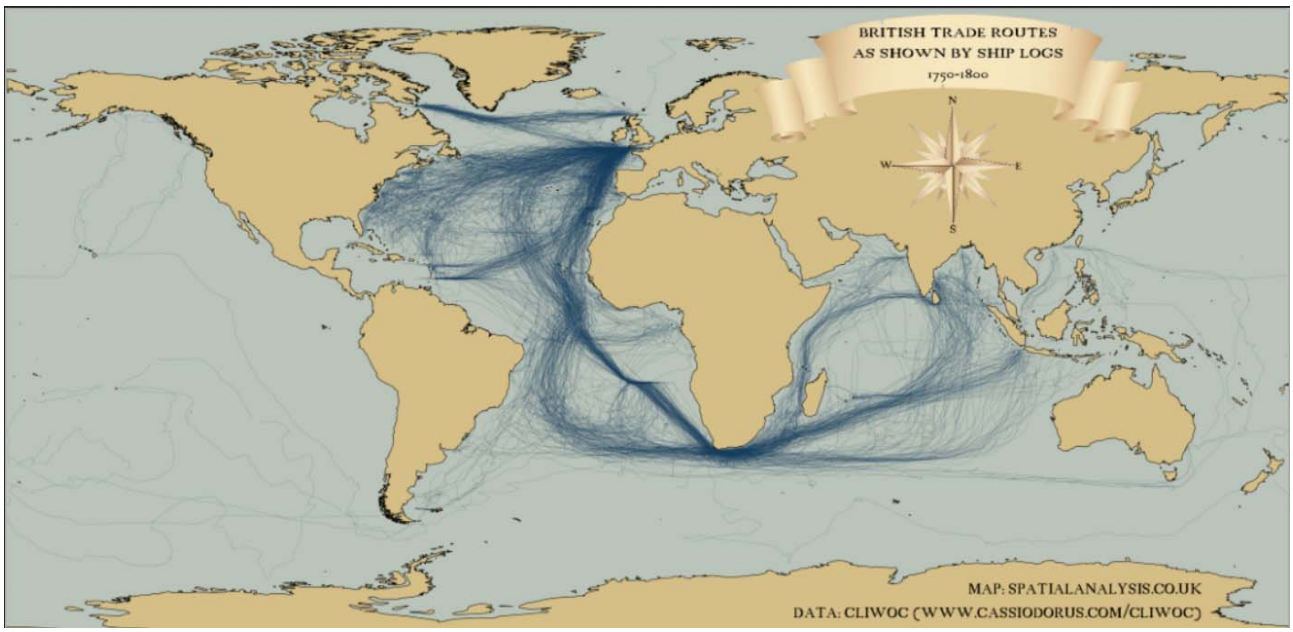


Figure 1.4 Map of British vessel flows based on log books, 1750–1800.
Source: James Cheshire (2012).

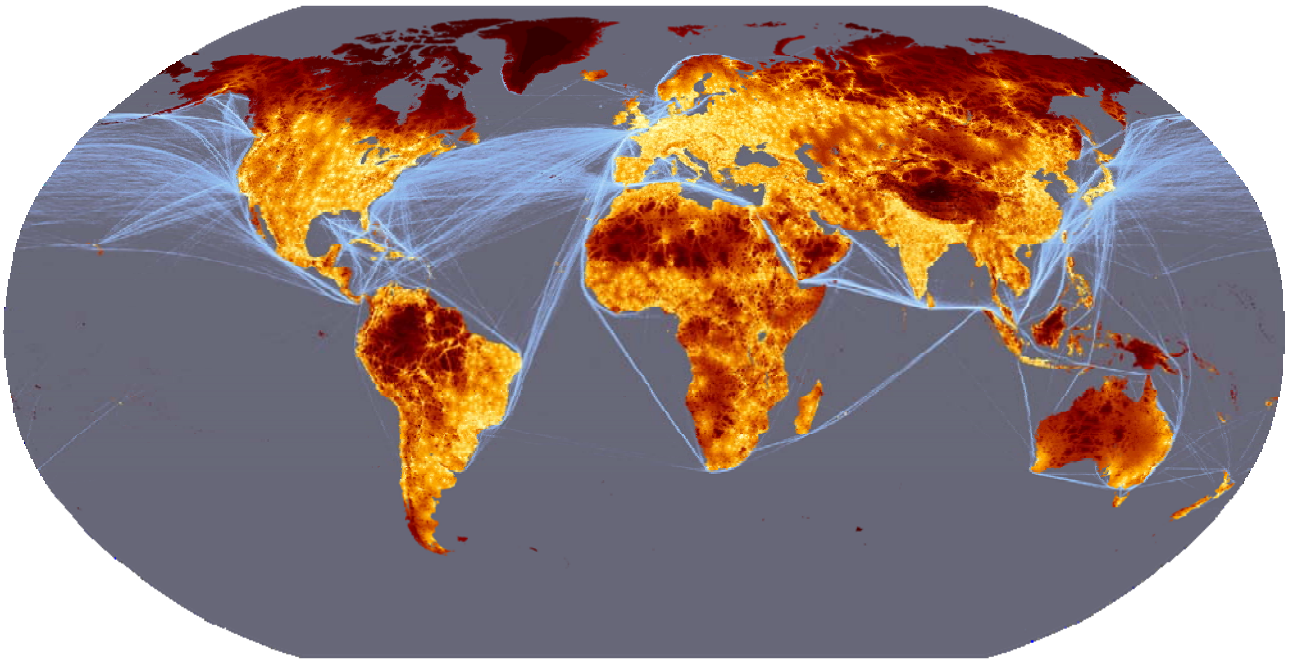


Figure 1.5 A global map of urban accessibility.
Source: Nelson (2008).

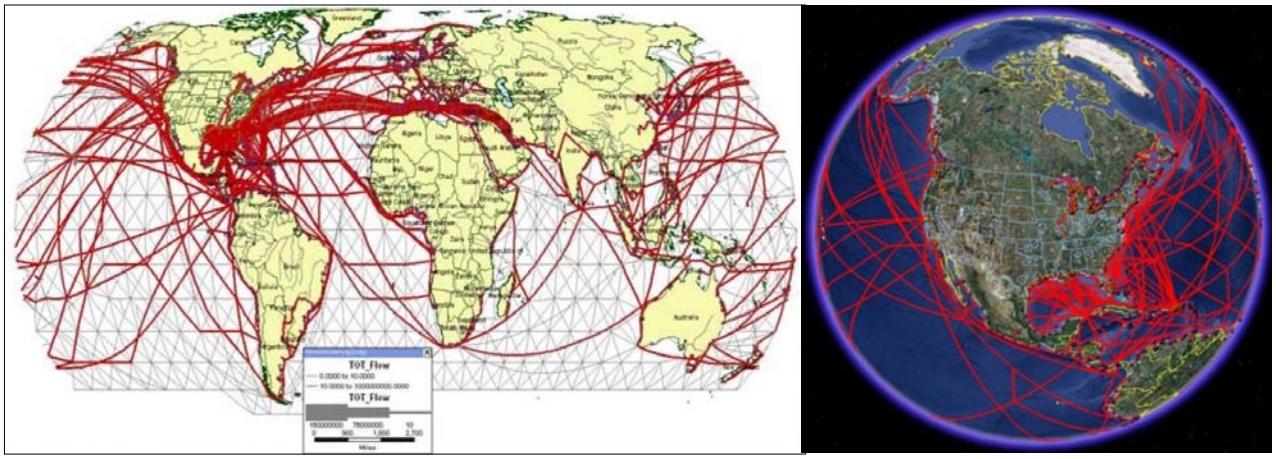


Figure 1.6 World distribution of US maritime trade in 2D and 3D, 2002.
Source: Shen *et al.* (2013).

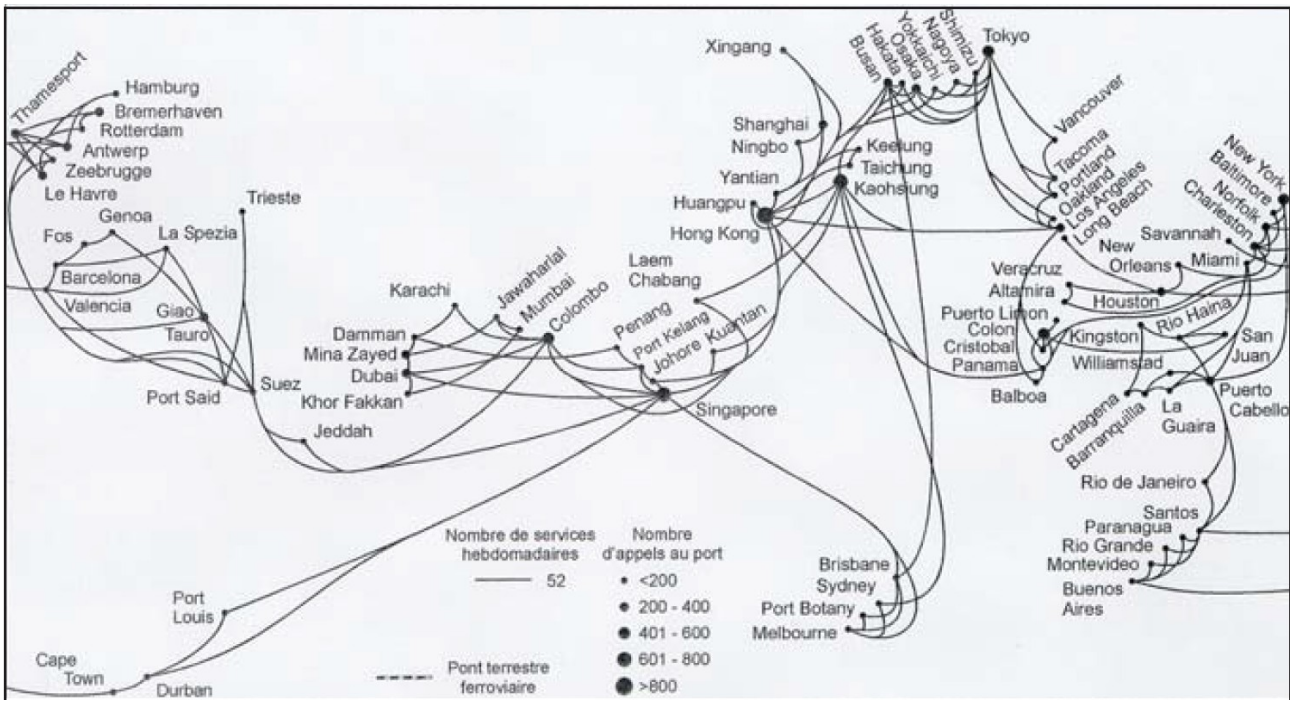


Figure 1.7 The port network of Evergreen based on schedule data, 2000.
Source: Comtois and Wang (2003).

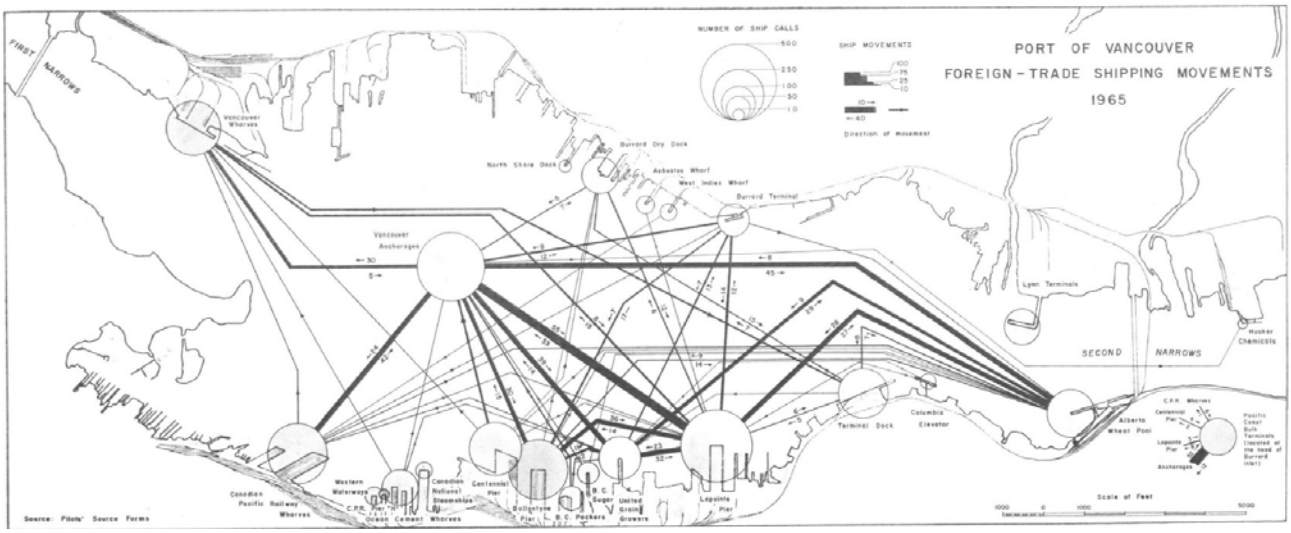


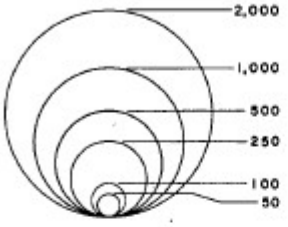
Figure 1.8 The foreign trade shipping network of Vancouver (a), British Columbia ports (b) and related spatial model (c)

FOREIGN-TRADE SHIPPING NETWORK

B.C. PORTS

1965

NUMBER OF SHIP CALLS



SHIP MOVEMENTS BETWEEN PORTS

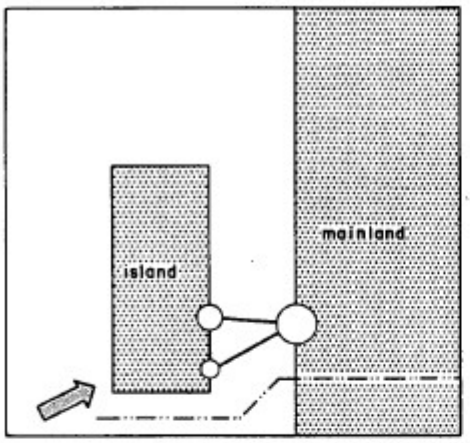


NETWORK PORTS AND ENTRY POINTS

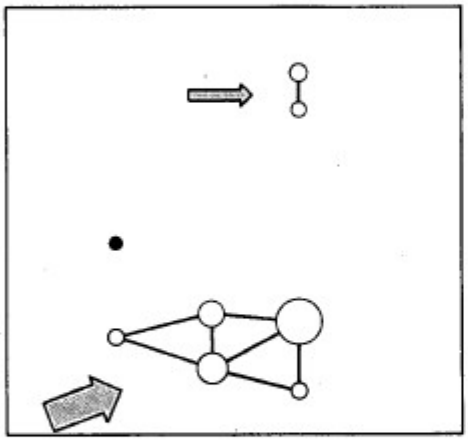
(Ranked according to number of ship calls)

	Rank	Code	Port
ENTRY POINTS	1	A	Fairway
	2	B	Cape Beale
	3	C	Triple Island
NETWORK PORTS	1	4	Vancouver
	2	30	Fraser River
	3	33	Seattle
	4	15	Victoria
	5	13	Port Alberni
	6	18	Crofton
	7	21	Harmac
	8	34	Tacoma
	9	20	Nanaimo
	10	19	Chemainus
	11	12	Tahsis
	12	25	Powell River
	13	24	Duncan Bay
	14	8	Kitimat
	15	27	Port Mellon
	16	5	Prince Rupert
	17	35	Everett
	18	36	Bellingham
	19	9	Ocean Falls
	20	10	Port Alice
	21	28	Woodfibre
	22	6	Watson Island
	23	22	Texada Island
	24	17	Cowichan
	25	14	Taquart
	26	32	Esquimalt
	27	11	Zeballos
	28	31	Port McNeill
	29	7	Jedway

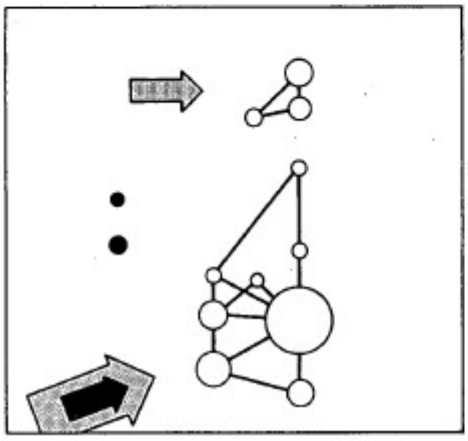
PORT NETWORK DEVELOPMENT



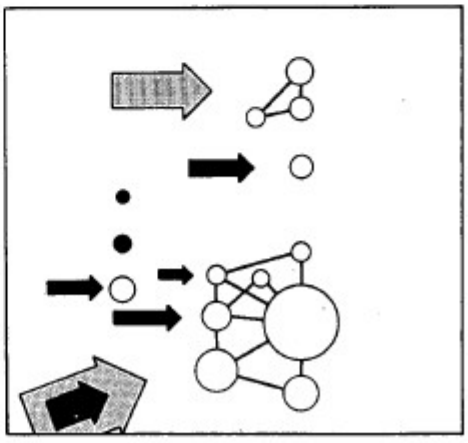
I. SIMPLE NETWORK



II. NETWORK EXTENSION



III. NETWORK INTENSIFICATION



IV. NODAL CENTRALIZATION

Volume (G.R.T.) of general shipping

Volume (G.R.T.) of specialized shipping

International boundary

Shipping linkages between ports

Ports shipping foreign-trade tonnages

Obsolescent ports

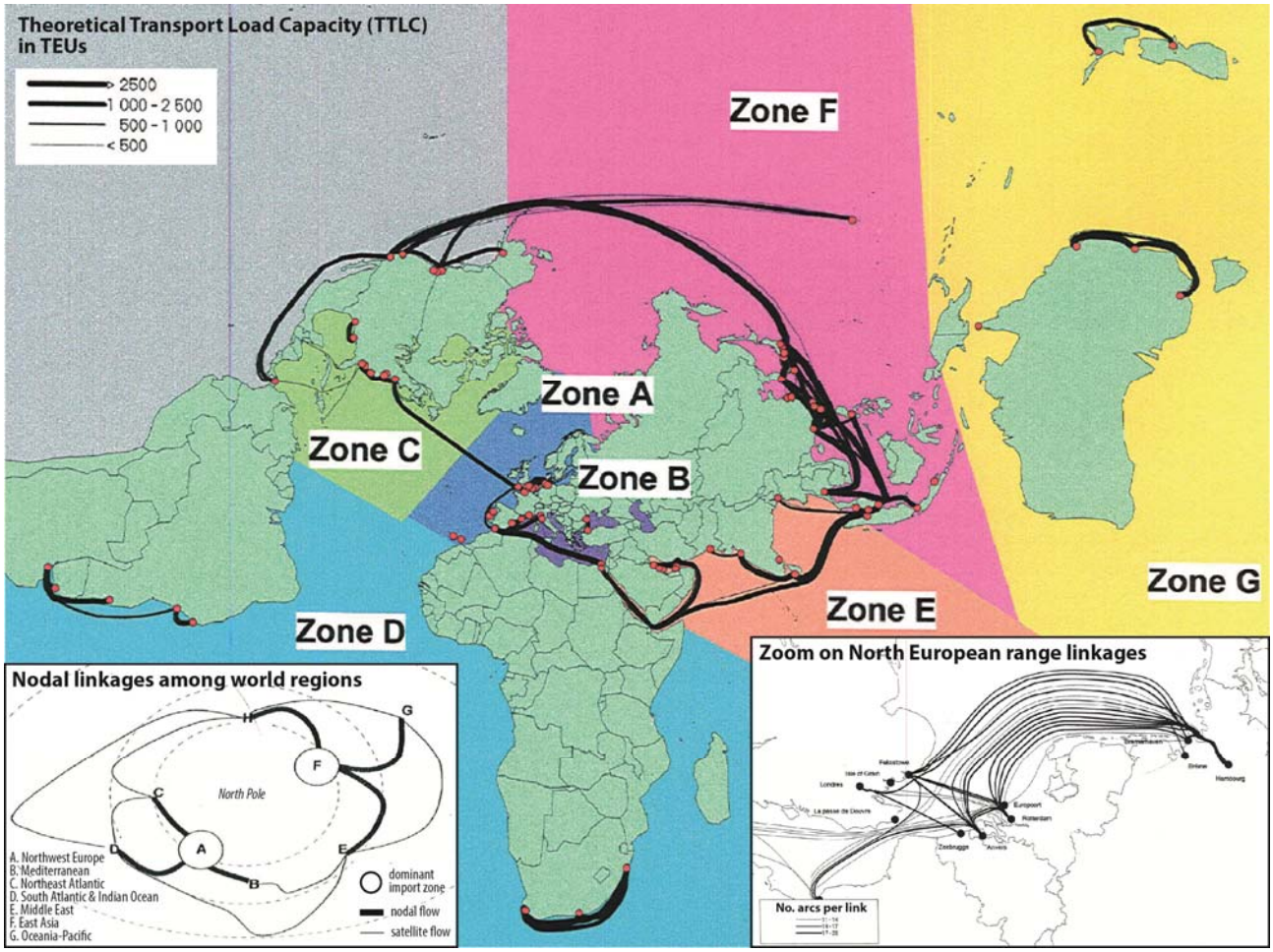


Figure 1.9 Modelling and mapping global maritime container flows on various scales, 1992. Source: Joly (1999).

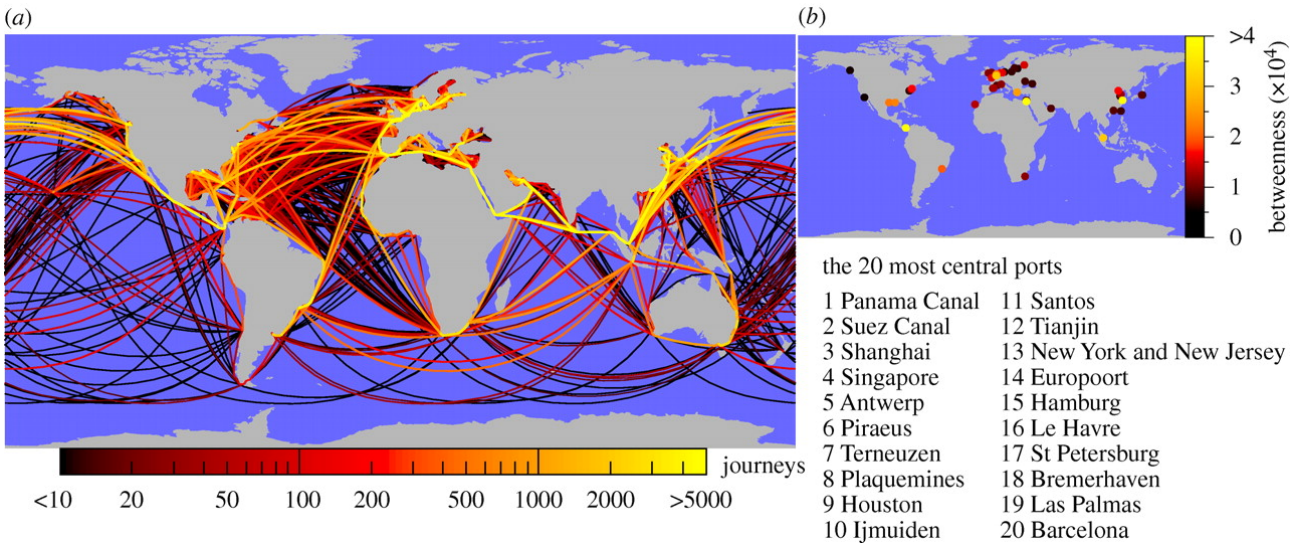


Figure 1.10 Distribution and density of world maritime flows based on AIS data, 2007.