Introduction of High Risk Harmful Algal Blooms to the Gulf of Mexico via Ships' Ballast

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Historically, oceanic ports were built in coastal embayments or at the mouths of tidally influenced rivers, i.e. estuaries, for protection from inclement weather and hostile invasions. Rivers were also valued as waterways for transfer of goods to inland cities. Most HAB occurrences are associated with bays or estuaries having ports and/or major urban centers. The earliest anecdotal written accounts of 'red tide' phenomena date back to the mid 18th century from the ships logs of Spanish and Dutch explorers (add refs) but the first taxonomic identification of a red tide causing organism did not occur until an 1835 description of a bloom off the coast of Chile was recognized 122 years later (in 1957) as *Mesodinium rubrum* (Avaria 1979). Increasing numbers of HAB occurrences have been observed worldwide since the early 1950's (Table X). Coincidentally, by the early 1950's, diesel engines had replaced steam technology for ship propulsion and passenger steamships were rapidly replaced by transoceanic vessels that could carry goods in bulk and in the decades to follow, containerization allowed for shipment of more goods on increasingly larger ships (fig. 1; Stopford 2010). And, in the late 1960's tanker ships were built for transport of crude oil to ever demanding global markets.

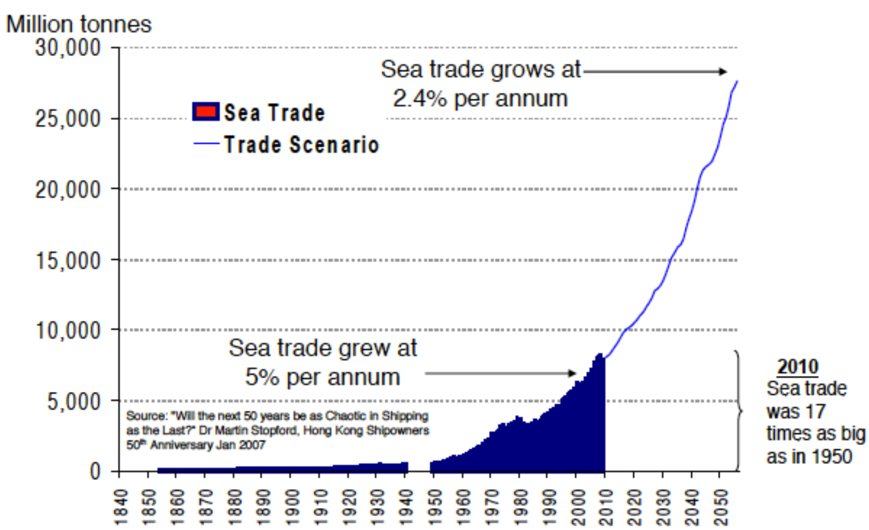

Figure 1. Increase of global sea trade since 1840 (Stopford 2010)

Prior to the 1983 ratification of the *International Convention for the Prevention of Pollution from Ships*, (MARPOL) by International Maritime Organization (IMO) member states, establishing regulations for the prevention of pollution caused by operational or accidental causes, ships could dump or discharge oil, liquid chemicals, sewage and garbage at ports unless restricted by regulations of the 'port of call' nation. MARPOL forbids the discharge of any liquid chemical, oil, or air pollutant and any disposal of garbage or sewage must occur beyond the 12 nm territorial sea delimitation. However, MARPOL failed to address pollutants and potentially invasive species or agents of disease in ballast water (IMO 2012). A "Ballast Water Convention" was not developed until 2004 and has to date, not been ratified by all member states and is still voluntary. In summary, this convention states that vessels should undergo complete ballast water exchange (BWE) beyond a 200 nm delimitation, i.e. a country's exclusive economic zone (EEZ), before proceeding to the port of destination. The rationale is that any species thriving in lower salinity coastal waters will not be able to survive when released into higher salinity, open ocean water, and vice versa.

Transits that remain within a country's EEZ (i.e. 200 nm from shore) are defined as 'coastwise' and ballast taken up in these waters are considered to be from the same 'geographic' waters and therefore do not require BWE. Vessels that transit beyond the EEZ regardless of port of departure (i.e. domestic or foreign) are classified as 'overseas' and require one of three management procedures: "1) complete mid-ocean BWE on all tanks containing this ballast water before the ballast from these tanks are discharged into domestic waters; 2) retain this ballast water on board the vessel while in domestic waters; 3) prior to the vessel entering a country's contiguous zone, use an alternative environmentally sound method of BWM. However, it is important to emphasize that the EEZ is merely a political jurisdictional boundary and has no bearing on the ocean currents and wind patterns that provide natural transport of planktonic organisms. (See Appendix A for further explanation of the Ballast Water Convention).

The evolution of global shipping in the early 1950's, lack of regulations for control of pollutants and invasive species from ships until 2004, and eutrophication of coastal zones caused by the rapid doubling of world's human population that began in the late 1960's (Cohen, 2005) are a convincing combination of factors that would have caused the observed increases in HAB events during the same time period.

Hallegraef (1998) reviewed evidence for global dispersal of *Alexandrium tamarense* and developed a general scenario for successful dispersal and introduction of HABs by ships ballasting activities: 1) presence of the harmful algal species in port, 2) uptake in ship's ballast water, 3) survives ballast uptake, 4) survives voyage in ballast tank, 5) survives de-ballasting, 6) survives in new environment, and 7) harmful algal species is able to reproduce and become established in new environment.

The lack of regulation for ships' ballasting activities in ports and coastal zones has certainly allowed for the uptake and discharge of harmful algal organisms with ballast water. The increased frequency and global distribution of HAB occurrences would, in turn, increase the likelihood of their uptake with ship ballast water. Since 1948, the total number, geographic distribution, and species diversity of HABs has increased more than 10 fold (fig. 2).

(fig. 2 Maps with bays-estuaries, ports, HAB occurrences by year-still in progress)

Several studies have examined water and sediments from ballast tanks and observed presence and often survival of harmful algal species:

- Hallegraeff and Bolch (1992) surveyed 343 cargo vessels for ballast tank sediments and found that 50% contained dinoflagellate cysts and 5% of these contained toxic dinoflagellate cysts. A total of 53 taxa were identified and 20 species were successfully germinated.

- Gosselin et al. (1995) found viable *Alexandrium* spp. and *Dinophysis* spp. in ships calling at ports in the Gulf of St. Lawrence.

- McDonald and Davidson (1998) found that 17% of ships calling at Scottish ports were contained *Alexandrium* spp. cysts in ballast water, 11% contained *Dinophysis* spp., and 38% contained *Pseudo-nitzschia* spp.

- Hay et al. (1997) detected *Pyrodinium bahamense* in ballast water from ships calling at ports in New Zealand.

- Dickmann et al., 1999. Comparison of ballast water in ships sailing from Manzanillo, Mexico to Hong Kong between 1996 and 1998 that had conducted complete BWE versus no BWE. Ballast water from ships conducting open ocean BWE contained 54 to 397 (average 190) vegetative cells representing 4 different HAB taxa. Ballast water from ships that did not conduct BWE contained 463 to 1,928 (average 482) vegetative cells representing 3 to 12 individual species of HABs including *Pseudonitzchia multiseries*, *P. delacatissima*, *Gymnodinium catenatum* and *Gonyaulax polyedra*.

- Hamer et al. (2001) sampled sediments in ballast tanks from 113 different types of vessels calling at English and Welsh ports. More than 50% of container ships viable dinoflagellate cysts, as well as 67% of tankers, 78% of bulk carriers, 54% of vehicle RoRos, 66% of car ferries, and 100% of ‘other’ types i.e. barges and tugboats. All ships sampled contained at least one harmful algal taxa, including *A. tamarense*, and many contained >20.

- Doblin et al. (2004) identified the highly aggressive and toxic *Pfiesteria* spp. (*piscicida* and *shumwayae*)in ballast water and residuals from ships calling at ports in Chesapeake Bay and the Great Lakes in 2001.

- Burkholder et al. 2007 compared phytoplankton in ballast water originating from different ports, with variable residence times in tanks, and subjected to BWE. Diversity and survival of phytoplankton in ballast water of >33 days residence time in tanks was decreased. Harmful algal taxa included *Chaetoceros concavicornis*, *Dinophysis acuminate*, *Gambierduscus toxicus*, *Heterosigma akashiwo*, *Karlodinium veneficum*, *Prorocentrum minimum*, and *Pseudo-nitzschia multiseries*.

- Bolch and Salas (2007) used ribosomal RNA sequences to confirm introduction of *Gymnodinium catenatum*, *A. tamarense* and *A. cantonella* to Australia from Asian waters via ballast water.

- Smayda (2007) also suggests that the pelagophyte *Aureococcus anophagefferens* and toxic dinoflagellate *Gymnodinium catenatum* due to their sudden new emergence in widely separated geographic regions. *Aureococcus* is example of previously undescribed species in the southern U.S. Viable cells were found in ballast water of commercial ships and bilge of a local small craft arriving from upper northeast ports. Likely dormant for 100 years but once reactivated, carried south via ship along Atlantic Coast of U.S. Prior to 1970, *Gymnodinium catenatum* was only found in Gulf of California and along the Coast of Argentina (opposite sides of American continents?) but has since been observed at 16 global sites. It is also suggested that cysts were lying dormant in sediments since 1898 and then bloomed when conditions were favorable.

- Klein et al. (2009) detected multiple species of viable *Chaetoceros* in ballast water from 52 out of 67 ships calling at ports on the east and west coasts of Canada and the Great Lakes. The ships originated from ports in the United States.

- Kang et al. (2010) tested survival and growth of phytoplankton in ballast water from commercial ships calling at the ports of Ulsan and Onsan, Korea using different media, nutrients, and temperature combinations and concluded that *Skeletonema costatum* and

Cylindrotheca closterium would be the most likely taxa to be successfully established.

- Bienfang et al. (2011) tested survival and growth of Gambierdiscus spp. collected from ballast water in a ship calling at the Port of Hawai'i (M/V Maunalei). Transit time prior to calling at the port was 9 days. Cells did not appear to be living after 9 days of transit in the ship. Inoculated coastal to determine if cells could be revived or if cysts were present, excystment would occur. After 10 weeks incubation, no growth or cysts were observed. Authors concluded that *Gambierdiscus* spp. are not likely to be dispersed via ships' ballast water due to their sensitivities to agitation, changes in salinity, temperature, light, and culture medium i.e. metals and silicate.

At least two studies have examined the potential for introduction of HABs to the Gulf of Mexico.

- Garett et al. (2011) sampled ballast water and sediments from ships calling at ports in Tampa Bay, Florida. Greater than 1,600 dinoflagellate cysts were found in 63 samples. Notably, viable *A. balechii* was collected from the same vessel at during 2 separate port calls.

- Steichen et al. (in prep) detected *Alexandrium monilatum*, *Exuviella pussilla*. *Gyrodinium* spp., *Heterocapsa* spp., *Karlodinium* spp., *Pfiesteria* spp, and *Scrippsiella* spp. both coastwise and overseas ballast water samples collected from 13 ships calling at the Port of Houston (Galveston Bay, Texas) between 2007 and 2010.

First time blooms of HAB species are suggested by Smayda (2007) and Anderson (2006) to be evidence of introduction by ships' ballast water.

In the past decade, an alarming rate of first time observations of new HAB species were observed in Florida—

1997 - 2004. First-time blooms of *Pyrodinium bahamense* & *Pseudo-nitzchia spp.* in Indian

River Lagoon.

August-November 2005 and August-November 2010. First-time bloom of *Peridinium quinquecorne* from southern Sanibel Island and southward to Seagate.

September 9 - 29, 2010. First -time bloom of *Takayama cf tuberculata* (30×10^6 cells L^{-1}) in coastal waters just off Barefoot Beach and Estero Bay, Collier County. September 22, bloom still at Barefoot Beach, Vanderbilt, and Seagate beaches and background concentrations at Naples Pier 1. By September 29, bloom had migrated to Marco Island Beaches, still medium concentrations at Barefoot Beach, and reduced to background concentrations at Vanderbilt Beach, Naples Pier, and South Marco Beach.

February 2011. *Noctiluca scintillans* bloom off Florida panhandle

July 5 - August 2, 2011. Recurring bloom of *Takayama tuberculata* plus the diatom species *Hemiaulus* atVanderbilt Beach and Naples, Florida. Present in Collier County—samples taken between 2 and 10. miles offshore of Collier beaches.

March 2011 to March 2012. First time bloom of *Pedinophyceae* in Indian River Lagoon. Called the "Super Bloom" of 2011. Extended for 131,000 acres in the Banana River Lagoon and into northern Indian Lagoon and southern Mosquito Lagoon.

Early? July 2012. First time blooms of *Aureoumbra lagunensis* in Indian River Lagoon (first time for Florida). First time bloom of *Pyrodinium bahamense* in Mosquito Lagoon and northern Indian River Lagoon.

In Texas, the 2008 *Dinophysis* spp. bloom in Texas coastal waters was a first-time observation— In March and April 2008, a rapidly increasing bloom of *Dinophysis spp.,* (predominantly *D. ovum*) was monitored in the "coastal bend" region of Texas (Swanson et al. 2008) in response to early detection by an imaging FlowCytobot (Cambell et al. 2010). This was the first observance of a *Dinophysis* spp. bloom in Texas coastal waters. Cell density patterns indicated that the bloom initiated in the nearshore and then migrated through passes in barrier islands. Highest densities reached >3,000 cells per ml in a small semi-enclosed harbor. Shellfish harvesting grounds were temporarily closed for several weeks in three nearby bays after oysters were found to contain up to 68.1 ug okadaic ccid (OA) per 100 g tissue. The Texas Parks and Wildlife Department also collected samples from four other stretches along the coast having multiple inlets through barrier islands and determined that the bloom was restricted to the coastal bend region. Two years later in early April 2010, Alabama closed its shellfish harvesting areas because *Dinophysis acuminata* were detected at 3,800 cells L^{-1} in Grand Bay (Raines 2010). According to Lisa Cambell (2010), bloom began offshore and moved into bays through the passes. (my note--but in coast of France seem to begin within the bays. Is it possible that once established, cysts are then seeded in bays?)

Increased observations of *Pseudo-nitzchia* blooms 2007 to 2011 in Mobile Bay—xAlabama Department of Public Health (Novoveska et al. ????) collected biweekly samples for phytoplankton analysis at four sites along the Alabama coast from 1999 to 2008. Thirty-seven genera and potentially 114 species were identified and included 22 potential HAB species. Bloom qualifying cell densities (10^6 L^{-1}) of *Prorocentrum minimum* were present in winter and spring samples collected in 2003, 2005, 2007, 2009, and 2011. The only other HAB in 2007 was *Karlodinium veneficum*. *Karenia brevis* cell counts approached bloom densities in October to December with average monthly densities of 2,500 to 30,000 cells per L. Highest average monthly densities for *Alexandrium monilatum* (3,000 to 4,000 cells per L) occurred in August and September. *Pseudo-nitzchia* spp., blooms at three sites on the Fort Meyer Peninsula, were found to occur in response to nitrogen rich discharges from surface and, in particular, groundwater (Liefer et al. 2009).

Pseudo-nitzchia bloom durations and recurrences increasing—

Mississippi River Delta, Louisiana, 1969-1990. Six blooms of Pseudo-nitzchia. And 18 from 1990 to 1999 (Dortch, 1999)

South Carolina., 2010. Major blooms of *Pseudo-nitzchia* occurring brackish stormwater retention ponds. (Also first time bloom of Pfiesteria)

Pfiesteria-like organisms isolated from Mobile Bay (Burkholder and Glasgow 1997)

Historic HAB events in Gulf States

1528, time of Spanish Explorers (Cabeza de Vaca)

Summers 1936-1941, Anecdotal from local residents-Offatts Bayou "dense, red slick" indicative of at least 1×10^6 cells L^{-1} Samples taken though out bayou (Gunter 1942)

Since 1947, *K. brevis* was associated with massive fish kills in near *west coast of southern Florida* (Wilson & Ray 1956)

1948 to 1950, USFWS maintained lab in Sarasota Fl and collected samples from large areas of the adjacent Gulf waters but no *K. brevis* found (Wilson & Ray 1956).

Mid-July to September 10, 1949, *Gonyaulax* spp. blooms in Offatts Bayou from (Connell and Cross 1950)

November 1952, *K. brevis* bloom occurred south-southwest of Sanibel Island (by USFWS M/V Alaska)

September 1953 to January 1955, *K. brevis* consistently found along Florida west coast, and sporadically thereafter until 1956.

1953 to 1955, samples taken along coast from Galveston, TX to Florida. No *K. brevis* observed.

September 1955 , Offatts Bayou in *Gonyaulax monilata* 500 to 1,000 cells per ml (Gates and Wilson, 1960)

September 1955, Mouth of Rio Grande to ten miles north of Port Isabel (20 square mile area) 50 to 500 cells per ml. No *K. brevis* in samples from Laguna Madre (Wilson and Ray 1956).

September 15-27, 1955 Rio Grande to 45 miles south along beach of Tamaulipas. Aerial observation of fish kills at 40 miles south of Rio Grande. September 16, 1955 aerial observation from Playa Washington observed massive fish kills for 21 miles of beach. Water sample collected 36 miles south of mouth of Rio Grande had 22,000 cells per ml of *K. brevis*. Anecdotal info from fishermen and airplane pilots stated 120 miles of coastline in Tamaulipas affected (Wilson and Ray 1956) *Gulf Fishery Investigations, USFWS, Galveston, TX*

From published and grey literature (reports, letters, maps) for HABs in the GOM.
The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute offered the most comprehensive (1954 to present) database (web address).. Alabama Department of Health (ref).

	Florida	Alabama	Mississippi	Louisiana	Texas
Dinophyceae					
Karenia brevis	1954-2013		X	X	X
Gyrodinium estuariale	X				
Pyrodinium bahamense	X				
Karlodinium veneficum		2007		X	
Dinophysis spp.				X	2008
Prorocentrum spp.				X	
Prorocentrum rhathymum	X				
Prorocentrum minimum		2003 2005 2007	X		

		2009 2011			
Heterocapsa spp.				X	
Gamberdiscus spp.					
Bacillariophyceae					
Pseudo-nitzschia spp.		X	X	X	
Thalassiosira spp.	X			X	
Rhizosoleniaceae	X			X	
Cyanophyceae					
Trichodesmium	X				
Lyngbya majuscula				X	
Anabaena spp.				X	
Microcystis				X	
Cylindrospermopsis raciborskii				X	
Pelagophyceae					
Aureococcus anophagefferens					X
Aureoumbra lagunensis					X

Pyrodinium bahamense- Tampa Bay, also in Puerto Rico
Pyrodinium bahamense var. compressum-Roy (1977)
Kota Kinabalu, Malaysia, restricted to the Indo-Pacific
occur in June–July and December–January-Adam et. Al (2011)
Paralytic shellfish poisoning-Ting, Wong (1989)

Prorocentrum minimum-
GOM 1979 (from Sierra-Betran 2005)
Yucatan 2001, 2003
Pacific coast of Mexico 1980
In Gulf of California since 1985
Sinaloa 1990, 1991, 1992 (may/july, aug/oct) 1993 (feb/mar)
San Ignacio 1998
Ballenas 1998
Mazatlan 1999
Pacific Coast 2000
Hermosillo Son 2003
Chiapas 2002-2003
La Paz 2003 mostly associated with heavy rains or large source of N

Found in ship ballast water from Manzanillo Bay- P. minimum Associated with urban wastewater discharges (Cortes-Altamirano & Agraz-Hernandez 1994)

Florida-St. Joseph Bay, Tampa Bay, Perdido Bay, southwest Florida
Alabama-Mouth of Mobile Bay, Perdido Bay
Mississippi

Number of Papers reporting Prorocentrum minimum blooms:
1995 2
1996 1
1997 2
2005 3
2007 7
2008 4
2009 2
2010 4
2011 4
2012/13 8

Surveys of phytoplankton diversity in ports and their associated water bodies would provide a baseline for future monitoring of HAB species. A recent 16S rRNA survey of dinoflagellate species in Galveston Bay (TX) detected 6 toxic taxa including those found previously in ballast water from ships calling at Galveston Bay ports (Table 1; Steichen et al., in review). Native regions and growth conditions for these taxa are listed in Table 2).

Dominant dinoflagellates	Toxic	BW	Viable
Akashiwo sanguinea [m]	*	+	
***Alexandrium* sp.** [m,g]	+	+	+
Ceratium sp. [m,g]		+	
***Dinophysis* sp.** [m]		+	
Gonyaulax sp. [m]		+	
Gymnodinium sp. [g]	+	+	+
Gyrodinium sp. [g]	+		
Heterocapsa rotundata [g]		+	+
***Noctiluca* sp.** [m]			
Oxyphysis sp. [m]		+	+
Peridinium spp. [g]		+	
***Prorocentrum* sp.** [m,g]	+	+	+
Protoperidinium sp. [m]	+	+	+
Takayama sp. [g]			
Woloszynskia sp. [g]			

Species	Native Region	Invaded location	Distribution	Reference
Akashiwo sanguinea			Temperate to tropical	Burkholder et al., 2007
***Alexandrium* sp.**		Australia	Temperate to tropical	Hallegraeff and Bolch, 1992; Scholin et al., 1996; Tomas, 1997
Alexandrium catenella	Japan and Europe	Australia	Cosmopolitan	Scholin et al., 1995; Tomas, 1997
Alexandrium minutum	Japan and Europe	Australia	Cosmopolitan	Tomas, 1997
Alexandrium tamarense	North Sea		Cosmopolitan	Pertola, Faust, Kuosa 2006
Amphidinium spp.				David et al., 2007
Ceratium sp.			Temperate to tropical	Burkholder et al., 2007; David et al., 2007
***Dinophysis* sp.**			Polar to tropical	Burkholder et al., 2007; Gollasch et al., 2000; David et al., 2007
Gonyaulax sp.			Temperate, tropical, subtropical	Burkholder et al., 2007; Hallegraeff and Bolch, 1992
Gymnodiniales spp.				Pertola, Faust, Kuosa 2006
Gymnodinium catenatum	Japan and Europe	Australia		Hallegraeff & Bolch 1993
Gyrodinium sp.				David et al., 2007
Heterocapsa rotundata			Temperate	Burkholder et al., 2007; Pertola, Faust and Kuosa 2006
Oxyphysis sp.			Cosmopolitan	Burkholder et al., 2007
Peridiniales spp.			Cosmopolitan; Freshwater/estuarine	Pertola, Faust, Kuosa 2006
Peridinium grenlandicum				Pertola, Faust, Kuosa 2006
Peridinium sp.			Cosmopolitan	Burkholder et al., 2007; Hallegraeff and Bolch, 1992
Prorocentrum minimum	English Channel	Baltic Sea	Cold, temperate, tropical	Burkholder et al., 2007; Olenina et al., 2010
Protoperidinium spp.			Cold, temperate, tropical	Burkholder et al., 2007; Hallegraeff and Bolch, 1992; David et al., 2007

Growth requirements for first time and recurring HABs in the GOM

Karlodinium veneficum—Gymnodinoid "naked" dinoflagellate (ref for describer) typically occuring in shallow, stratified coastal ecosystems, mixotrophs, background densities 10^2-10^3 cells per ml, and bloom densities 10^4-10^5 cells per ml. Produces "karlotoxins" with hemolytic, icthyotoxic, and cytoxic properties. First observed in Walvis Bay (Namibia, Africa) as a bloom occurring in the upper meter of highly anoxic water. *K. veneficum* is frequently associated with fish kills. Grows at temperatures between 7-24°C and salinities of 10-34 psu. Responsible for 30,000 to 50,000 fish kill occurring from September 26 to 29, 2005 in Chesapeake Bay and blooms of increasing cell density followed for next three years (Place et al. 2012).

Prymnesium parvum* & *P. saltans. Haptophyte. FW strains are apparently restricted to one site in Germany with high sulfate and chloride concentrations. Most marine species have clear tendencies to bloom in brackish water embayments and estuaries. Salinity is primary factor controlling distribution – in culture died at salinities less than 1.12 ppt but grew well from 5.6 to 22.5 ppt

From Brand 2012
Karenia brevis-salinity 5 to 24 PSU, K. brevis has a compensation point around 6–8 mmol m_2 s_1 and saturation around 35–120 mmol photon m_2 s_1. All Karenia species have chlorophylls a and c; and have fucoxanthin, 190-butanoyloxyfucoxanthin, 190-hexanoyloxyfucoxanthin, and 19-hexanoyloxyparacentrone 3-acetate (gyroxanthindiester) as accessory pigments instead of peridinin (Steidinger et al., 2008a). K. brevis and K. mikimotoi also have gyroxanthin (Richardson and Pinckney, 2004). While K. brevis appears well adapted to low light levels, it appears to use the photoprotective xanthophyll cycle pigments diadinoxanthin and diatoxanthin to tolerate high light intensity when it accumulates at the surface during the day (Evens et al., 2001). Studies with field populations of K. brevis show that it can use nitrate, ammonia, urea, glutamate, and dissolved organic matter from Trichodesmium (Bronk et al., 2004). Sinclair et al. (2009) have shown that K. brevis takes up ammonia and urea at night as well as day, which could be important in obtaining nutrients during diel vertical migration. Baden and Mende (1979) showed that K. brevis can use glycine, valine, and methionine. Shimizu et al. (1995) found that urea and glycine added to cultures of K. brevis stimulates a shift to a more heterotrophic mode, and increased biomass and brevetoxin amount 2–4 fold. Mulholland et al. (2004, 2006) have shown that K. brevis can utilize dissolved organic matter that has been excreted by Trichodesmium. Vargo and Shanley (1985) have shown that K. brevis uses organic

P. minimum is a toxic species; it produces venerupin (**hepatotoxin**) which has **caused shellfish poisoning resulting in gastrointestinal illnesses in humans and a number of deaths**. This species is **also responsible for shellfish kills** in Japan and the **Gulf of Mexico,** Florida (Nakazima, 1965,Nakazima, 1968, Okaichi and Imatomi, 1979, Tangen, 1983, Shimizu, 1987, Smith, 1975, Steidinger and Tangen, 1996)
Heil et. Al (2005) distributed geographically in temperate and subtropical waters, Japan; France; Norway; Netherlands; New York, USA, also Mediterranean coast of France-Heil et. Al (2005) high temperatures, incident irradiances, low to moderate salinities in coastal and estuarine environments (often characterized as eutrophic), high amount of physiological flexibility-Heil et. Al (2005) harmful to humans via shellfish poisoning, relationship with increasing eutrophication-Heil et. Al (2005)

Detected in Ballast Water Yes-Yoshida et. Al (1996)

Pseudo-Nitschia -cosmopolitan in coastal waters (found in both coastal and open water)
Salinity tolerance appears to be species specific (Thessen et al. 2005)
Coast of Texas & Louisiana 1 to 35 psu, Alabama- variable from fresh to 35
Occurs year round in Alabama-Mobile Bay and Perdidio Bay (Liefer 2012)
euryhaline, eurythermal
Toxigenic species are typically coastal

(Sea of Japan 12-20 deg C
(China Sea 12-20 deg C)

‘Hotspots’ for HABs in the Gulf of Mexico?

The study of “hotspots” is a relatively new approach for determining factors contributing to HABs. Hotspots are highly localized and regularly recurring bloom events. Data from intensive multi-year monitoring of biotic and abiotic parameters prior to, during, and after hotspot bloom events are then integrated into ocean models to forecast future events. Modeling HAB hotspots is one of the latest target areas for the National Centers for Coastal Ocean Sciences programs (ECOHAB, MERHAB, PCM, CHRP, and NGOMEX). One of these hotspots is the Juan de Fuca Eddy in the Pacific Northwest (http://www.ecohabpnw.org). This cyclonic eddy forms at the each spring between opposing northwest flowing currents and southeast upwelling and topographic jets and, in doing so, entrains nutrients and initiates high density *Pseudo-nitzschia* spp. blooms (Trainer et al. 2009). In California, upwelling jets and coastal land use in two regions, Monterrey and San Pedro, for clues to initiation of *Pseudo-nitzschia* blooms (http://oceandatacenter.ucsc.edu/MBHAB/hotspots/).

Undoubtedly, the west coast of Florida with its quasi-annual, recurrences of *Karenia brevis* blooms is one of the most studied HAB hotspots in the U.S. (refs) The multi-agency collaborative mapping and prediction system, harmful algal bloom operational forecast system (HAB-OFS, http://tidesandcurrents.noaa.gov/hab/) for *K., brevis* in the Gulf of Mexico serves as a model for design of similar systems in U.S. Data from remote sensing monitoring of blooms as well as wind speed/direction, ocean current speed/direction, temperature, light penetrance, barometric pressure, sea level, tide, and salinity data can be used for “hind-casting” identification of previously unrecognized factors.

After assembling data for all harmful algae species observed within the Gulf of Mexico and associated bays & estuaries, either at bloom densities, $\geq 1 \times 10^6$ cells L^{-1} (Smayda, ref) or background densities, typically <1,000 cells L^{-1}, dates and durations of blooms, and the latitudes-longitudes, if given, or approximate positions from text descriptions, no other HAB ‘hotspot’ phenomena, besides *K. brevis* blooms on the West Florida Shelf, were obvious. However, given the almost 100 year documentation of ever-increasing bloom periodicity and duration of extant HAB species and the first-time observations of new or rare (to the GOM) HAB species, one could convincingly argue that all of Gulf of Mexico, including Cuba, is a hotspot or rather ‘test bed' for introduction and of new HAB taxa and either successful or failed establishment in their adapted life strategy or niche.

Again, consider the recurrence of *K. brevis* blooms on the West Florida Shelf. Despite several decades of studies, the initiation factors for *K. brevis* blooms in the Gulf of Mexico are still poorly understood. However it is largely accepted that they are initiated offshore, seeded by cysts in bottom sediments or water column (Steidinger, 1975). More recent surveys of cyst distributions in sediments from the West Florida Shelf provide additional support (Kang, 2010). *K. brevis* also appears to be strategically adapted for extended bloom durations in oligotrophic, offshore waters through its ability to downward migrate to bottom sediments and acquire organic and inorganic N at the sediment-water interface (Sinclair and Kamykowsi, 2008) even in the dark (Sinclair et al., 2006). And, there is increasing evidence to that *K. brevis* utilizes organic N, fixed by co-occurring cyanobacteria (Havens et al., 2004).

The adaptive life strategy or 'niche' of *K. brevis* places it squarely as a "Type VI—Coastal Entrained Taxa" within Smayda's (2002) "Turbulence-Nutrient Matrix Along an Onshore-Offshore Continuum," a diagonal gradient of eight dinoflagellate life form types (fig. 1).

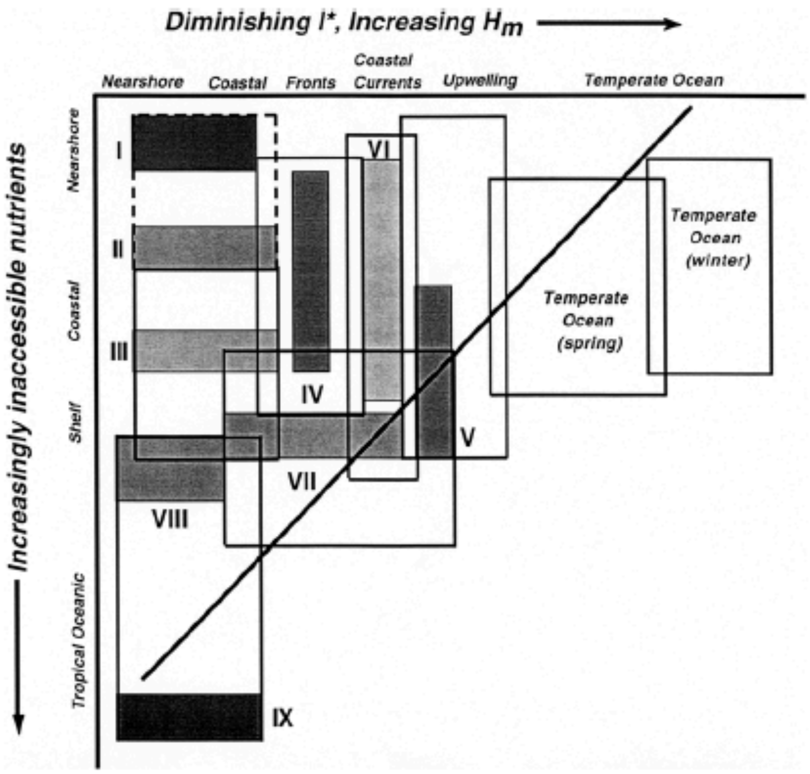

Figure 1. Smayda's (2002) predominant dinoflagellate life forms associated with a nutrient requirement and turbulence tolerance matrix lies between near shore to temperate- or tropical-oceanic habitats. (**NOTE:** Permission has not yet been obtained from publisher for reproduction)

Type I. Gymnodiniods that prefer bays & estuaries and have the highest nutrient requirements (e.g. *Gymnodinium* spp, *Heterocapsa rotundata*);

Type II. Peridinians/*Prorocentroids* that prefer coastal to nearshore and have greater nutrient requirements (e.g. *Heterocapsa triquetra*, *Scrippsiella trochoidea*, *Prorocentrum micans*, *P. minimum*);

Type III. Ceratians that prefer coastal to nearshore and have lower nutrient requirements (e.g. *Ceratium tripos*, *C. fusus*, *C. lineatum*);

Type IV. Frontal Zone taxa that prefer frontal zones near edge of shelf (e.g. *Karenia mikimotoi*, *Alexandrium tamarense*);

Type V. Upwelling Relaxation taxa that prefer upwelling zones i.e. at sharply declining rather than gradual slopes (*Gymnodinium catenatum*, *Ligulodinium polyedrum*);

Type VI. Coastal Current Entrained taxa that prefer region between offshore current and nearshore at the edge of the coastal-shelf boundary (e.g. *Karenia brevis*, *Ceratium* spp., *Pyrodinium bahamense*);

Type VII. Dinophysoids that prefer the continental shelf and frontal zones (e.g. *Dinophysis acuta*, *D. acuminate*)

Type VIII. Tropical oceanic flora (e.g.*Amphisolenia*, *Histionies, Ornithocercus*, *Ceratium* spp.);

Type IX. Tropical shade flora (e.g. *Gambierdiscus* spp., *Pyrocystis noctiluca*, *Pyrocystis pyriformis*)

Oceangoing Ships calling at Major Ports in Gulf States, 2008-2012

Florida

Alabama

Mississippi

Louisiana

Estuaries—Mississippi River Delta Estuary: because Mississippi River is leveed, any HABs in ballast water discharges would be expected to remain in the river and then flow downstream to the coastal zone. Navigation channels cut perpendicular to coast, allow for GOM water to intrude into the wetlands. Vermilion River (bayou) was created by forcing of seawater into the wetlands (bottom up). Atchafalaya River is formed by a watershed (top down)

Texas

Panama Canal expansion and impacts on Gulf States (Move to discussion?)

The Panama Canal is currently undergoing an expansion to add a third lane of locks that are sized for the next class of 150,000 to 170,000 DWT "megaships" (length 366 m, beam 49 m, draft 15 m). Completion scheduled for late 2014, will allow for direct transits of "megaships" between Asia and the Gulf of Mexico. XX "new panama" ships (12,000 TEU) have already been added to the world fleet (Panama Canal Authority).

USACE & US markets project to increase exports and imports via U.S. Gulf of Mexico and South Atlantic ports because of their geographic proximity to the canal. USACE anticipates a shift in US grain exports from the Midwest via the Columbia/Snake Rivers/trans-Pacific Route to Asia to the Mississippi River/Gulf of Mexico/trans-Pacific Route (USACE 2012). Port of New Orleans is the leading port for grain exports in the U.S. and is expected to increase in this capacity. Ports able to handle new panama ships require a minimum channel depth of 50 ft, width xx ft, turning basin x ft, as well as larger cranes and docks. However, none of the Gulf States ports currently have channel depths of ≥ 50 ft. USACE has been evaluating which port expansions would be economically justified for federal appropriations. Proportion of local cost share is also a major factor in the evaluation. The Port of Mobile (AL) recently deepened its channel to 45 ft.

Also- inland waterways- GIWW, EIWW

Expansion of Gulf States ports also affects health of coastal zones.

Table X. Depth, channel width, turning basin, cranes, docks etc. for each major port in Gulf States that could be expanded.

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Appendix A.

Ballast Water Management

As a ship takes on ballast at one port, it is likely that all organisms in that water have potential to be picked up and transported to wherever the ballast water is then discharged. Any organisms that are released into the new environment are considered "biological invaders" and are often invasive species (Carlton, 2001). Some invasions have dramatic economic and ecological consequences (Miglietta & Lessios, 2009). An estimated 10,000 different species of marine microbes, plants and animals may be carried globally in ballast water each day (Carlton, 1999; Raaymakers, 2002). The ballast capacity of a vessel varies from about 1 m^3 in sailing or fishing boats to over 100,000 m^3 in commercial cargo carriers

(Hayes, 2002). Shipping moves over 80% of the world's commodities and transfers approximately 3 to 5 billion tons of ballast water internationally each year (Tsolaki & Diamadopoulos, 2010). All of the ports in the U.S. receive over 79 million metric tons of ballast from foreign ports (Globallast Project, 2010). Of these, the State of Texas receives over 31 million tons of ballast discharge from all ship types (NBIC, 2008) and it has become crucial to develop a maintenance program for a ship's ballasting operations to prevent further spread of invasive species.

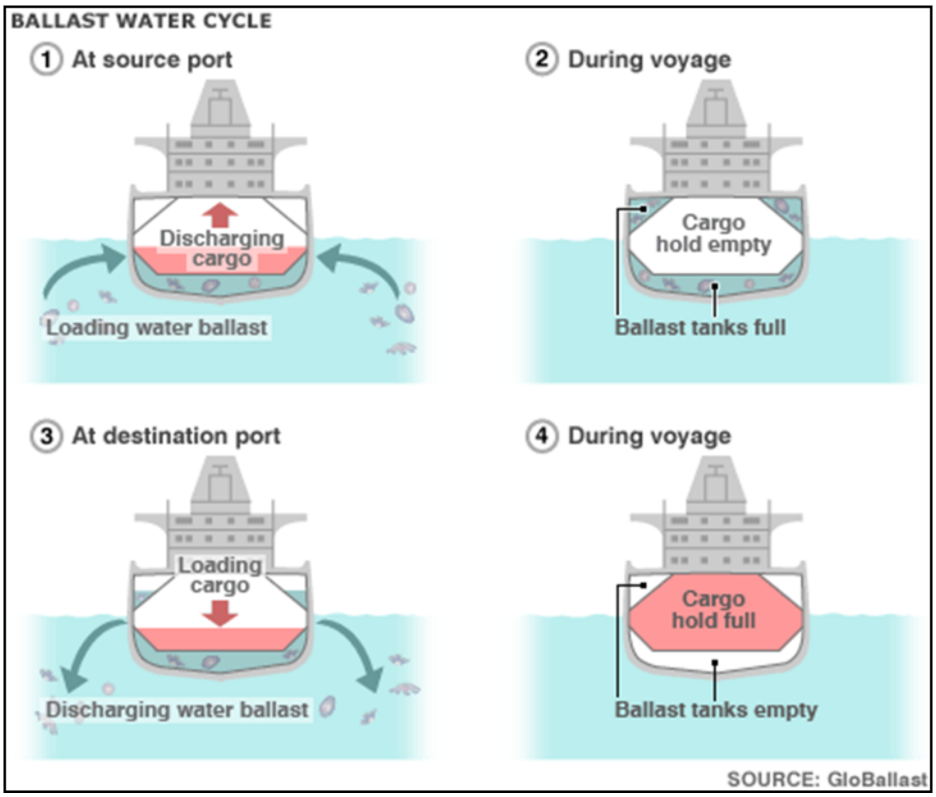

Figure 1: Ballast water uptake and discharge in cargo ships (www. globallast.imo.org)

There are two basic methods for the BWE. The most common method is to completely 'empty' and then 'refill' (E/R) ballast tanks with fresh seawater. However, to prevent the ship from listing (tilting), tanks must be carefully and precisely emptied and refilled in a sequential order. The other method is 'flow-through' (F/T) in which rather than each tank being filled and emptied, they are filled continuously with fresh seawater (Murphy et al., 2008). In the course of this study, it was discovered when some vessels are in port, they will not discharge any water at all but transfer residual ballast from tank to tank to maintain buoyancy as cargo is loaded or off loaded.

In the Great Lakes region of the U.S., all vessels are required to chemically (e.g. chlorine or UV oxidation) or physically (e.g. heat or filtration) treat ballast water to remove all living organisms before discharging. Operating at the port of origin, filtration can dramatically reduce densities of larger plankton and other taxa in the ballast intake stream without generating chemical or thermal residuals; however, this can significantly delay departure and cut into profits (Rigby, 2001; Cangelosi, 2002). Additionally, most chemical treatment systems risk the delivery of potentially toxic substances into port waters or the open ocean, and the cost of operation alone is estimated to be between $0.24 and $40 per m^3 of ballast volume (Rigby, 2001). Treatment of ballast water in the Great Lakes region is estimated to cost millions of dollars each year for U.S. and international merchant fleets (Rigby, 2001).

Globally, the introduction of aquatic nonindigenous species (ANS) from discharge of ships' ballast water or detachment from ships' hulls have been viewed as an increasing threat to coastal and inland aquatic ecosystems for more than 100 years (Ruiz & Crooks, 2001; Ruiz & Reid, 2007). Most research of ANS in the U.S. has been focused in the Great Lakes and Chesapeake Bay (Ruiz & Crooks, 2001). At least 126 out of 180 identified marine invasive species were introduced into the Great Lakes and associated waterways via ships' ballast water (Bailey & Smith, 1981; Mills et al., 1993; Reavie et al., 2010). One of the more familiar ANS introductions in the U.S. is the European Zebra Mussel (*Dreissena* *polymorpha*), that is now found in more than 40% of inland waterways (Raaymakers, 2002). In the late 1980's, ecologists began to recognize the global transfer of toxic phytoplankton (Hallegraef, 1998; Smayda, 2007) and human pathogenic bacteria (McCarthy, 1992; McCarthy, 1994; Colwell & Huq, 2001) in ships' ballast water.

In response to concerns such as these, the International Marine Organization, (IMO), was created to supply a set of rules that could be followed on a global scale. Currently, every ship that enters the maritime borders of a country, including its own, and intends to load or discharge ballast must undergo 100% ballast exchange in waters at least 200 nautical miles offshore and at least 200 m deep. Mid ocean exchange can be dangerous for vessels that require ballast to maintain balance during travel. Not only is it a challenge for some ships, it may be proven to be an inconsistent means of the prevention of spreading invasive species (SERC, 2004).

Alternative methods for ballast exchange are either costly or time consuming. These are both major concerns for the shipping industry (GLC, 2000). BWE is the only treatment method available at present that has obtained international acceptance and remains the primary treatment method identified by all of the countries that currently have some form of control in place. Very little information is available concerning the uses or choices pertaining to other treatment options. Ballast water is absolutely essential to the safe and efficient operation of modern shipping, providing balance and stability to un-laden ships, however, it may also pose a serious ecological, economic and health threat (Globallast Project, 2010).

Exclusive Economic Zone as Delineation for Ballast Water Management

The exclusive economic zone (EEZ) is defined by the United Nations Convention on the Law of the Sea as "a sea zone over which a state (country) has special rights over the exploration and use of marine resources, including production of energy from water and wind." It is generally understood that an EEZ stretches from the seaward edge of a state's territorial sea out to 200 nautical miles (nm) from its coast. The EEZ includes the territorial sea as well as continental shelf beyond the 200 mile limit (Figure 1). The 200 nm boundary, formally recognized in May 2008 by all parties of the United Nations, replaces the three nm mile boundary, equivalent to the firing distance of a 17th century cannon. The idea of the "freedom of the seas" essentially declares the rights of maritime traders to "navigate through the global expanse of the oceans as one sees fit, carrying what cargo one wishes" (Hawkins, 1982). The delimitation of the EEZ is inexplicably linked to the delimitation of the jurisdictional 'Continental Shelf' which is defined as that part of the continental margin extending 200 nm from a country's coastal baseline and includes the continental rise and slope ([Robertson, 1992 #6108]; [Brilmayer, 2001 #6128]). Figure 2 illustrates the EEZs for the world's coastal and island nations.

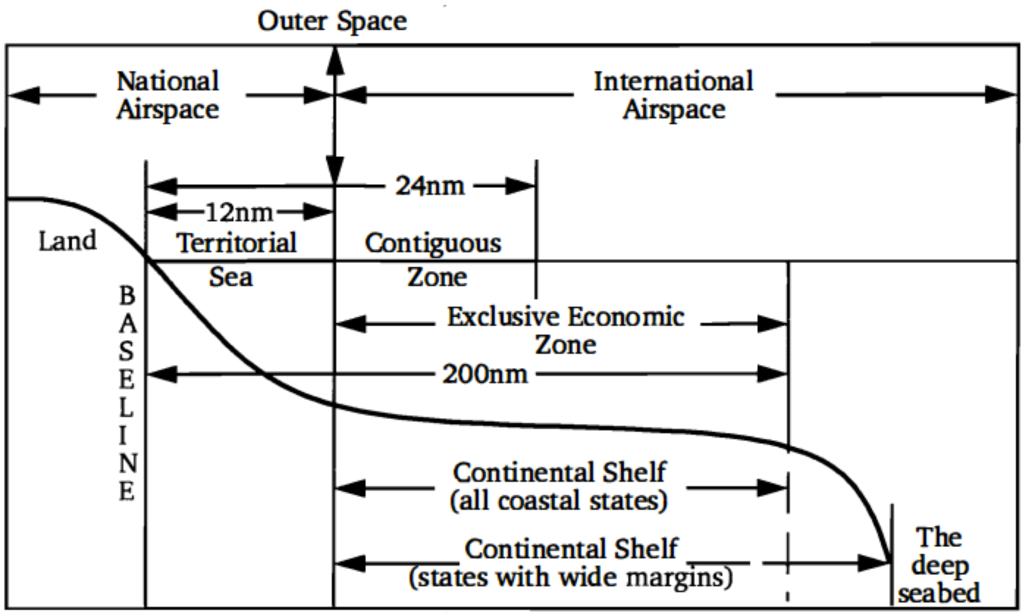

Figure 1. Jurisdictional zones for coastal and island nations [Robertson, 1992 #6108]. A country has indisputable sovereignty to its 'Territorial Sea,' 12 nm from the coastal baseline i.e. mean low tide mark, and 'Contiguous Zone,' 24 nm from the coastal baseline, but only sovereign rights to its 'Continental Shelf 'and EEZ, both delimited at 200 nm from the coastal baseline. Coastal countries having wider continental margins can petition the United Nations to extend their jurisdictional continental shelf to 350 nm ([Brilmayer, 2001 #6128]).

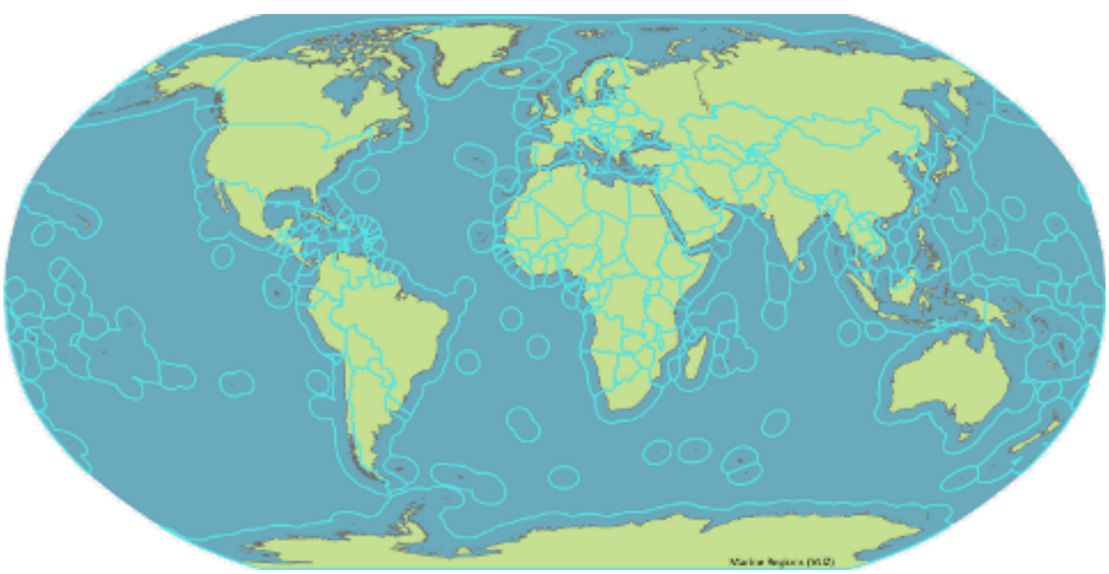

Figure 2. EEZ boundaries of the world.

International Laws for Pollution from Ships and Ballast Water

The International Maritime Organization (IMO) was established in 1948 by the United Nations "to provide machinery for cooperation among governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships" ([IMO, 2012 #6113]). The *International Convention for the Prevention of Pollution from Ships*, better known as 'MARPOL,' was adopted by IMO member states, i.e. countries, in 1973 but not ratified until 1983 to establish regulations for the prevention of pollution caused by operational or accidental causes. Later annexes added specific handling regulations for oil, noxious liquids carried in bulk, harmful substances in packaged form, and air pollution, as well as establishing that vessel sewage discharges and disposal of garbage must occur beyond the 12 nm territorial sea delimitation, but failed to address pollutants and potentially invasive species or agents of disease in ballast water ([IMO, 2012 #6113]). MARPOL also defined certain sea areas as "marine protected areas" (MPAs) that require additional mandatory measures for the prevention of pollution. There are approximately 2,679 MPAs in coral reef areas worldwide (WRI, 2012) including coral the Florida Keys National Marine Sanctuary (Alexander, 2005).

In 2004, the IMO adopted the *International Convention for the Control and Management of Ships Ballast Water and Sediments* for the management of ballast water ([IMO, 2012 #6113]), commonly referred to as the "Ballast Water Convention." In summary, this convention states that vessels should undergo complete ballast water exchange (BWE) beyond a 200 nm delimitation, i.e. a country's exclusive economic zone (EEZ) before proceeding to the port of destination. The rationale is that any species thriving in lower salinity coastal waters will not be able to survive when released into higher salinity, open ocean water, and vice versa.

Transits that remain within a country's EEZ (i.e. 200 nm from shore) are defined as 'coastwise' and ballast taken up in these waters are considered to be from the same 'geographic' waters and therefore do not require BWE. Vessels that transit beyond the EEZ regardless of port of departure (i.e. domestic or foreign) are classified as 'overseas' and require one of three management procedures: "1) complete mid-ocean BWE on all tanks containing this ballast water before the ballast from these tanks are discharged into domestic waters; 2) retain this ballast water on board the vessel while in domestic waters; 3) prior to the vessel entering a country's contiguous zone, use an alternative environmentally sound method of BWM. However, it is important to emphasize that the EEZ is merely a political jurisdictional boundary and has no bearing on the ocean currents and wind patterns that provide natural transport of planktonic organisms.

The "Ballast Water Convention" will not enter into force until 12 months after the ratification by at least 30 coastal and/or flag states, contingent upon these states collectively representing 35% of the world merchant shipping tonnage (IMO, 2011). To date, 31 countries have adopted the convention, with ~26% of world tonnage represented, indicating that implementation is eminent (Table 1). A number of countries including Argentina, Australia, Canada, Chile, Israel, New Zealand, United Kingdom, and the United States, as well as regions known as 'Sea Areas' such as the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (formerly Kuwait Action Plan Region), Northwest Europe/North Sea Area, Baltic Sea Area, Mediterranean Sea Area, and the Antarctic Area have developed their own specific regulations for vessel transit operations and BWM within their territorial waters (Table 2) (IMO, 2011). Only ten countries currently have not developed their own specific regulations for ballast water management: Denmark, Finland, Germany, Greece, Italy, Japan, Netherlands, Norway, Singapore, and Sweden.

Regulation of ship ballasting activities

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Ballast Water Management in United States Waters

In countries that enforce IMO BWM practices, the maritime and environmental sectors are often regulated by different authorities or agencies that potentially have conflicting policies. This is the case in the U.S. The U.S. Federal Maritime Commission (an independent federal agency) and the U.S. Maritime Administration (Dept. of Transportation) regulate foreign and domestic shipping commerce, respectively. The "Water Permits" and "Oceans and Coastal Protection" divisions of the U.S. Environmental Protection Agency (an independent federal agency) are responsible for setting limits on pollutant discharges from vessels as charged by amendments to the Clean Water Act (CWA) and the National Pollutant Discharge Elimination System that include ballast water (EPA, 2011). The USCG is charged with enforcing or assisting with the enforcement of all U.S. laws and regulations applicable to U.S. territorial waters, as well as required by the National Invasive Species Act of 1996 to establish and update regulations for BWM (USCG, 2011).

The National Oceanographic and Atmospheric Administration (NOAA; Dept. of Commerce) and the U.S. Fish and Wildlife Service (Dept. of Interior) are authorized by the Non-Indigenous Aquatic Nuisance Prevention and Control Act to have joint responsibility for control and management of invasive aquatic species. In addition to federal regulations, several states such as California, Hawaii, Maryland, Michigan, Ohio, Oregon, Pennsylvania, Virginia, Washington, and Wisconsin have autonomous delimitations of their submerged lands and outer continental shelf (Figure 4) and have enacted their own laws for ballast water practices that are more stringent that those established by the USCG (Albert et al., 2010). For example, California state regulations allow “zero detectable living organisms” for organisms that are ≥ 50 µm and <50 ≥10 µm, all bacteria (typically >0.2 µm), and all viruses and viral particles (<250 nm), whereas the USCG regulations specifically list limits for *Vibrio cholerae* (< 1 CFU per 100 ml), *Escherichia coli* (< 126 CFU per 100 ml), and *Intestinal enterococci* (< 33 CFU per 100 ml), < 10^3 living bacteria, and < 10^4 viruses and viral particles per 100 ml (ref = OW paper). New York state regulations are a combination of limits set by California, the IMO, and the USCG (Table 3).

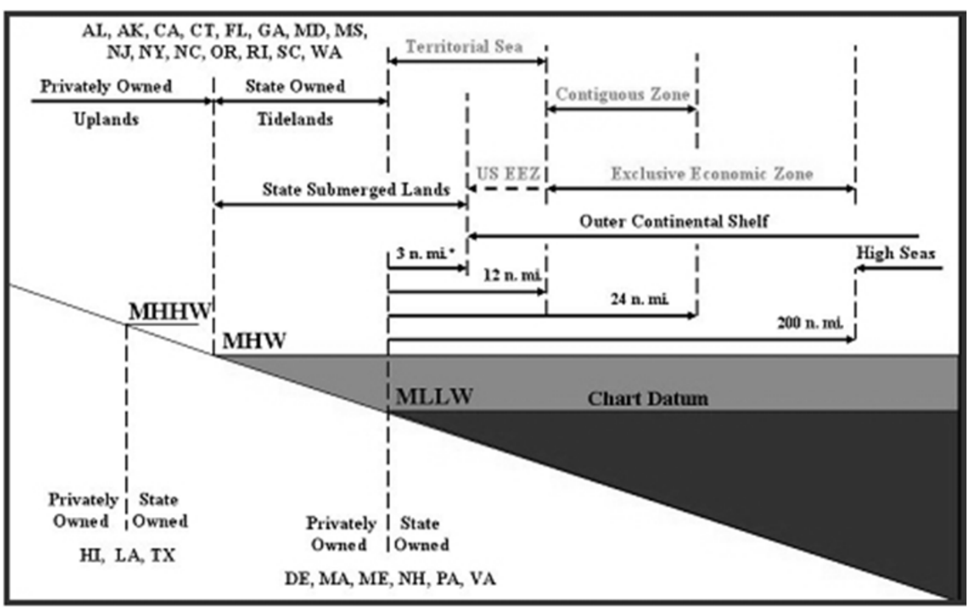


Figure 2. Delineations of boundaries for U.S. territorial waters including the EEZ (NOAA, 2012).

The USCG and the Smithsonian Environmental Research Center created the "National Ballast Information Clearinghouse" to compile data from BWM reports from vessels calling at port in the U.S. NBIC data are analyzed by the Aquatic Nuisance Species (ANS) Task Force, a government agency dedicated to preventing and controlling aquatic nuisance species (ANS, 2012). The IMO and USCG recognize two major issues with BWE. The first, to safely conduct a ballast exchange mid ocean depends entirely on sea and weather conditions, leaving the ultimate decision up to the captain. And, the second, without being rinsed, the ballast tanks will continue to hold residual water and organisms will then be flushed out when new water is added and released.

Albania	Algeria	Angola	Antigua & Barbuda	Argentina
Australia	Austria	Azerbaijan	Bahamas	Bahrain
Bangladesh	Barbados	Belgium	Belize	Benin
Bolivia	Bosnia & Herzegovina	Brazil	Brunei Darussalam	Bulgaria
Cambodia	Cameroon	Canada	Cape Verde	Chile
China	Colombia	Comoros	Congo	Cook Islands
Costa Rica	Côte d'Ivoire	Croatia	Cuba	Cyprus
Czech Republic	North Korea	DR Congo*	Denmark	Djibouti
Dominica	Dominican Republic	Ecuador	Egypt	El Salvador
Equatorial Guinea	Eritrea	Estonia	Ethiopia	Fiji
Finland	France	Gabon	Gambia	Georgia
Germany	Ghana	Greece	Grenada	Guatemala
Guinea	Guinea-Bissau	Guyana	Haiti	Honduras
Hungary	Iceland	India	Indonesia	Iran
Iraq	Ireland	Israel	Italy	Jamaica
Japan	Jordan	Kazakhstan	Kenya	Kiribati
Kuwait	Latvia	Lebanon	Liberia	Libya
Lithuania	Luxembourg	Madagascar	Malawi	Malaysia
Maldives	Malta	Marshall Islands	Mauritania	Mauritius
Mexico	Monaco	Mongolia	Montenegro	Morocco
Mozambique	Myanmar	Namibia	Nepal	Netherlands
New Zealand	Nicaragua	Nigeria	Norway	Oman
Pakistan	Panama	Papua New Guinea	Paraguay	Peru
Philippines	Poland	Portugal	Qatar	South Korea
Moldova	Romania	Russian Federation	St. Kitts & Nevis	Saint Lucia
St. Vincent & Grenadines	Samoa	San Marino	Sao Tome & Principe	Saudi Arabia
Senegal	Serbia	Seychelles	Sierra Leone	Singapore
Slovakia	Slovenia	Solomon Islands	Somalia	South Africa
Spain	Sri Lanka	Sudan	Suriname	Sweden
Switzerland	Syria	Thailand	Macedonia	Timor-Leste
Togo	Tonga	Tanzania	Tunisia	Turkey
Turkmenistan	Tuvalu	Uganda	Ukraine	United Kingdom
Trinidad &Tobago	USA	United Arab Emirates	Uruguay	Vanuatu
Venezuela	Viet Nam	Yemen	Zimbabwe	
Assoc. Members:	Hong Kong, CN	Macao, CN	Faroe Islands, DK	

Table 1. Countries that comply with the IMO Ballast Water Convention (IMO, 2011).

Country	Authority	Ships Affected	Methods
Argentina	Argentine Maritime Authority	All from overseas ports	Discharge, change or treat
Australia	Australian quarantine and inspection service (AQIS)	All from overseas ports	Ballast exchange in deep ocean areas
Brazil	Not known	All ships	Notification of where ballast was picked up to avoid anchoring for inspection
Canada	Canadian coast guard	All- ships headed to Great Lakes must abide by U.S. regulations	Ballast exchange in open ocean, retention on board, discharge at reception facilities
Chile	Chilean navy	All ships from abroad	Ballast exchange in deep water, in tank treatment- 100 grams per ton of sodium hypochlorite or 14 grams of calcium hypochlorite
Israel	Ministry of transport	All ships with ballast pumped out in port	Exchange in open water
Hong Kong, China	No legal requirement- Hong Kong Marine Dept.	Not specified	Not specified
New Zealand	New Zealand Ministry of Fisheries	Ships with foreign ballast	Ballast exchange in deep water, use of fresh water in tanks, on shore facility, in tank treatment
United States	U.S. Coast Guard	All ships with ballast tanks that picked up foreign water	Ballast water exchange, ballast water management policy, discharge to facility
United Kingdom	IMO	All ships wishing to discharge at Flotta Terminal	Discharge to reception facilities

Table 2. Countries having BWM requirements in addition to or instead of IMO rules (IMO, 2011).

	Size: ≥ 50	Size: < 50pm, but "Lakers**"	Bacteria	Viruses	Compliance	Date
IMO BW Treaty (Reg. D-2)	< 10 "viable" organisms per m^3	< 10 "viable" organisms per ml	*Vibrio cholera* < 1 CFU per 100ml *E. coli* < 250 CFU per 100 ml *Intestinal enterococci* < 100 CFU per 100 ml	----	N/A	2009-2019 (varies by vessel construction date/BW capacity/survey date as per Reg B-3)
US Negotiating Position (BWM/CONF/13 & 14)	< 0.01 "living" organisms per m^3	< 0.01 "living" organism per ml	*Vibrio cholera* < 1 CFU per 100 ml *E. coli* <126 CFU per 100 ml *Intestinal enterococci* < 33 CFU per 100 ml	----	N/A	ASAP
USCG NPRM (74 FR 44632)	[PHASE 1 STANDARD] < 10 organisms per m^3	[PHASE 1 STANDARD] < 10 organisms per ml	[PHASE 1 STANDARD] *Vibrio cholera* < CFU per 100 ml *E. coli* < 250 CFU per 100 ml *Intestinal enterococci* < 100 CFU per 100 ml	[PHASE 1 STANDARD] ----	Yes	On delivery for all vessels constructed on or after 01/01/12 All other vessels: varies by BW capacity & drydock cycle with latest compliance date of Ast 1 drydock after 01/01/16
	[PHASE 2 STANDARD] < 1 organism per 100 m^3	[PHASE 2 STANDARD] < 1 organism per 100 ml	[PHASE 2 STANDARD] *Vibrio cholera* < 1 CFU per 100 ml *E. coli* < 126 CFU per 100 ml *Intestinal enterococci* <33 CFU per 100 ml < 10^3 "living" bacterial cells per 100ml	[PHASE 2 STANDARD] < 10^4 viruses or viral-like particles per 100 ml	Yes	On delivery for all vessels constructed on or after 01/01/16 All other vessels: 1st drydocking after 01/01/2016, unless prior installation of Phase 1 BW system, in which case 5 years from such installation
CALIFORNIA (VGP 401 cert/State regulations)	[INTERIM STANDARD] 0 detectable "living" organisms	[INTERIM STANDARD] US negotiating position	[INTERIM STANDARD] *Vibrio cholera* IMO Reg D-2 # *E. coli* US negotiating position *Intestinal enterococci* US negotiating position < 10^3 bacteria per 100 ml	[INTERIM STANDARD] < 10^4 viruses per 100 ml	N/A	01/01/10 – 01/01/16 (varies by vessel construction date/BW capacity)
	[FINAL STANDARD] 0 detectable " living" organisms	[FINAL STANDARD] 0 detectable "living" organisms	[FINAL STANDARD] 0 detectable "living" organisms	[FINAL STANDARD] 0 detectable "living" organisms	N/A	1/1/20
ILLINOIS (VGP 401 cert)	IMO Reg D-2 # (as daily average)	IMO Reg D-2 # (as daily average)	*Vibrio cholera** *E. coli* IMO REg D-2 # (as daily average) *Intestinal enterococci* IMO Reg D-2 # (as daily average)	----	Yes	Constructed before 01/01/12: 01/01/16 Constructed after 01/01/12: Prior to operation
INDIANA (VGP 401 cert)	IMO Reg D-2 # b (as daily average)	IMO Reg D-2 # b (as daily average)	*Vibrio cholera** *E. coli* IMO REg D-2 # (as daily average) *Intestinal enterococci* IMO Reg D-2 # (as daily average)	----	No	Constructed before 01/01/12: 01/01/16 Constructed after 01/01/12: Prior to operation
MICHIGAN (VGP 401 cert/State permit)	Use a treatment process approved by MI DEQ	Use a treatment process approved by MI DEQ	Use a treatment process approved by MI DEQ	Use a treatment process approved by MI DEQ	No	1/1/07
MINNESOTA (VGP 401 cert/State permit)	IMO Reg D-2 # b (as daily average)	IMO Reg D-2 # b (as daily average)	*Vibrio cholera** *E. coli* IMO Reg D-2 # (as daily average) *Intestinal enterococci* IMO Reg D-2 # (as daily average)	----	Yes	Constructed before 01/01/12: 01/01/16 Constructed after 01/01/12: Prior to operation
NEW YORK (VGP 401 cert)	[INTERIM STANDARD] < 1 "living" organism per 10 m^3	[INTERIM STANDARD] < 1 "living" organism per 10 ml	[INTERIM STANDARD] *Vibrio cholera* IMO Reg D-2 # (as daily average) *E. coli* US negotiating position *Intestinal enterococci* US negotiating position	[INTERIM STANDARD] ----	Yes (vessels operating exclusively within Lakes Ontario and Erie are exempt)	01/01/12 (subject to case-by-case time extension)
	[FINAL STANDARD] Same as California #s	[FINAL STANDARD] US negotiating position	[FINAL STANDARD] *Vibrio cholera* IMO Reg D-2 # *E. coli* US negotiating position *Intestinal enterococci* US negotiating position Other bacteria: Same as CA interim #s	[FINAL STANDARD] Same as California interim #s	Yes (vessels operating exclusively within Lakes Ontario and Erie are exempt)	Constructed on or after 01/01/13 (subject to case-by-case time extension)

Table 3. International, federal and state ballast water discharge standards with regard to organisms as of June 28, 2010
(Albert et al., 2010).

Multiple laws in the U.S. have been passed in the last 20 years to either prevent or at the very least curb the influx of invasive species. The Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (16 U.S.C §§ 4701 et seq.) mandates that all vessels transiting the Great Lakes from beyond the Exclusive Economic Zone (EEZ) must undergo an open ocean BWE or another approved ballast treatment approved by the Federal Water Pollution Control Act. In 1972, the Federal Water Pollution Control Act was later reorganized and expanded into what is now commonly referred to as the Clean Water Act (CWA; 33 U.S.C. §§1251 et seq.). In the same year, the U.S. Congress passed the Marine Protection, Research, and Sanctuaries Act also known as the "Ocean Dumping Act." The National Invasive Species Act (NISA) was passed in 1996 as a reauthorization and amendment of the NANPCA to specifically address ballast water NISA (USCFR, 1990). The Act requires BWM reporting and mandates that the USCG develop voluntary ballast exchange guidelines for all vessels entering United States' territory from outside the EEZ. However, due to lack of voluntary compliance, the NISA provision of "voluntary" BWM compliance was amended by the USCG in 2004 to "required."

A year later, in 2005, the exclusion of vessel discharges from the National Pollutant Discharge Elimination System (NPDES) permit certification program, part of the original 1972 CWA, was overturned in federal court and four years later the USEPA issued the first permits for vessel discharges, including ballast water (Albert et al., 2010). Vessel discharges include exhaust gas scrubber wash water effluent, fish hold effluent and fish hold cleaning wastewater discharge, gray water discharge (i.e. from sinks and showers), oily bilge water separators, and ballast water (EPA, 2011).

There are also class-specific vessel requirements for large cruise ships that carry more than 500 people, medium cruise ships carrying 100 to 499 people, large ferries, barges, chemical barges, tank barges, fuel barges, crane barges, dry bulk cargo barges, oil or petroleum tankers, research vessels, and emergency vessels such as fire or police boats. The U.S. also requires all U.S. flagged ships anywhere in the world and all foreign vessels operating in U.S. waters to comply with the international Act to Prevent Pollution from Ships (USCFR, 2007). Exemptions for compliance with federal and state laws are U.S. military vessels and certain passenger ships that are equipped with ballast treatment systems.

Classifications and Ballast Volumes of Vessels in the World Maritime Fleet

Ninety-nine percent of oceangoing vessels calling at ports in the Gulf States are commercial or "merchant marine" and are classified according to type of cargo carried, either dry or wet, size, and carrying capacity.

Vessels carrying dry goods have the greatest variety of sizes and hold configurations. Container ships transport "non-bulk" dry goods packaged in steel or fiberglass containers that are quickly transferred from and to trucks or railcars with large dockside cranes. Bulk carriers "bulkers" transport unpackaged, bulk cargo, such as metal ores, dry sulfur, fertilizers, coal, cement, and grains in large cargo holds. Basic bulk carriers have several hatch openings through which cargo is loaded into lower and tween decks using onboard cranes, gearless carriers lacking cranes, self-discharging bulkers are equipped with conveyor belts, and "bulk in-bag out" (BIBO) bulkers bag bulk cargo, e.g. sugar, at time of loading. "Reefers" transport perishable goods or any other type of product that must be stored under refrigeration. Liquid cargo, nowadays mostly hydrocarbon or chemical products, is carried by tanker ships or "tankers." General-cargo carriers transport goods that are not bulk, containerized, or liquid in bundles, barrels, crates, or drums. Vessels carrying moving vehicles such as tractors, automobiles, or semi-trucks that are driven, under their own power, onto and off, with a ramp, are "roll on-roll offs," (RoRos).

Size (length, beam, i.e. width, draft, i.e. distance from waterline to deepest point on ship), "deadweight tonnage" (DWT), and ability to pass through the transoceanic canal system (Brandt, XXXX; Rodrique 2012). DWT is a measure of a vessel's carrying capacity that affects its draft (depth from water line to lowest point on a ship e.g. keel) and displacement (weight of water displaced by the ship). DWT is calculated from the combined weight (mt) of the ship, boiler water, crew, cargo, stores, fuel, and ballast minus the weight of the ship and water in its boiler tanks (lightship weight) (Fig. 1). The first general size class of dry cargo ships is "handysize" with a carrying capacity of up to 60,000 DWT and length of 150 to 200 m that allow for entry into smaller, shallower water ports. Within this size class are "small handysize" with carrying capacities up to 28,000 DWT, "handysize" with carrying capacities of 28,000 to 40,000 DWT, and "handymax" with carrying capacities of 40,000 to 50,000 DWT. The "panamax" family of ships can carry 60,000 to 79,999 DWT and are sized for the dimensions (length, width, depth) of the sequential lock chambers of the Panama Canal. Panamax ships are currently limited to a length, beam, and draft of ≤ 294 m, 32.2 m, 21.9 m, respectively (Panama Canal Authority, 2012). "Capesize" bulkers (80,000 to 175,000 DWT) are too large to transit through the Panama and Suez canals and so must sail around the Cape of Good Hope or Cape Horn. The largest bulkers (>200,000 DWT) are "very large ore carriers" (VLOC) and transport of iron ore, primarily to China (IMC, 2007; Rodrique, 2012). Container ships are also classified according to their carrying capacity for containers that are sized in twenty-foot equivalent units (TEU). One TEU is roughly 20 ft long, 8 ft wide, and 8.5 ft high (Brand-the box boat). In the panama family of container ships, range from the panamax (3,000-3,400 TEU), panamax-max (3,400-4,500), post-panamax (4,000-5,000 TEU), post-panamax plus (6,000-8,000 TEU),

Classifications for tankers also include handymax (10,000 to 50,000 DWT) and panamax (50,000 and 80,000 DWT) and typically make short hauls (definition) of finished petroleum products (refs). The mid-sized "AFRAmax" (80,000 to 120,000 DWT) is the most commonly operated tanker for short- to mid-ranged hauls of crude oil. AFRA (Average Freight Rate Assessment) is the rating system for standard oil tankers (Shell Oil XXXX). Tankers that can pass through the pre-2010 dimensions of the Suez Canal (no locks, i.e. no length restrictions, width 70 m, depth 18.8 m) are called "suezmax" tankers (beam 50 m, draft 50 m) (Suez Canal Authority, XXXX). Two new classes of "supertankers" were built after the Suez Canal was deepened to 20 m in 2010. They are the "very large crude carriers" (VLCC) and the "ultra large crude carriers" (ULCC), holding 120,000 to 315,000 DWT and 320,000 to 550,000 DWT, respectively, of unrefined crude oil (Rodrigue, 2012).

(Add info for vessels on inland waterways?)

Ballast volumes by vessel size classifications.

The number of individual ballast tanks and their volume capacities is variable between the different vessel types, i.e. container ships, tanker, etc., and even within the same vessel type depending upon the ship builder and year built. Ballast volumes are expressed either as cubic meters (m^3) or metric tons (mt). Large cargo tankers can hold over 200,000 m^3 or 50,000 mt of ballast [McGee, 2006 #2681], [National Research Council, 1996 #4332].

Table 1. Description, size, build year, and ballast volume capacity for representative vessel types [Karaminas, 2000 #6117].

Vessel Type Description	Length × Beam × Draft [m]	Year	Total ballast capacity [m³]	Dead weight tons [DWT]
Oil Tanker				
Single skin[1] with two long bulkheads[2]	177×27.43×17	1988	40,397	62,485
″ ″	217×32.2×19.6	1990	59,168	106,679
″ ″	294×42.68×21.5	1990	122,308	258,076
Double side	264×43.9×24.4	1992	19,636	39,988
Double hull with a centerline bulkhead	313×56.6×28.6	1996	21,865	74,252
Double hull	173×32.2×17.8	1996	73,097	154,970
Double hull with two long bulkheads	327×56.4×30.4	1993	119,878	298,900
″ ″	320×58×31	1998	13,263	311,189
Bulk Carrier				
Handysize, single side skin	177×30.4×16.5	1996	26,575	45,664
Panamax, single side skin	216×32.2×19.1	1994	35,151	73,236
Capesize, single side skin	256×40.5×21.2	1996	55,171	122,301
″ ″	270×43.0×24.1	1994	85,592	151,301
Container Ship				
1,725 TEU[3]	174×27.4×15.8	1998	9,677	24,554
2,668 TEU	225.5×32.2×18.8	1993	19,199	47,120
3,429 TEU	241.5×32.2×19.2	1996	13,830	46,350
3,842 TEU	246×32.25×19.3	1998	11,991	48,224
4,477 TEU	263×37.1×21.7	1995	19,933	61,428
Liquefied Natural Gas Tanker				
Membrane type[4]	260×43.3×25.4	1997	46,538	62,500
Moss type[5]	276×46×25.5	1990	53,751	78,988
Self-discharging Bulker				
Double hull	170×27.6×16.1	1988	18,576	36,634
Double hull	194×32×19	1993	33,473	50,687
Oil-Bulk-Ore Carrier				
Double hull	200×32.2×17.4	1984	32,851	54,500
Double hull	234×38×22.3	1991	61,311	95,000
Double hull	275×45×25.9	1992	61,436	16,9416
General Cargo				
Multipurpose cargo ship	162×25.6×14.2	1999	6,300	22,948
General cargo/container carrier	185×32.2×17	1984	11,865	41,600

[1] Explanation of "skin" (ref)
[2] Explanation of bulkhead (ref)
[3] "Twenty Foot Equivalent Unit." TEU is the standard unit for containers. One twenty foot container = 1 TEU. One forty foot container = 2 TEU ([Branch, 2007 #6129])
[4] Explanation of membrane type-what are the types? (ref)
[5] Explanation of moss type-what are the types? (ref)

TABLE 2-1 Typical Vessel Types, Ballast Needs, and Pumping Rates

Ballast Needs[a]	Vessel Types	Typical Pumping Rates (m^3/h)
Ballast replaces cargo Ballast required in large quantities, primarily for return voyage.	Dry bulk carriers	5,000–10,000
	Ore carriers	10,000
	Tankers	5,000–20,000
	Liquefied-gas carriers	5,000–10,000
	Oil bulk ore carriers	10,000–15,000
Ballast for vessel control Ballast required in almost all loading conditions to control stability, trim, and heel.	Container ships	1,000–2,000
	Ferries	200–500
	General cargo vessels	1,000–2,000
	Passenger vessels	200–500
	Roll-on, roll-off vessels	1,000–2,000
	Fishing vessels	50
	Fish factory vessels	500
	Military vessels	50–100
Ballast for loading and unloading operations Ballast taken on locally in large volumes and discharged in same location.	Float-on, float-off vessels	10,000–15,000
	Heavy lift vessels	5,000
	Military amphibious assault vessels	5,000
	Barge-carrying cargo vessels	1,000–2,000

[a] The three categories of ballast needs are not mutually exclusive. For example, a vessel in which ballast replaces cargo may also require ballast to control stability.

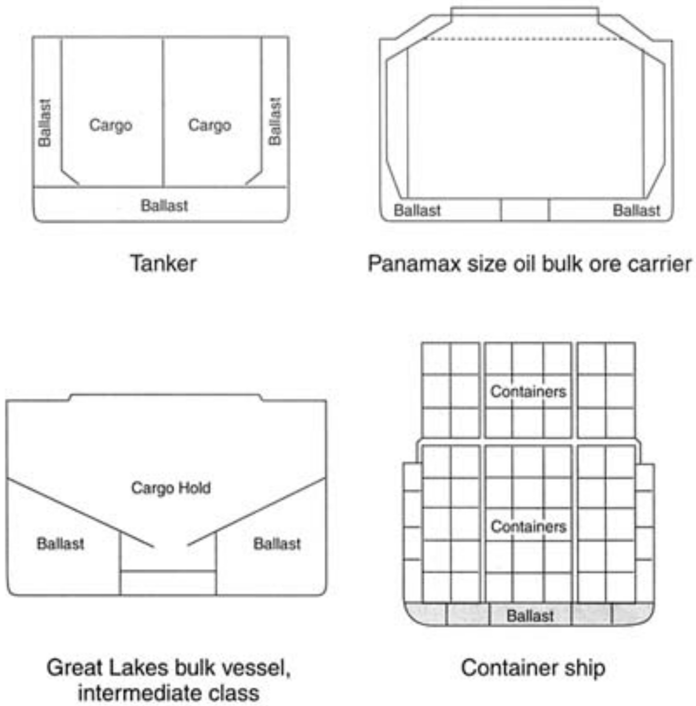


FIGURE 2-1 Typical ballast tank arrangements.

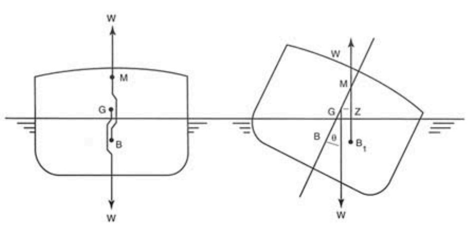


FIGURE C-1 Righting lever.

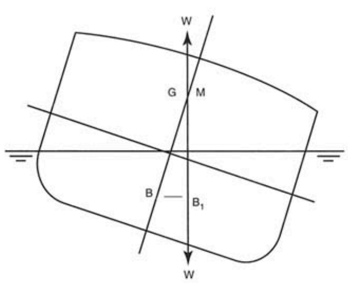
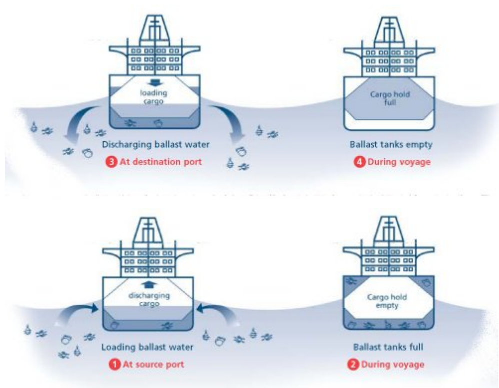


FIGURE C-2 Zero GM.

Phytoplankton in harbors- same reason as ships- water is still or less turbulent, harbors typically on rivers or estuaries that supply iron and other nutrients, allelopathy of HABs prevent other phytoplankton from blooming?



Ballast water capacities for different types of ships

		BALLAST CONDITION			
VESSEL TYPE	DWT	NORMAL (tonnes)	% of DWT	HEAVY (tonnes)	% of DWT
Bulk carrier	250,000	75,000	30	113,000	45

Bulk carrier	150,000	45,000	30	67,000	45
Bulk carrier	70,000	25,000	36	40,000	57
Bulk carrier	35,000	10,000	30	17,000	49
Tanker	100,000	40,000	40	45,000	45
Tanker	40,000	12,000	30	15,000	38
Container	40,000	12,000	30	15,000	38
Container	15,000	5,000	30	n/a	
General cargo	17,000	6,000	35	n/a	
General cargo	8,000	3,000	38	n/a	
Passenger/RO RO	3,000	1,000	33	n/a	

Suez Canal- made in 13th century BC by Egyptian pharaohs to connect the Nile River Delta to the Red Sea (global security.org/world/Egypt). Red Tide access to Mediterranean!

Review of HAB Observation Data Resources

NOAA Harmful Algal Bloom Operational Forecast System (HAB-OFS) add web address

Data Contributors:

1. Florida Fish and Wildlife Research Institute
   HAB Events
      Florida Red Tide Current Status
      Other Florida HAB Events
         HAB Archive
            Historical Database

1. "Looking at the Florida Red Tide Historical Database" Electronic HAB database contains detailed description of historical data including dates, measured parameters, methods for sampling and analyses. *Karenia brevis* data expressed as "# samples containing ≥ 100,000 cells per liter were collected in response to bloom events occurring between 1954 and 1997 and include some offshore transects. Between 1998 and 2002, K. brevis data were collected during 1 to 3 week cruises and from permanent sampling stations. Nutrients, chlorophyll, and dissolved oxygen measurements were included. Data availability: