Vessels and Ballast Water

Matej David

Abstract Commercial vessels are built for the transport of various cargoes or passengers. When a vessel is not fully laden, additional weight is required to provide for the vessel's seaworthiness, e.g. to compensate for the increased buoyancy which can result in the lack of propeller immersion, inadequate transversal and longitudinal inclination, and other stresses on the vessel's hull. The material used for adding weight to the vessel is referred to as ballast. Historically, ballast material was solid, but after the introduction of iron as basic vessel building material in the middle of the nineteenth century, loading of water (i.e., ballast water) in cargo holds or tanks had shown to be easier and more efficient. Even when a vessel is fully laden it can require ballast water operations due to a non-equal distribution of weights on the vessel, weather and sea conditions, an approach to shallow waters, and the consumption of fuel during the voyage. As a result of these factors, vessels fundamentally rely on ballast water for safe operations as a function of their design and construction. This chapter describes vessel's ballast water systems, ballast tank designs, ballasting and deballasting processes as well as safety and legislative aspects of ballast water operations. In addition a detailed ballast water discharge assessment model is provided. Using concepts of this model an estimation of global ballast water discharges from vessels engaged in the international seaborne trade was estimated as 3.1 billion tonnes in 2013.

Keywords Ballast water • Vessels design • Ballast water system • Ballast water tank design • Ballasting and deballasting processes • Ballast water safety and legislative aspects • Ballast water discharge assessment

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The Importance of Ballast for Vessels

Commercial vessels are built for the transport of various commodities or people by the sea or inland waterways. When a vessel is not fully laden, additional weight is required to compensate for the increased buoyancy that can result in:

- the lack of propeller immersion,
- inadequate transversal inclination, i.e., heeling,
- inadequate longitudinal inclination, i.e., trim,
- static and dynamic stresses on the vessel's hull including shear and torsion forces, bending moments and slamming, and
- static and dynamic transversal and longitudinal instability,

in order to provide for the vessel's seaworthiness. This implies that not only commercial vessels, but also some other vessels (e.g., navy vessels, bigger pleasure boats) use ballast water to provide for adequate seaworthiness (David 2007).

The material used for adding weight to the vessel is referred to as ballast. Historically, ballast material was solid (e.g., sand, rocks, cobble, iron). After the introduction of iron, replacing wood, as basic vessel building material in the middle of the nineteenth century, the doors were opened to new technologies. Loading of water (i.e., ballast water) in cargo holds or tanks (i.e., ballast water tanks) was shown to be easier and more efficient, and hence was adopted as a new practice of increasing importance.

A vessel deemed to be "not fully laden" is a situation when she is not at her maximum allowed draught; i.e., when her carrying capacity in terms of weight, i.e., deadweight (DWT), is not fully exploited. This is typically a dynamic situation during cargo operations in a port; i.e., a vessel will experience changes in loading as it loads and/or unloads cargo. This condition may also result from either the lack of cargo available for transport, or occurs when cargo is light and the total volume of a vessel's cargo spaces becomes a limiting factor (David 2007). However, even when a vessel is fully loaded it can require ballast water operations due to a non-equal distribution of weights on the vessel; i.e., loading of non-homogeneous cargoes, e.g., general cargoes, very heavy cargoes or heavy containers on top of light containers.

Other dynamic factors may also require ballast water operations, such as weather and sea conditions on the route, the approach to shallow waters, and the consumption of fuel and diesel oil during the voyage. According to expected weather conditions, a vessel would sail in a heavy ballast condition, i.e., maximum ballast loaded, when expecting bad weather, or a light ballast condition, i.e., partial ballast loaded, when it is ensured that the weather conditions and rough seas will not impair the vessel's stability, e.g., when approaching a port or inland waterways. Vessels would go from heavy ballast to light ballast conditions when safe and weather as well as sea conditions are favourable to consume less fuel, and when in save haven close to a port or at the ports anchorage, to get ready for loading cargo. When approaching shallow waters a vessel may also need to discharge some ballast water to provide for less draught, or when she needs to sail below a bridge she may need to add ballast to provide for lower air draft.[1] In relation to the fuel and diesel oil consumption during a voyage, e.g., a Panamax container vessel consumes approx. 100–180 tonnes of heavy fuel per day, and according to the *International Convention for the Safety of Life at Sea* (SOLAS), 1974, vessels need to be adequately trimmed[2] to provide for optimal hydrodynamics, they need to provide for bridge visibility standards, and for minimum aft draught for adequate propeller immersion.

Some types of vessels, especially Ro-Ro, container and passenger vessels, which load cargo or passengers also very high above the waterline, and cargoes frequently are non-equally distributed, have so called anti-heeling tanks to compensate for transversal unequal distribution of weight and prevent vessel from listing. This is especially important in port during cargo operations. Vessels usually do not load and discharge water in or from the anti-heeling tanks, but have a constant volume of water in these tanks which is than being pumped from one side of the vessel to another.

As a result of these factors, vessels fundamentally rely on ballast water for safe operations as a function of their design and construction.

Vessel's Ballast System

The number, volume and distribution of ballast tanks are vessel type and size related. The ballast tanks can be in the vessel's double bottom (DBT – double bottom tanks), port and starboard along the sides (ST – side tanks or WT – wing tanks), in the bow (FPT – forepeak tank), in the stern (APT – after peak tank), port and starboard underneath the main deck (TST – topside tanks or upper wing tanks), and other (e.g., CT – central tanks). Though FPT and APT tanks are traditional on all types of vessels, some does not have these tanks, e.g., The Hamburg Express class containerships. Some older vessels, mainly tankers, were also using cargo holds (or cargo tanks respectively) to ballast, but today's vessels have tanks that are dedicated only for ballasting, i.e., segregated ballast tanks (see Figs. 1 and 2). The specific case today to ballast in cargo holds may apply to bigger bulk carriers, which may load water in some of the central cargo holds to sail in so called "heavy ballast condition" when exposed to heavy sea conditions.

Ballast tanks are connected with the ballast water pump(s) by a ballast water pipeline. Water from the vessels surrounding area is loaded on the vessel through the vessel sea-chest(s) and strainer(s) (see Fig. 3) via the ballast pipeline to ballast tanks.

Inside the ballast tanks water is loaded and discharged via the ballast water pipeline suction head (see Fig. 4).

Vessels with greater ballast capacity are usually equipped with two ballast pumps (see Fig. 5) in order to ensure ballast water operations are carried out even in case

[1] i.e., the distance from the water to the highest part of the vessel.

[2] i.e., difference between the forward and aft draft, when this exists, means longitudinal list of this vessel; when there is no trim, vessel is on even keel.

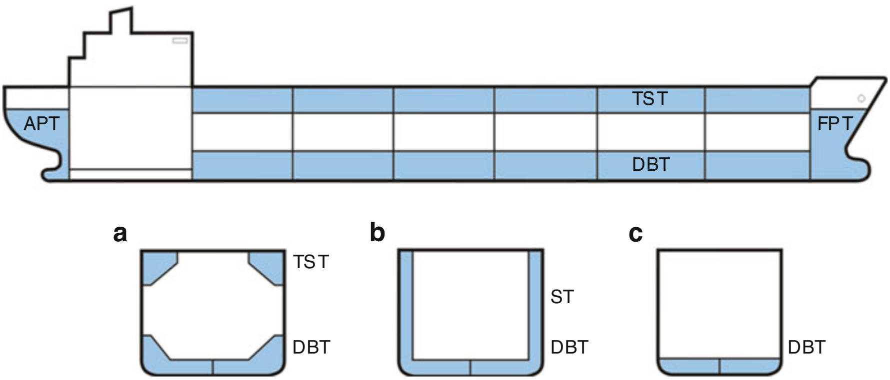

Fig. 1 Ballast tanks on: (**a**) most bulk carriers, (**b**) tankers, container vessels, and some newest bulk carriers, and (**c**) Ro-Ro and general cargo vessels. (*APT* after peak tank, *DBT* double bottom tanks, *FPT* forepeak tank, *ST* side tanks, *TST* topside tanks or upper wing tanks)

Fig. 2 Interior of a DBT (*left*) and ST (*right*) ballast tank on a bulk carrier (Photos: Guy Mali)

of a failure of one pump, while some smaller vessels may use service pumps also for ballast operations.

Ballast tanks may be accessed/entered for maintenance, cleaning and other purposes via manholes or tank hatches. Ballast tanks are equipped with air vents, which allow the air in the ballast tanks to be expelled from the tank to prevent over-pressurisation when the ballast tanks are filled, or to let the air in and prevent under-pressurisation when ballast tanks are emptied (see Fig. 6).

Fig. 3 Ballast water intake area with the strainer in the front below the walk-on grating connected to the sea-chest

Fig. 4 Ballast water pipeline suction head (Photo: Guy Mali)

Fig. 5 Two ballast pumps of 1,500 m^3 capacity on a container vessel

Fig. 6 An air-vent on the *left*, a sounding pipe in the *center back*, and a TST hatch on the *right* on a bulk carrier

Fig. 7 Discharge of ballast water below the water level from a container vessel

It is absolutely critical to know how much ballast is in each tank to be able to provide for the vessels seaworthiness. On older vessels these measurements are done via sounding pipes (see Fig. 6), and then by means of sounding tables, the quantity of ballast water can be calculated. Most modern ships are equipped with instruments that enable automatic measurements of the quantity of ballast water in ballast tanks, while these still need to be equipped with sounding pipes to allow direct measurements in the case of automatic system failure.

Ballast water is discharged through the overboard discharge, which is on most vessels situated below the water level (see Fig. 7). On some vessels ballast water discharge is situated above the water level, and mainly on bulk-carriers ballast water can be discharged directly from the topside tanks high above the water level (e.g., see chapter "Ballast Water Sampling and Sample Analysis for Compliance Control", Fig. 4).

Vessel Ballast Capacity

The vessel ballast capacity is mainly determined by the vessel cargo capacity in terms of cargo weight, and the speed at which the cargo operations may be conducted. Generally, the more tonnes of cargo a vessel is capable to carry, the more ballast may be needed when sailing without cargo on board, and if the cargo operations on a vessel are very fast, then the ballast uptake or discharge has to be correspondingly fast. The ballast water capacity of a vessel is given in terms of volume of spaces that are available for ballasting expressed in m^3, and in terms of the ballast pumps capacity expressed in m^3/h.

The volumetric ballast water capacity mainly determines the vessels seaworthiness in different static and dynamic conditions. For instance, according to Det Norske Veritas, Rules for Classification of Ships (Part 3, Ch. 1, Sec. 3) (DNV 2000), ships of 20,000 tonnes DWT and above having the class notation Tanker for Oil and ships of 30,000 tonnes DWT and above with the class notation Tanker for Oil Products are required to have segregated ballast tanks. The capacity of segregated ballast tanks is to be at least such that, in any ballast condition at any part of the voyage, including the conditions consisting of lightweight plus segregated ballast only, the ship's draughts and trim can meet each of the following requirements:

The moulded draught amidships (dm) in meters (without taking into account any ship's deformation) is not to be less than:

$$dm = 2.0 + 0.02L \quad (1)$$

where L means length between perpendiculars.

The draughts at the forward and after perpendiculars are to correspond to those determined by the draught amidships (dm) association with the trim (t) by the stern of not greater than

$$t \leq 0.015L \quad (2)$$

In any case the draught at the after perpendicular is not to be less than that which is necessary to obtain full immersion of the propeller(s) (Perkovič and David 2002a).

In general, cargo vessels such as, general cargo, Ro-Ro, e.g., ferries and car carriers, use only small quantities of ballast water, i.e., generally some 20 % of their DWT, with some exceptions even of more than 40 % of DWT for special uses (Capt. Peter Stapleton personal communication). On the other hand, vessels for the transport of liquid and dry bulk cargoes, e.g., tankers, dry-bulk carriers, require significantly larger quantities of ballast water, i.e., mostly between 30 and 50 % of their DWT, what may result to more than 100,000 m^3 of ballast water per vessel. A summary of the ballast water capacities for main ship types identified by different authors is presented in the Table 1 (David et al. 2012).

The ballast water pumps capacity is mainly related to the speed of vessels cargo operations, i.e., how much cargo can be loaded or discharged in a certain period of time, as the ballasting operations are mainly being conducted in the opposite way than the cargo operations. Some vessels may be loading cargo at much higher speeds than the others, hence need much faster ballast pumping rates otherwise the cargo operation may have to be slowed down. Bigger tanker vessels, i.e., crude oil tankers, are the fastest in cargo loading/discharging rates, nowadays conducting cargo operations at 10,000 tonnes/h or even faster, and bigger bulk carriers with up to 6,000 tonnes/h, hence having ballast water pumping capacities in the range of 6,000–15,000 m^3/h.

Container vessels when in most developed ports manage to load or discharge approx. 18–22 containers[3] per crane per hour (Chief Officer Kiril Tereščenko per-

[3] i.e., 40 ft containers or instead of one 40 ft container can be two 20 ft containers loaded or discharged at the same time.

Table 1 Percentage of vessels ballast water capacity in relation to the vessels DWT, based on different vessel types. *BC* bulk carrier, *C* container, *GC* general cargo, *T* tanker, *Pas* passenger, *RR* Ro – Ro (After David et al. (2012) (Reprinted from Decision Support Systems, 53, David M, Perkovič M, Suban V, Gollasch S, A generic ballast water discharge assessment model as a decision supporting tool in ballast water management, 175–185, copyright 2012, with permission from Elsevier)

Vessel type/ DWT	AQIS (1993)	Walters (1996)	Wiley (1997)	Carlton et al. (1995)	Farley (1996)	Cohen (1998)	Dobes (1997)	Hay and Tanis (1998)	Behrens et al. (2003)	Suban (2006)
All vessels			30	38	40	36	33		36	33
BC		41		43				60		33
BC/250,000	30–45									
BC/150,000	30–45									30–45
BC/70,000	36–57									30–45
BC/35,000	30–49									33–57
T		26		38						
T/100,000	40–45									
T/40,000	30/38									43
C		30		32				30–60		35
C/40,000	30–38									28–40
C/15,000	30									30
GC		35						30–60		29
GC/17,000	35									
GC/8,000	38									
Pas/RR	33	38								43

sonal communication) and an experienced crane driver can handle also up to 30 containers per hour (Chief Officer Guy Mali personal communication). The number of gantry-cranes that can be employed at a time depends on the vessel size, port/terminal and priority of vessel. The number of container operations is also very much related to the capacity of containers handling at the terminal. There are usually several, e.g., three to five, cranes in operation at the same time., e.g., in average the container vessel Hamburg Express when in the Port of Rotterdam handles 4,100 containers in ~24 h, what results in approx. 46,000 tonnes of cargo loaded or discharged (Chief Officer Guy Mali personal communication.). In general container vessels manage to be served by ballast water pump capacities in the range of 1.000–3.000 m^3/h, i.e., two pumps, each 500–1,500 m^3/h.

As the port cargo loading and unloading capacities are increasing through time mainly with the use of newer technologies supporting faster cargo operations, newer vessels of similar cargo capacities in general have ballast water systems of higher capacity. An increase in ballast water capacities of new vessels can be expected also in the future.

Ballasting and Deballasting Process

Vessels conduct ballast water operations usually in the port as opposite to the cargo operations, i.e., when a vessel would load cargo, ballast water would be discharged, and when more or heavier cargo is loaded on one side, ballast water would be discharged from that side or loaded/moved to the other side. Ballasting and deballasting may also be conducted during navigation or at the anchorage, depending on the vessel type, weather and sea conditions, and vessel operations.

Ballast water is taken onboard by:

– gravity through opening valves which enables a vessel to take on water into ballast tanks (or cargo holds used for ballast) below the water line;
– pumping water into ballast tanks (or cargo holds used for ballast) above the water line.

Nevertheless, all the water may be taken on board by pumping, instead of using the gravity method.

The tanks are filled according to a predetermined sequence, depending on the type of the vessel and current cargo operation. The ballast tanks are usually filled up to maximum capacity in order to prevent the free surface effects.[4] This "rule",

[4] i.e., movements of water in the tank from side to side and hence changing centres of gravity as well having dynamic side effects, and with this negatively impacting the transversal stability of the vessel; this is especially important for cargo holds and wider ballast tanks; e.g., double bottom, topside.

however, generally does not apply to fore-peak and after-peak tanks since these are frequently filled partially because of trimming the vessel.

Deballasting is conducted in the opposite sequence by:

- gravity through opening the valves that enables a vessel to discharge ballast water into the surrounding environment from ballast tanks (or cargo holds used for ballast) above the water line;
- pumping out the ballast water from ballast tanks (or cargo holds used for ballast) below the water line.

Nevertheless, all ballast water may be discharged into the surrounding environment by pumping, instead of using the gravity method (David 2007).

When tanks are getting close to empty, ballast pumps start loosing suction as they start getting air in the system. The remaining water in tanks after pumping with ballast pumps is in general between 5 and 10 % of ballast water tank volume, what is mainly depending on the vessels trim. The ballast pipes suction heads are usually installed on the back side of the ballast tanks, hence for pumping out most of the remaining ballast water the vessel needs to be trimmed astern, what is also a very general practice. This astern trimming is to compensate the change of trim during the voyage because of fuel consumption from tanks, which are more in the stern part of the vessel, to arrive in the next port of call approximately on even keel. However, when Gollasch and David conducted shipboard tests of different BWM methods we noticed that on vessels which were trimmed ahead about 15 % and more of unpumpable water remained in the tanks during the empty-refill (sequential) BWE. Actually, practice on some newer container vessels has shown that when trimmed ahead the vessel consumes less fuel during navigation probably due to better hydrodynamics, hence these would nowadays usually start the voyage on even keel or even be trimmed ahead (Captain Alok Kumar personal communication, Chief Officer Guy Mali personal communication). When at the start of the voyage a vessel could not be trimmed ahead because of some limitations (e.g., limited maximum draft, required even keel), ballast operations would be conducted at see what is done by internal transfer of ballast water or pumping in some additional ballast water. For almost total deballasting of tanks, i.e., 1–2 % of the ballast water tank volume remaining as unpumpable ballast, a ballast ejector pump is used. This is also so called "stripping" and is done by using the firepump together with the ballast stripping eductor (Chief Officer Guy Mali personal communication).

All ballasting and deballasting activities are usually led by the first (chief) officer, who is responsible for the vessel's stability. Following his instructions, the pumps and valves are operated automatically from a ballast control console or from a computer by an officer (Fig. 8).

Some older vessels do not have an automated control over ballast pumps and valves, then this may be done manually by an engineer, while the bosun (senior deck crewman, ranked below the deck officers) has to monitor the conditions of ballast in the ballast tanks by measuring the water level via sounding pipes at adequate

Fig. 8 Ballast control console (*top*) and computer ballast system control (*bottom*)

time intervals, and regularly reporting them to the officer or engineer. The entire ballasting and deballasting process, as well as internal transfers of ballast, has to be recorded in the ship's logbooks (e.g., Ballast Water Handling Log (Chief Officer Guy Mali personal communication). Some states require also Ballast Water Reporting Forms (BWRF).

Safety and Legislative Aspects of Loading and Discharging Ballast

Loading and discharging of cargo and ballast directly affects the transversal and longitudinal stability as well structural integrity of the vessel, and consequently safe navigation and the safeguarding of human lives. Hence, the examination of all

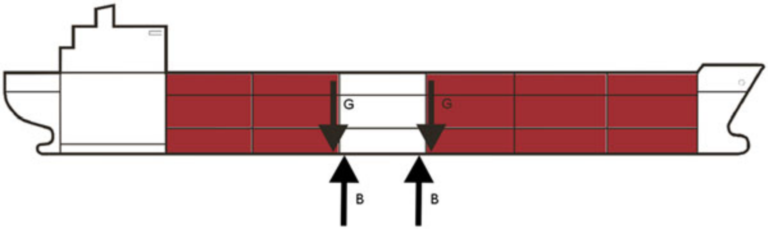

Fig. 9 *Arrows* showing where in this case shear forces act; i.e., where two tank sections next to each other, one being fully ballasted having more gravity (*G*) than the empty tank section, where the buoyancy (*B*) effect is stronger

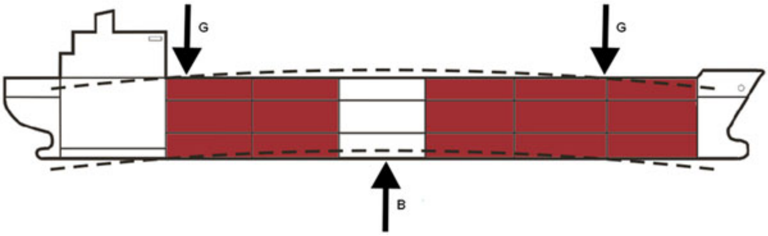

Fig. 10 *Arrows* showing the acting of bending forces with increased buoyancy (*B*) in the amidships and increased gravity (*G*) in fore and aft part, causing longitudinal deflection of the vessel hull, so called hogging

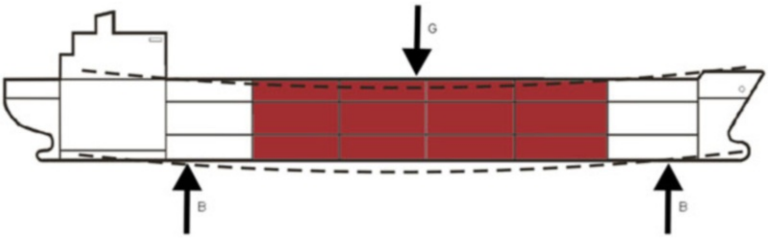

Fig. 11 *Arrows* showing the acting of bending forces with increased buoyancy (*B*) in the fore and aft part and increased gravity (*G*) in the amidships part, causing longitudinal deflection of the vessel hull, so called sagging

ballast-related procedures has to lay special emphasis on safety. The interim phases in loading and discharging ballast water generate changes that usually exert different negative influence on a vessel's stability and induce additional static forces on the vessel hull (see Figs. 9, 10 and 11). Improper management of cargo and ballast operation may result in structural failure of the vessel hull in the port (see Fig. 12) or even results in the vessel to capsize.

When the vessel is sailing, she is exposed to more dynamic conditions as compared to being in a port, influenced from the outside by waves and wind (see Figs. 13 and 14). One of the undesirable effects is that caused by free surfaces affecting vessels stability, where ballast water is able to move inside the tanks if these are not

Fig. 12 Vessel structure that failed because of overstress in hogging (Source: Cornelius de Keyzer, Master Mariner, Port of Rotterdam, the Netherlands)

Fig. 13 Vessel in heavy weather conditions, waves in transversal effect (Source: Cornelius de Keyzer, Master Mariner, Port of Rotterdam, the Netherlands)

Fig. 14 Vessel in heavy weather conditions, waves in longitudinal effect (Source: Cornelius de Keyzer, Master Mariner, Port of Rotterdam, the Netherlands)

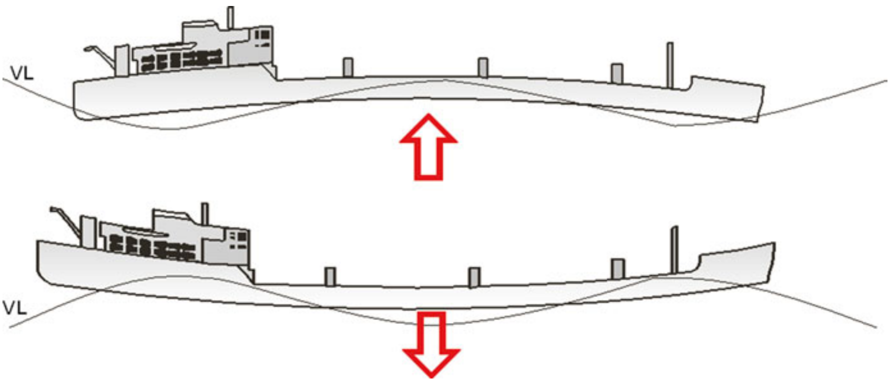

Fig. 15 Longitudinal wave effects on the vessel hull, inducing additional (*top drawing*) or reduced (*bottom drawing*) buoyancy amidships, that may result in vessel structure failure. *VL* water line

completely filled, while waves may exert extensive additional forces on the vessel hull, especially as additional shear forces and bending moments (Perkovič and David 2002a, b) (see Fig. 15).

Inappropriate ballast water operation and with this reduced transversal stability may result in a vessel to flip aside (see Fig. 16).

Safe navigation and the safeguard of human lives at sea are regulated by the SOLAS Convention of IMO. Aiming to increase safety and reduce pollution from

Fig. 16 The Cougar Ace flip (Photo credit: Capt. Kevin Bell, US Fish and Wildlife Service)

ships, on 24th May, 1994, the convention was supplemented with amendments in a new chapter, IX – Management for the Safe Operation of Ships. The main objective of Chapter IX is the mandatory consideration of the International Safety Management Code (ISM Code).

The ISM Code was adopted following the tacit consent procedure. It became mandatory on 1st July, 1998, for all passenger vessels including high speed craft, tankers, chemical tankers, and liquefied gas carriers, including high speed cargo craft of GT 500 or more. On 1st July, 2002, it became mandatory for other cargo ships and mobile offshore drilling units of GT 500 or more.

Based on the ISM Code requirements, all ships listed above are required to conduct ballast water operations in accordance with a previously prepared plan delineated in the Safety Management Manual that has to be available on board the vessel at all times. The responsibility for the preparation of safety plans for specific vessel types is by the shipowner, who also has to provide for regular inspection and the proper functioning of the safety and ballast water system (David 2007).

How Much Ballast Water Vessels Discharge?

As stated above, vessels in general discharge ballast when loading cargo, and the reverse. Logically, it appears that all vessels that load cargo in the port consequently discharge ballast. But in reality the situation is not so simple. Vessels load different types of cargoes, which could be divided into specifically heavy, e.g., metal rolls, steel, iron, ore, carbon, oil; and light cargoes, e.g., grains, timber, paper, vehicles, containers.

In the case of loading a heavy cargo, a vessel will be most probably immersed to her maximum draught, i.e., one of the load lines,[5] hence needs to discharge all ballast to load as much cargo as possible. This means that the vessel will discharge all ballast except the quantity unable to be discharged, and the quantity needed for trimming and heeling where appropriate.

Some vessels in ports usually undertake both cargo loading and discharge operations, e.g., containers, vehicles, general cargoes. In these cases the ballast water situation fully depends on the quantity of discharged and loaded cargo. If the quantity of discharged cargo is greater than that loaded, it is supposed that the ship will not discharge ballast and vice versa.

The quantity of ballast water may also depend on weather conditions. When expecting to sail through bad weather conditions and heavy seas, vessels would be in heavy ballast condition to improve the safety of navigation.

Tanker vessels carrying heavy oil or vessels specialized for the carriage of orange juice, for instance, as a rule return to the port of loading empty and therefore require larger quantities of ballast water for safe navigation. On the other hand, a general cargo and container vessel will when in operation always carry some cargo, i.e., some will be discharged and some loaded at the next port of call. These vessels can thus carry ballast water taken up in different ports. The quantity of ballast water carried, however, primarily depends on the cargo handling operations carried out. Therefore, if a significantly greater quantity of cargo is discharged than loaded, it may be assumed that ballast water will be required on board, and vice versa (David et al. 2012).

However, when a vessel loads a light cargo, her maximum DWT capacity will not be exploited, because the limiting factor becomes the volume available to store the cargo, and not the cargo weight. Some light cargoes are frequently also loaded on the deck as well as in cargo holds. Consequently, the vessel has diminished transversal stability and needs to improve it by adding ballast in her double bottom tanks. A typical example is that of loading timber on deck, and this may also be the case when heavier containers would be loaded on top of lighter containers or on the upper deck of a car carrier.

The above described situations and conditions show that the ballast water operations are related to different vessel types, vessel construction, cargo operations and weather conditions. However, there are no clear limits among all these factors, but the decision on ballast water operations is under the discretion of the chief officer and direct control of the captain, who is responsible for the vessels stability and safety (David et al. 2012).

[5] i.e., appropriate load line according to the IMO Load Line Convention.

Ballast Water Discharge Assessment

Different ballast water studies around the globe involved an assessment of ballast water discharges in a port or wider area (e.g., AQIS 1993; Walters 1996; Wiley 1997; Carlton et al. 1995; Farley 1996; Dobes 1997; Cohen 1998; Hay and Tanis 1998; Behrens et al. 2003; Perkovič et al. 2004). This is clearly one of the information needed for understanding how biological invasions are facilitated (Bailey et al. 2011; Briski et al. 2012; Chan et al. 2013), and this information had impacted the wider public opinion and consequently government administrations, policies etc. It is also very important to understand the ballast water operation patterns to enable provisions of adequate decision support tools for ballast water management (David et al. 2012), i.e., horses for courses. However, having in mind the complexity of ballast water operations, it becomes clear that such assessments are very challenging, and that an accurate ballast water discharge assessment for each vessel call to a port, especially for those that only partially load and unload cargo in the same ports, is almost impossible.

A ballast water discharge assessment model was prepared during two ballast water management studies conducted in Slovenia and the model was applied to the Port of Koper data. For the purpose of a wider application of the model a detailed model verification study was conducted (David et al. 2012) and the model has been applied in different studies to assess ballast water discharges in some ports around Europe (EU FP7 VECTORS project,[6] IPA Adriatic BALMAS project[7]). The model can be used for the assessment of ballast water discharges in past years as well as for a prediction of ballast water operation of a ship calling to a port. In more biological terms, historical data may be helpful when studying vessels and ballast water patterns through time and relating them to known introduced species, to assess biological propagule pressure, as well as background data for RA assumptions. In terms of ballast water management, the ballast water discharge assessment model provides responsible authorities with many tools; e.g., for targeting vessels for adequate BWM measures based on the risk posed, check for false BWM reporting, targeting vessel for compliance monitoring, etc. Furthermore, model calculations may also be used to identify the dimensions of land-based ballast water reception facilities should it be planned to make such facilities available. A ballast water discharge assessment is also helpful to evaluate the environmental acceptability of ballast water treatment systems which use active substances (chemical treatment) to kill organisms. The model may be used to calculate, e.g., the annual amount of ballast water discharges, and in a worst case scenario where all ballast water discharged was assumed to be treated with the same active substance, it could be evaluated if the remaining toxicity of the ballast water at discharge is environmentally acceptable (David et al. 2012).

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[6] European Community's Seventh Framework Programme under Grant Agreement No. [266445] for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS). http://www.marine-vectors.eu/

[7] IPA Adriatic Cross-Border Cooperation Programme - strategic project Ballast Water Management System for Adriatic Sea Protection (BALMAS), http://www.balmas.eu/

The model is presented in Fig. 17. More details about the model logic, application and accuracy of results are presented in David et al. (2012).

Estimation of Ballast Water Discharges World-Wide

In the past global ballast water discharges were assessed or quoted by, e.g., 10 billion tonnes by Gollasch (1998), and 3.5 billion tonnes by Endresen et al. (2004). At the time these assessments were conducted, the world seaborne trade amounted to around 5 billion tonnes of cargo per year, i.e., in 1995 it was 4.651 billion tones, and in 2000 it was 5.871 billion tonnes (UNCTAD 2006). The Endresen et al. (2004) assessment considered the world seaborne trade to be 8.734 billion tonnes of cargo, 5.434 billion tonnes in international and 3.3 billion tonnes in national seaborne trade.

The ballast water capacity varies as a function of the cargo carrying capacity and ship type, with an average value of 33 % of the vessel's DWT (Suban 2006). However, the ballast capacity is only partially utilized because the vessel's DWT is commonly not fully exploited. First of all it is necessary to consider the fact that the ship is not loading the full DWT capacity. From DWT it is necessary to deduct weight of stores, fuel, fresh water and other weights. This weight usually represents around 5–10 % of a ship's DWT (Suban et al. 2006), hence the ballast water capacity would be about 37 % of the vessels cargo capacity in terms of weight. Secondly, vessels frequently do not exploit also their maximum DWT dedicated to cargo, e.g., different vessels, especially container vessels, car carriers, and general cargo vessels are usually only partially loaded, and bulk carriers when they load light cargoes as grains or wood. The BWDA model (see section "Ballast water discharge assessment") considers all this, hence the estimated discharge would amount to 33 % of the cargo volume in the world seaborne trade, not considering the lightweight cargoes.

The world international seaborne trade in 2011 amounted to 8.748 billion tonnes of cargo (UNCTAD 2012), thus the global ballast water discharges from vessels engaged in the international seaborne trade in 2011 would be about 2.88 billion tonnes. If we want to estimate the global ballast water discharges for 2013, the information needed is not yet available, but needs to be estimated. According to the UNCTAD (2012) data the world wide economic crisis was reflected in the decrease of world seaborne trade especially in 2009, after which it recovered with an annual growth of about 350 million tonnes per year until 2011, while the average annual growth from 2000 to 2011 was about 250 million tonnes per year. Assuming an average annual growth of 300 million tonnes per year as the global economy recovered after the 2009 crisis and continued to grow (UNCTAD 2012), the world international seaborne trade in 2013 would amount to about 9.35 billion tonnes of cargo, thus the global ballast water discharges from vessels engaged in the international seaborne trade in 2013 would be about 3,1 billion tonnes.

The amounts estimated here are much lower than some earlier estimations mentioned above, especially when considering that the global cargo transport today is

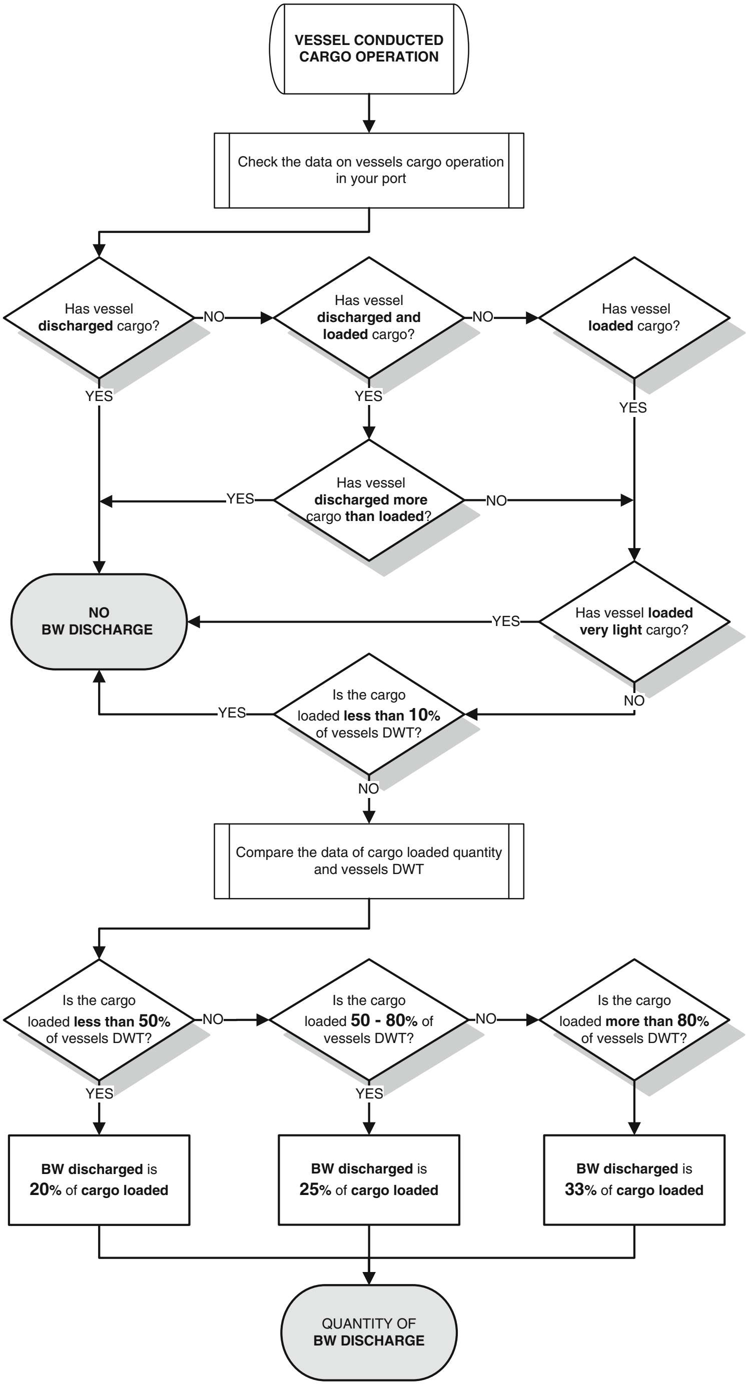

Fig. 17 Ballast water discharge assessment model (David et al. 2012) (Reprinted from Decision Support Systems, 53, David M, Perkovič M, Suban V, Gollasch S, A generic ballast water discharge assessment model as a decision supporting tool in ballast water management, 175–185, copyright 2012, with permission from Elsevier) (This figure can be downloaded from http://extras.springer.com/)

much higher. Nevertheless, it is important to understand, that the volumetric estimation of ballast water discharges is only one very superficial expression when ballast water is seen from a different perspective, the perspective of transfer of harmful aquatic organisms and pathogens. From this perspective, volumes of ballast water being discharged are much less important then what is actually in the ballast water discharged (see chapter "The Transfer of Harmful Aquatic Organisms and Pathogens with Ballast Water and Their Impacts").

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