1.Introduction 簡介

Almost two thirds of traded goods worldwide are transported by ship (Kumar and Hoffmann, 2002).
全世界約有三分之二的貿易品都藉由船運輸。

To ensure ship buoyancy, stability and manoeuvrability, oceangoing ships need ballast water.
為了確保船的浮力、穩定性與機動性，在海洋上運輸的船都需要使用壓艙水。

Based on an estimation that the world seaborne trade in 2013 amounted to 9.35 billion tons of cargo, the global ballast water discharges in 2013 are estimated to about 3.1 billion tonnes (David, in prep.).
據估計，2013 年世界海運貿易達 93.5 億噸貨物，2013 年全球壓艙水排放量估計約為 31 億噸。

There is significant transfer of ballast water between different continents and oceans, and it has been known for decades that ballast water also transports organisms into new ecosystems, where, under favorable conditions, they can become invasive (Carlton, 1985； Williams *et al*., 1988).
壓艙水在不同的陸地與海洋之間有著重要轉移生物的角色，已知數十年來，壓艙水在有利的條件下，會將水生物體運送到新的生態系統，但那些水生物體可能成為侵入性者。

The introduction of invasive aquatic species into new environments has been identified as one of the four greatest threats to the world’s oceans.
將入侵的水生物種引進新的環境已被確定為世界海洋的四大威脅之一。

When including terrestrial species, invasive species were identified as key factor in 54% of all known species extinctions as documented in the Red List database maintained by the International Union for Conservation of Nature (Clavero and Garcia-Berthou, 2005).
根據國際自然保護聯盟維護的紅色名單所登記的絕滅紀錄，包括陸地物種在內，所有物種滅絕的 54%，滅絕原因都來自入侵物種。

Aquatic invasions are virtually irreversible and, once the newcomers are established, their impacts may also increase in severity over time.

水生物種入侵實際上是不可逆轉的，因為一旦外來物種已佔領，對他們的影響會隨的時間而增加。

The transfer of invasive species does not occur only over larger distances, between continents, but also as a secondary spread in regional seas (David et al., 2013).
入侵物種的傳遞不僅發生在較遠的距離上，在陸地之間，也在區域海域發生。

Invasive aquatic species can result in ecosystem changes and disruptions of ecosystem services (Vilà et al., 2010).
入侵的水生物種可能導致生態系統變化與生態系統營運中斷。

Invasive species management in marine and coastal environments are major challenges.
入侵物種管理是海洋與沿海環境的重要挑戰。

In European Seas alone, more than 1000 alien species are known.
就歐洲海洋而言，擁有超過 1000 種的外來物。

A list of the 100 most impacting species introduced into European waters was prepared within the project “Delivering Alien Invasive Species Inventories for Europe (DAISIE)” (Vilà et al., 2009).
在"歐洲提供外來入侵物種紀錄（DAISIE）"的項目中，編制引進歐洲水域的 100 個最具影響力的物種清單。

Ecological impacts were categorized, e.g. competition with native species, hybridization with native species, use of resources, or habitat modification.
對生態的影響被分類幾種，例如與原始物種競爭、與原始物種繁殖、資源的利用或是棲息地的改變。

Among the top scorers of overall impact, for which ballast water could be identified as a major vector, are organisms from different taxonomic groups originating from different native ranges.
其中，總體影響最高的是壓艙水可以被認定為主要的帶菌者，將源自於不同原生範圍的生物體傳送到不同的生物群體。

Two species in particular, which were introduced by ballast water and are widespread in Europe, illustrate the possible impact of invasion: The first is the

Chinese mitten crab (*Eriocheir sinensis*), a decapod crab, which is native in Asia.
特別是被壓艙水引進與歐洲廣泛使用壓艙水，說明了入侵可能的影響有兩種：第一種是中國手螃蟹(中華絨螯蟹)，是一種在亞洲本土出生的螃蟹。

The crab, which reaches a size of approx 7 cm body length, reproduces in marine waters, juvenile crabs migrate up to 1000 km upstream where the adults live for two years in lakes and rivers before they migrate back to the sea for reproduction.
這螃蟹大約有 7 公分的身長，繁殖魚海洋中，較年幼的螃蟹會往上游方向遷徙到成年螃蟹在湖泊與河流居住兩年的地方，大約 1000 公里，然後再返回海域中繼續繁殖。

This invader was first recorded in Europe in 1912 in the Aller River (Germany).
而這個入侵者在 1912 年被歐洲紀錄生存在德國的阿勒河。

Mass development of this crab in several decades of the last century highlighted its negative impact.
上個世紀幾十年來，這螃蟹的大規模發展突顯出牠的負面影響。

Fishermen were affected by the crabs preying upon fish caught in nets and they damaged fishing nets by rope cutting.
漁夫也被這些螃蟹所影響，這些螃蟹會把漁網切割，讓漁夫捕撈不到魚。

It was also observed that the crabs clogged commercial water intakes and increased the river bank erosion by burrowing.
還觀察到，螃蟹會堵塞了商業用進水口，並經由挖洞而增加了河岸被侵蝕的結果。

A “beneficial” impact was also documented as the crabs are considered an Asian delicacy and are sold to Chinese restaurants.
這種螃蟹也被認定為一種亞洲美食，賣給中國餐館，是個”有益”影響。

Today this species is found from Portugal to Norway and Russia (Gollasch and Rosenthal, 2006).
現今從葡萄牙到挪威與俄羅斯都知道這個物種。

A second example is the comb jelly (*Mnemiopsis leidyi*), which is a more recent case of a drastically impacting invasive species.
第二種是梳狀果凍(蛇尾草)，這是一種更具影響力的入侵物種。

This species originates from the East Coast of the USA and the Caribbean Sea and was introduced in the 1980s to the Black Sea where it caused, in combination with pollution and overfishing, a devastating reduction in fish catches (Shiganova and Bulgakova, 2000).
這種植物來自於美國東海岸與加勒比海，在 1980 年代在黑海生產，因為結合汙染與過度捕撈的原因，使這黑海的捕撈魚類量減少。

Since then, the comb jelly spread further and is today also found in the Mediterranean, Baltic and North Seas, luckily without causing a comparable negative impact.
從此以後，這梳狀果凍傳播至地中海、波羅的海與北海，幸運的是，這沒有造成更糟的負面影響。

In 2004, the GloBallast programme – a cooperative initiative of the International Maritime Organization (IMO), the United Nations Development Programme, and the Global Environment Facility – undertook an initial scoping study on the global economic impacts of invasive aquatic species (Hassell, 2003； GEF-UNDP-IMO GloBallast Partnerships Programme and IUCN, 2010).
在 2004 年，全球壓艙水管理項目程序-國際海事組職、聯合國開發計畫署與全球環境基金的合作倡議，對入侵水生物種的全球經濟影響進行初步範圍界定研究。

Direct economic impacts due to currently known aquatic invasions, including costs from reductions in fisheries and aquaculture production, physical impacts on coastal infrastructure, loss of income for the shipping industry, and impacts on recreational areas and tourism, are estimated to exceed US$ 100 billion per year.
目前已知水生物種入侵造成經濟有直接影響，還包括漁業和水產養殖產銷量減少，對沿海基礎設施的影響，航運業的收入損失以及對娛樂區和旅遊業的影響，估計每年超過 1000 億美元。

Additional costs will be incurred by response measures, such as prevention, control and eradication of pests, research and monitoring, education and communication, compliance monitoring and enforcement, as well as costs of

the development and onboard installation of ballast water treatment technologies.
必須做一些應對措施如預防、控制與根除害蟲、研究與監測、教育與溝通，合規監測與執法，以及壓艙水處理技術的開發與板載安裝成本。

Another aspect of species transfer by ballast water concerns the spreading of organisms with potentially harmful effects on human health, such as toxin-releasing algae (Baldwin, 1992; Doblin *et al*., 2004; Hallegraeff and Bolch, 1991； Lilly *et al*., 2002) or pathogenic bacteria (Ruiz et al., 2000).
另一方面，藉由壓艙水傳遞物種，還需擔憂傳播對人體有害的潛在生物體，例如釋放毒素的藻類或病原菌。

Eighty years ago, concerns about hygiene and public health already prompted the U.S. National Institute of Health to advocate a regulation of ballast water discharge and ballast water treatment (Ferguson, 1932).
八十年前，關心衛生與公共衛生已經促使美國國家衛生研究所主張對壓艙水排放調整與壓艙水的處理。

Discharged ballast water at that time was described as “usually seriously contaminated”, and ballast water treatment with sodium hypochlorite was proposed for all ships travelling along the North American Coast and the Great Lakes.
當時排放的壓艙水被描述為“相當嚴重污染”，對於沿著北美海岸與北美五大湖行進的所有船，都檢查出用次氯酸鈉進行壓艙水處理。

In view of the anticipated side effects, the chlorine dosage was to be controlled by “dividing harbour waters into classifications on the basis of plate counts of total bacteria and specifying a chlorine dosage for each class.”
以副作用的觀點來看，氯劑量應把“總細菌的盤數劃分到不同類別，並指定每個類別的氯劑量”。

Although it was reported that there were no “physical difficulties in the way of effectively chlorinating ballast water”, further work on this issue was discontinued in view of the more serious problems that were caused by the pollution of water with discharged vessel sewage.
雖然報導沒有“有效氯化壓艙水的實際困難”，但由於排放污船污水污染造成的嚴重問題，中止了這一步的工作。

Since the 1930s, ships have become larger and faster, and the importance of global cargo shipping has changed dramatically.
自從 1930 年代以來，船越變越大、越來越快速，全球貨運的重要性有著巨大的改變。

Ballast water moved back onto environmental and public health agendas.
壓艙水返回到環境與公共衛生議程上。

While some countries, i.e. Australia and Canada, which were particularly affected by aquatic invasions, put in place national regulations for ballast water management, it was also clear that the global nature of shipping would require a global response to the ballast water problem.
然而有一些國家，即澳洲與加拿大，特別受到水生物侵入影響，因此制定壓艙水管理國家條例，明顯地，全球航運性質需要全球對壓艙水問題作回應。

In the 1990s, the IMO developed guidelines for the control and management of ships' ballast water, while at the same time preparing for a binding international treaty.
在 1990 年代，國際海事組織對壓艙水的控制與管理提出方針，同時為有約束力的國際條約作準備。

This was finally put into practice at a diplomatic conference in 2004, which adopted by consensus the "International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention)" (IMO, 2004).
最後在 2004 年一次外交會議上終於實施了，以協商一致方式通過"國際船舶壓艙水與沈積物管理公約"(BWM 公約)。

The BWM Convention enters into force twelve months after the date on which not less than 30 states with combined merchant fleets of not less than 35% of the gross tonnage of the world's merchant shipping have signed it.
BWM 公約在不少於 30 個州與世界商船總噸位不少於 35%的商船組合簽署，日起十二個月後生效。

At the end of April 2014, 38 states constituting 30.38% of the world's tonnage had ratified the Convention.
到 2014 年 4 月底時，佔世界噸位的 30.38%的 38 個國家，已經批准了"公約"。

The BWM Convention provides a set of management tools through which the maritime industry can be regulated.
BWM 公約提供一套管理工具，通過該工具可以管理海洋事業。

At its core are two different protective ballast water management regimes with a sequential implementation:
其核心是兩個不同的保護性壓載水管理制度

1. Ballast Water Exchange Standard (Regulation D-1) requiring ships to exchange a minimum of 95% ballast water volume at least 50 nautical miles from the nearest shore and in waters of 200 m depth or more。
   壓艙水交換標準(規則 D-1)-要求船舶從最近的岸邊而且位於 200 公尺深的海域換到最低 95%的壓艙水量，距離至少 50 航海英里。
2. Ballast Water Performance Standard (Regulation D-2), which requires that discharged ballast water contain viable organisms only in numbers below specified limits (Table 1).
   壓載水性能標準(規則 D-2)，要求排放的壓艙水僅含有低於規定的數量的活生物體。

In order to ensure uniform implementation of the Convention, a set of regulatory and technical guidelines were needed, which the IMO developed together with representatives of the member states, industry, and other organizations.
為了確保統一實施，一套國際海事組織與國家代表們、產業與其他組織共同開發的，是需要監管與技術指導的。

As it was already foreseen that one option of ballast water treatment would be the use of active chemicals or radiation to achieve the D-2 standards, regulations had to be put into place to make sure that the employment of such treatment methods would not cause inacceptable risks to the aquatic environment, human health, or the safety of the ship itself.
正如預見那樣，壓艙水選擇處理方案中，使用活性化學品或輻射來達到(D-2)的標準，規定必須遵守，使用這種處理方法，對水生環境、人們健康或船本身的安全，會不會造成不可接受的風險。
※(D-2)壓載水性能標準-要求排放的壓艙水僅含有低於規定的數量的活生物體。

Hence, IMO guideline G8 (IMO, 2008a) outlines the approval requirements of ballast water management systems (BWMS) by competent flag state authorities and IMO procedure G9 (IMO, 2008b) controls the approval of specifically those BWMS that make use of active substances, which must be endorsed by the IMO Marine Environment Protection Committee (MEPC).
因此，國際海事組織指引 G8 的概要，由合格的船旗國主管機關當局以及國際海事組職對 G9 的程序，控制特定活性物質的壓艙水管理系統，都必須被國際海事組織-海洋環境保護委員會(MEPC)所認可。

To review and evaluate the often-confidential documents, which BWMS manufacturers provide with regard to the properties of their systems, MEPC established a technical group of experts, the GESAMP Ballast Water Working Group (GESAMP BWWG; GESAMP stands for “Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection”, a UN advisory body).
為了審查與評估壓艙水管理系統製造商提供的其屬性的機密文件，MEPC 成立了技術專家小組，也就是 GESAMP BWWG(聯合國海洋環境科學方面專家兼壓艙水工作小組；GESAMP 代表聯合國海洋環境科學方面專家小組)。

Today, we look back on eight years of experience with the IMO approval procedure.
今天，我們再回顧國際海事組織審批程序 8 年經驗。

During this time MEPC granted Final Approval to 31 BWMS that make use of active substances (as of May 2013).
在這段期間(2013 年 5 月)，海洋環境保護委員會授予 31 個壓艙水管理系統，使用活性物質的最終批准。

Both G8 and G9 have meanwhile been revised, and the GESAMP BWWG has further developed its “Methodology for information gathering and the conduct of work” (IMO, 2012).
G8 與 G9 同時修改，而且聯合國海洋環境科學方面專家兼壓艙水工作小組，也進一步發展”收集資訊的方法與工作的進行”。

Once the BWM Convention finally enters into force, >50 000 ships will need to be equipped with BWMS.
一旦國際船舶壓艙水與沈積物管理公約最後生效，超過 50000 船舶都需要配備壓艙水管理系統。

Prior to that seems to be the right time to summarize the experiences and observations made and to critically analyze, whether the existing protocols and practices for BWMS testing and approval provide sufficient protection from the environmental and health risks that have so far been identified for the application of these technologies.
在這之前，是一個正確時機去總結經驗與觀察結果，做批判性分析，無論現有協議與實踐，壓艙水管理系統測試與批准都要提供充分的保護環境與健康風險，以避免到目前為止已被確定為應用這些技術。

The German Federal Institute for Risk Assessment (BfR), which recently published two studies with particular relevance to human health (Banerji *et al*., 2012； Werschkun *et al*., 2012b), has initiated an extension of the ballast water discussion to a wider circle of scientists, administrators, and stakeholders in the areas of water treatment and marine resources, public health and marine environmental protection (Werschkun et al., 2012a).
德國聯邦國風險評估最近發表兩項研究，特別是與人體有關的健康，由範圍較廣的科學家、管理員、再水處理與海洋資源的利害攸關者，發表延伸壓艙水討論議題，即公共衛生與海洋環境保護。

This paper intends to reflect the current state of understanding and invites further discussion of this issue.
本文旨在反映目前的理解狀態，並對此進行近一步討論。

2.Ballast water management systems 壓艙水管理系統

Many different water treatment technologies are available for municipal and industrial applications.
許多不同的水處理技術可用於市政和工業應用。

However, when applying them without modifications for ballast water treatment, none of these technologies has shown the capability to achieve the treatment level required by the BWM Convention D-2 standard.
然而，在不經過壓艙水處理的情況下應用它們時，這些技術都沒有顯示達到國際船舶壓艙水與沈積物管理公約 D-2 標準要求的處理水平的能力。

However, the soon expected entry into force of the Convention is an important driving force for ballast water treatment technology developments worldwide (David and Gollasch, 2008).
然而，“公約”即將生效,是全球壓艙水處理技術發展的重要推動力。

While there are still concerns regarding certain types of vessels and regarding the retrofitting capacity of shipyards, many different BWMS are already on the market and others are under development (Dobroski *et al*., 2009; Gregg *et al*., 2009; American Bureau of Shipping, 2010; California State Lands Commission, 2010; Lloyds Register, 2012; Witherby Seamanship International, 2011； David and Gollasch, 2012).
雖然仍然關注某些類型的船隻以及造船廠的改造能力，但有許多不同的壓艙水管理系統已經在市場上，而且正在開發船隻。

By July 2012, information on 95 different systems was brought together as background information for the EU FP7-funded project VECTORS.
到了 2012 年 7 月，有 95 個不同系統的資訊匯集在一起，作為歐盟 FP7 資助項目"矢量"。

Of these, 23 systems were already type approved with others being in different stages of testing and approval processes (David and Gollasch, 2012).
目前已經批准 23 個系統，其他系統處於不同的測試與審批階段。

The system capacities range predominantly from 50 m^3 h^{-1} to more than 10 000 m^3 h^{-1}, while five manufacturers announced a capacity of 20 000 m^3 h^{-1} and higher.
系統容量主要從 50 立方米 h-1 到超過 10 000 立方米 h-1，然而有五家製造商宣稱容量為 20 000 立方米 h-1 及以上。

BWMS footprints occupy from less than 1 m^2 up to 145 m^2; some operate without electricity, while others may consume up to 0.2 kW h m^{-3} (David and Gollasch, 2012).
BWMS 的佔地面積從不足 1 平方公尺到 145 平方公尺;有一些是不用用電力運行的，而另一些則可能消耗高達 0.2 kW h m-3。

Since the completion of this summary, even more BWMS became known so that the total number is now higher than one hundred.
總結下來，有更多的壓艙水管理系統已成為眾所皆知的情形，其總數已高於 100 個。

2.1 Treatment methods 處理方法

Measures for ballast water treatment can be divided into mechanical–physical and chemical processes (Fig.1).
壓艙水處理措施可分為機械物理與化學過程。

Practically all identified BWMS employ a combination of two or more different processes.
實際上，所有確定的壓艙水管理系統採用兩個或更多不同過程的組合。

In most cases, mechanical separation of larger particles by filters or hydrocyclones constitutes the first treatment step.
在多數情況下，只要通過過濾器或水力旋流器，都會機械分離較大顆粒，因此也成了第一個處理步驟。

Automatic, self-cleaning filter systems with mesh sizes of about 40 μm are frequently employed, leaving smaller organisms in the water.
經常使用孔徑大小約 40 奈米的自動清潔過濾系統，在水中會留下較小的生物體。

Other physical measures are (a) the application of ultrasound and cavitation, which lead to the mechanical destruction of particles and organisms, (b) high energy techniques, such as heating or (c) UV irradiation.
其他物理措施是
（a）應用超聲與空化，導致顆粒和生物的機械破壞，（b）高能技術，如加熱或（c）紫外線照射。

With the combination of high performance filters and UV radiation, there are several type-approved BWMS on the market that rely entirely on physical treatment methods to achieve the IMO D-2 standard.
結合高性能過濾器與紫外線輻射的組合，市面上有幾種認證的 BWMS 型號,完全依靠物理處理方法來達成國際海事組織的 D-2 標準。

While these systems have no potential to cause chemical hazards to humans or the environment, their downsides are high energy consumption and potential performance problems in waters of high turbidity or a high content of dissolved organic matter (DOM), which may reduce the penetration of UV light.
雖然這些系統沒有對人類或環境造成化學危害的可能性，但它們的缺點在於高濁度或高含量的溶解有機物（DOM）的水中，具有高能量消耗與潛在的性能問題，這可能會降低紫外線的滲透光。

The majority of BWMS make use of “active substances”, which are defined, according to the IMO, as “substances that have a general or specific action on or against harmful aquatic organisms and pathogens”.

大多數的壓艙水管理系統都使用國際海事組織定義的“活性物質”也就是“對有害水生生物和病原體具有一般或具體作用的物質”。

There is not always agreement about the interpretation of this definition.

關於這個定義的解釋，沒有統一的協議。

While a number of UV systems underwent the complete G9 risk assessment and approval procedure, even though not employing any “substance” in the common sense, another BWMS is currently side-stepping the G9 procedure, which relies on the so-called ‘inert gas’ technology: A gas mixture, which is generated by the combustion of high purity fuel, is released into the ballast tanks, where its main purpose is to replace oxygen and thus create an anoxic environment, in which many organisms cannot survive.

然而有些 UV 系統經歷了完整的 G9 風險評估和批准程序，儘管在常識上沒有採用任何“物質”，但另一個壓艙水管理系統目前正在逐步推行 G9 程序，該程序依賴於所謂的“惰性氣體技術：由高純度燃料的燃燒產生的氣體混合物被釋放到壓載艙中，其主要目的是取代氧氣，從而產生許多生物不能存活的缺氧環境。

At the same time, however, elevated carbon dioxide levels in the combustion gas decrease the pH in the water, and a number of trace compounds such as sulfur and nitrogen oxides or aldehydes may contaminate the treated water.

然而，同時，燃燒氣體中的二氧化碳水平升高降低了水中的 PH 值，並且許多痕量化合物,如硫與氮氧化物或醛可能污染處理過的水。

Even though this system, as any other BWMS approved in accordance with IMO guideline G8, must undergo the same ecotoxicity testing of treated water as required by IMO procedure G9 for active substances, the study reports need to be submitted to the competent flag state authority, only.

即使按照國際海事組織準則 G8 批准的任何其他 BWMS，也必須按照國際海事組織程序 G9 對活性物質進行相同的生態毒性試驗，該研究報告只能提交給船旗國主管機關。

Thus, no detailed data about the exact composition of the combustion gas mixture or the composition and toxicity of discharged ballast water resulting from this treatment have so far been made publically available.

因此，還未出現對於燃燒氣體化合物成分或由壓艙水排放出來的毒性成分準確詳細資料，但是這處理方法到目前為止已公開為可用的。

Chemical disinfectants act by a variety of mechanisms at the molecular level.
化學消毒劑藉由分子水平的各種機制起作用。

One approved BWMS utilizes ionic interactions to combine fine particles, colloids, and dissolved matter into removable aggregates by the addition of the common flocculants iron(III) oxide, polyaluminium chloride, and polyacrylamide.
一個批准的壓艙水管理系統，利用離子相互作用，添加常見的絮凝劑氧化鐵（III），聚氯化鋁和聚丙烯酰胺的細顆粒、膠體與溶解物質結合成可去除的聚集體。

Most agents inhibit biological processes by chemical reactions with biomolecules such as membrane constituents, proteins or nucleic acids.
大部分的藥物都是藉由生物分子的化學反應來抑制生物過程，如薄膜成分、蛋白質或核酸。

Applications in ballast water treatment have been discussed for metal ions (silver or copper), aldehydes (formaldehyde, acrolein), and quaternary ammonium compounds, but no system based on any of these compounds has so far entered the IMO approval process.
已探討壓艙水處理中的金屬離子（銀或銅），醛（甲醛，丙烯醛）和季銨化合物的應用，但至今為止沒有一個是基於這些化合物的系統進入國際海事組織批准過程。

By far the largest group of active substances used are oxidizing agents.
至今為止，使用的最大的活性物質是氧化劑。

Systems based on chlorine (either generated *in situ* by seawater electrolysis or from hypochlorite stock-solutions) clearly predominate, followed by ozone, peracetic acid, and chlorine dioxide (in this order).
基於氯的系統（無論是通過海水電解還是從次氯酸鹽儲存溶液中原位生成）都有明顯地占主導地位，其次是臭氧，過乙酸和二氧化氯（依次）。

The application of chloramine is under development.
氯胺的應用正在開發中。

Strong oxidants, due to their high reactivity, not only react with the organisms to be inactivated but also with a number of other water matrix components. In freshwater, the reactivity of chemical oxidants with matrix components has been of interest since the 1970s when trihalomethane formation was discovered following chlorine addition (Rook, 1974).
強氧化劑由於其高反應性，不僅與待滅活的生物體反應，而且還會與許多其它水基質成分反應，在淡水中，化學氧化劑與基質成分的反應性，自 1970 年代以來，當氯加入後，會形成三鹵甲烷，其反應性已經引起人們的關注。

Many more compounds, i.e. disinfection byproducts (DBPs), have been identified since this time.
自那以後，已經鑑定了更多的化合物，即消毒副產物（DBP）。

In general, DBPs form through the reaction of oxidants with organic matter (i.e. humic and fulvic acids) and/or various inorganic species (e.g. bromide and iodide).
通常，藉由氧化劑與有機物質（例如腐殖酸和富里酸）和/或各種無機物質（例如溴化物和碘化物）的反應形成消毒副產物。

Halides are of particular importance because they can form additional oxidizing species.
鹵化物是特別重要的，因為它們可以形成額外的氧化物質。

Chlorine (HOCl) reacts with bromide and iodide to form the oxidizing species HOBr and HOI, respectively (reactions (1)； (2); Kumar and Margerum, 1987； Nagy *et al*., 1988), but, may also generate lower levels of oxidants such as Br_2, BrCl, BrOCl, and even Cl_2 given the high concentration of chloride present in saline waters (0.54 M; Eigen and Kustin, 1962; Wang and Margerum, 1994; Liu and Margerum, 2001； Margerum and Huff Hartz, 2002).
氯（HOCl）分別與溴化物和碘化物反應形成氧化物質 HOBr 和 HOI，但也可能產生較低水平的氧化劑如 Br2，BrCl，BrOCl，甚至 Cl2，因為鹽水中存在高濃度的氯化物。

equation(1)化學式（1）

$$HOCl + Br^- \leftrightarrow HOBr + Cl^- \quad (BrO^- + H^+ \leftrightarrow HOBr)$$

equation(2)化學式（2）

$$HOCl + I^- \rightarrow HOI + Cl^- \quad (IO^- + H^+ \leftrightarrow HOI)$$

Turn MathJax on

HOBr, formed by reaction (1), also reacts fairly quickly with IO$^-$ to iodate (IO_3^-) (reaction (3); Criquet et al., 2012), a non-toxic sink for iodide (Bürgi et al., 2001).
透過反應（1）快速與 IO-碘酸鹽（IO3-)形成一種無毒的碘化沈澱物 HOBr。

This reduces the chance to form iodo-organic compounds significantly (Criquet et al., 2012).
有顯著減少形成碘-有機化合物的機會。

equation(3)化學式（3）

$$2HOBr + IO^- \rightarrow IO_3^- + 2H^+ + 2Br^-$$

Turn MathJax on

Similar processes may also be observed in the presence of ammonia in which chloramines (NH_2Cl, $NHCl_2$, and NCl_3) are initially formed.
在其中最初形成的氯胺（ NH2Cl, NHCl2, and NCl3）的氨，也可以觀察到類似的方法。

Monochloramine (NH_2Cl) may then further react with bromide and iodide to form bromamines/bromochloramine (Hofmann and Andrews, 2001; Duirk and Valentine, 2007； Trofe *et al*., 1980) and HOI (Bichsel and von Gunten, 1999), respectively.
然後，氯胺（NH2Cl）可以進一步與溴化物和碘化物反應形成溴胺/溴氯胺和 HOI。

Formation of such brominating/iodinating oxidants generates species that are often more reactive than the initial applied oxidant (Sivey and Roberts, 2012； Sivey *et al*., 2013) and form brominated/iodinated DBPs in the reaction with dissolved organic matter.

這種溴化/碘化氧化劑的形成產生的物質通常比初始使用的氧化劑更具反應性，並在與溶解的有機物反應中形成溴化/碘化的消毒副產物。

Ozone is also affected by the presence of halides.
臭氧也會受到鹵化物的影響。

Initially, ozone reacts with bromide and iodide to form HOBr and HOI (reactions (4)； (5)), respectively, but can further oxidize BrO^- to bromate (BrO_3^-; reaction (6), simplified; Haag and Hoigne, 1983; von Gunten and Hoigné, 1994； von Sonntag and von Gunten, 2012).
最初，臭氧與溴化物和碘化物反應分別形成 HOBr 和 HOI，但可以進一步氧化 BrO-溴酸鹽。

Since the reaction of ozone with $HOBr/BrO^-$ is relatively slow, this oxidant may react with the dissolved organic matter to form brominated organic compounds.
由於臭氧與 HOBr / BrO-的反應相對較慢，因此該氧化劑可與溶解的有機物反應形成溴化有機化合物

In contrast, ozone reacts quickly with HOI/OI^- to iodate (IO_3^-) (reaction (7); Bichsel and von Gunten, 1999).
相比之下，臭氧與 HOI / OI-至碘酸鹽（IO3-）能快速反應。

Thus, the formation of iodinated DBPs is minimized (Allard *et al*., 2013； von Sonntag and von Gunten, 2012).
因此，碘化消毒副產物的形成被最小化。

The impact of halides on other oxidants such as chlorine dioxide and peracetic acid remains less clear.
鹵化物對其他氧化劑如二氧化氯和過乙酸的影響仍然不太清楚。

Chlorine dioxide, while well documented to generate the inorganic DBPs chlorite and chlorate, does not react with bromide but does react with iodide (Hoigné and Bader, 1994).
二氧化氯雖然有文獻證明產生無機消毒副產物亞氯酸鹽和氯酸鹽，不與溴化物反應，但與碘化物反應。

This was followed by a study in which chlorine dioxide-treated water containing 2 mg L^{-1} bromide and 17–18 μg L^{-1} iodide did not generate brominated DBPs while formation of iodinated DBPs remained inconclusive (Richardson et al., 2003).
隨後進行了一項研究，其中含有 2mg L-1 溴化物和 17-18μgL-1 碘化物的二氧化氯處理水不產生溴化 DBP，而碘化 DBP 的形成仍未確定。

Only very limited evidence is available on peracetic acid, suggesting that DBPs such as chlorophenols and bromophenols form from phenol-spiked final effluent wastewater in the presence of chloride and bromide, respectively (Booth and Lester, 1995).
只有非常有限的證據可用於過乙酸，建議消毒副產物如氯酚和溴酚分別在氯化物和溴化物的存在下,從苯酚加標的最終廢水中形成。

2.2. Testing 測試

As long as the BWM Convention is not implemented, we derive our knowledge about BWMS performance and side effects from prototypes that are already installed on board ships and from BWMS testing in land-based facilities.
只要國際船舶壓艙水與沈積物管理公約沒有實施，我們從船上已經安裝的原型和陸上設施的壓艙水管理系統測試中獲得了有關壓艙水管理系統性能和副作用的知識。

The primary scope of land-based testing as described in IMO guideline G8 (IMO, 2008a) is to evaluate the effectiveness of BWMS in removing or killing organisms.
國際海事組織原則 G8 中描述的陸上測試的主要範圍是評估壓艙水管理系統在去除或殺死生物體方面的有效性。

BWMS that make use of active substances must additionally undergo toxicity testing as detailed in IMO procedure G9 (IMO, 2008b).
使用活性物質的壓艙水管理系統還必須經過國際海事組織程序 G9 中詳細的毒性測試。

Land-based tests are conducted at flow rates of 200 m^3 h^{-1} and a minimum holding time of 5 d for treated water.
陸上測試以 200 m3 h-1 的流速和處理水的最短保存時間為 5 天。

A control experiment with untreated water is conducted in parallel.

對照實驗與未經處理的水必須是並行進行的。

However, the holding tanks used for land-based testing differ significantly from a ship’s ballast water tank in size and design.
然而，用於陸上測試的儲容器，在尺寸和設計上與船的壓艙水箱有明顯不同。

Tanks used for land-based testing usually have less internal structures than a vessel’s ballast water tank, which influence the movement of the water within the tank, while filling and discharging.
陸上測試用的容器比船的壓艙水箱內部結構通常來得少，因為壓艙水在補充與排放時，會影響容器內水的流動。

Furthermore, the role of sediment cannot be assessed during land-based certification, since the protocols call for cleaning of the tanks between each test.
此外，在陸上測試期間，不能評估沉積物的作用，因為協議要求在每次測試之間都必須清理容器。

Water samples are generally taken on intake and on discharge.
水的樣本通常在攝入和排放時攝取。

In order to get reliable and representative samples, land-based test facilities are equipped with numerous sampling points at different locations.
為了獲得可靠而有代表性的樣本，陸上測試設施在不同地點配備了許多個採樣點。

Analysis of the samples focuses on biological parameters.
樣本分析集中於生物參數。

In addition, basic parameters characterizing the water matrix such as salinity, temperature, organic carbon and particulate matter content, pH and oxygen are measured.
此外，測量表徵水基質的基本參數，如鹽度，溫度，有機碳和顆粒物含量，pH值和氧氣。

Additional samples can easily be taken, for instance for toxicity testing or for the analysis of nutrients or chemicals.

The IMO guidelines G8 and G9 are generic in nature, and at the time the first versions were released in 2004/2005, there were no standard methods available.
用於毒性測試、分析營養物質或化學物質的額外增加的樣本都很容易被採取到，國際海事組織 G8 和 G9 的指導原則都是通用的，而在 2004/2005 年發布的第一個版本的時候，沒有標準的方法可用。

Test facilities had to find their own means of putting the guidelines into practice.
測試設施必須找到自己的方法來實施指南。

Harmonization efforts, e.g. via the GloBallast programme or the North Sea Ballast Water Opportunity project show that the different test facilities in general developed quite similar approaches to the problem (Gollasch, 2010).
協調一致的努力，例如通過全球壓艙水管理項目計劃或北海壓艙水機會項目，顯示不同的測試設施，一般開發出了非常相似的方法來解決問題。

Almost all test facilities use ambient, natural water.
幾乎所有的測試設施都使用自然環境的水。

However, the degree to which this water is altered varies.
然而，這種水的改變程度有所不同。

To ensure sufficient function of BWMS even under challenging conditions, guideline G8 requires that test water used for land-based testing must contain specified minimum concentrations of living organisms as well as abiotic matter.
為了確保壓艙水管理系統的充分功能，即使在具有挑戰性的條件下，G8 指南要求用於陸上測試的試驗水必須含有特定的最低濃度的生物體以及非生物物質。

Test facilities that are located in biologically highly productive and turbid areas need less manipulation of their water to fulfil these criteria.
位於生物高生產力和混濁區域的測試設施需要較少的操縱水來滿足這些標準。

Others, who either do not have suitable water conditions or want to test independently of surrounding conditions, add surrogate organisms and suspended and/or dissolved matter.
其他沒有適合水條件或不想獨立於周圍環境進行測試的人員，可以添加替代生物和懸浮和/或溶解的物質。

Working with natural water makes the tests less predictable, while working with heavily modified waters increases the possibility of artefacts.
使用天然水會讓測試不可預測性，而使用嚴重改性的水可能會增加人為因素的可能性。

When analysing data from certification tests of BWMS, it is important to keep in mind that the preparation of test water and water chemistry might have an influence on studies performed for toxicological risk-assessment, e.g. through differences in by-product formation.
在分析壓艙水管理系統認證測試的數據時，請務必記住，測試水和水分化學的準備可能對進行毒理學風險評估的研究產生影響，例如通過副產品形成的差異。

3. Hazards 危害

Chemical hazards associated with BWMS can be divided into acute effects from the action of strong oxidants and long-term effects from DBPs.
化學危害與壓艙水管理系統有關，它可以分為急性作用的強氧化劑與長期作用的消毒副產物。

While the employed oxidants generally act as corrosives on living tissue, the concentrations handled on board are mostly below toxicological concern, especially when generated *in situ*.
雖然所用的氧化劑通常在活組織上作為腐蝕劑，特別是在原位生成時，船上處理的濃度主要低於毒理學。

Only in a few cases concentrated chemicals are carried on board – ready-made hypochlorite solutions, peracetic acid, and starting materials for the generation of chlorine dioxide (hydrogenperoxide, sodium chlorate, 70% sulfuric acid) – and pose potential danger to the crew.
只有少數情況下，濃縮化學品才會帶到船上，像是現成的次氯酸鹽溶液，過乙酸與用於產生二氧化氯的原料（過氧化氫，氯酸鈉，70%硫酸），這些對船員而言，有著潛在危險。

The aquatic environment is protected from strong oxidants by the requirement to keep total residual oxidant concentrations in discharged treated water below 0.2 mg L^{-1}, which is achieved by reaction with reducing agents such as sodium bisulfite or thiosulphate.

水生環境被強氧化劑所保護，按要求將排出的處理水中的總殘留氧化劑濃度保持在 0.2mg L-1 以下，這是藉由與還原劑反應來達成的，如亞硫酸氫鈉或硫代硫酸鹽。

The generated mixtures of DBPs present far more complex toxicological challenges, both to human health and natural biota.
所產生的消毒副產物混合物對人類健康和天然生物群體的毒理學呈現出更複雜的挑戰。

3.1.Long-term toxicity of disinfection by-products 長期毒性消毒副產品

Many DBPs are associated with severe health hazards, such as the potential to cause cancer and reproductive and developmental effects (Nieuwenhuijsen *et al*., 2000; Richardson *et al*., 2007; Savitz *et al*., 2005; Villanueva *et al*., 2004； Waller *et al*., 1998).
許多消毒副產物與嚴重的健康危害有關聯，例如可能導致癌症與生殖、發育的影響。

Chloroform and other trihalomethanes (THMs) were the first DBPs identified in chlorinated drinking water in 1974 (Rook, 1974； Bellar *et al*., 1974).
氯仿與其他三鹵甲烷（THM）都是第一種消毒副產物，在 1974 年鑑定為氯化飲用水。

Soon after their discovery, the THMs were found to cause cancer in laboratory animals (National Cancer Institute, 1976).
不久就發現三鹵甲烷在實驗動物中會引起癌症。

As a result, they became regulated in the United States in 1979 (U.S. EPA, 1979), and later in several other countries.
因此，它們在 1979 年在美國受到監管，後來也在其他國家被列為管制品。

A few additional DBPs are now regulated in the U.S., including five haloacetic acids (HAAs), chlorite, and bromate (U.S. EPA, 2006).
現在美國加了些消毒副產物並且管制它們，包含五種鹵代乙酸（HAAs）、亞氯酸鹽與溴酸鹽。

Over the last 30 years, significant research efforts in the field of drinking water disinfection have been directed towards increasing our understanding of DBP formation, occurrence, and health effects.

過去 30 年來，在飲用含消毒成分的水之領域，有著重要的研究工作，已指示加消毒副產物越多，產生健康影響就越多。

More than 600 DBPs have now been reported in the scientific literature (Richardson, 1998； Richardson, 2011).
目前科學文獻報導了超過 600 種消毒副產物。

However, only less than 100 have been addressed either in quantitative occurrence or toxicity studies (Richardson et al., 2007).
然而，無論是在發生的量或毒性研究已被解決的，不到 100 件。

More than 50% of the halogenated DBP material formed during the chlorination of drinking water, and more than 50% of the DBPs formed during ozonation of drinking water are still not accounted for (Krasner *et al*., 2006； Richardson *et al*., 2008a), and nothing is known about the potential toxicity of many of the DBPs present in drinking water.
在飲用水氯化過程中形成超過 50%的鹵化消毒副產物材料，與在飲用水的臭氧化期間形成超過 50%的消毒副產物，都沒有解釋也沒有人了解飲用水中，存在許多消毒副產物對人們的潛在毒性。

Much of the previous health effects research has focused on cancer, genotoxicity, mutagenicity, or cytotoxicity (Richardson et al., 2007).
許多以前的健康影響研究都集中在癌症、遺傳毒性、致突變性或細胞毒性。

There are concerns that the types of cancer observed in animal studies (primarily liver cancer) for the regulated DBPs do not correlate with the types observed in human epidemiology studies (primarily bladder cancer).
有人擔心在動物研究（主要是肝癌）中觀察到受監管的消毒副產物類型與人類流行病學研究中觀察到的類型沒關聯。

Therefore, studies on DBPs beyond those that are currently regulated are needed.
因此，需要對目前監管的消毒副產物進行研究。

There is indication that brominated DBPs may be more carcinogenic than their chlorinated analogues (Richardson et al., 2007), and early evidence in epidemiologic studies also gives indication that brominated DBPs may be

associated with reproductive and developmental effects (Savitz *et al*., 2005； Waller *et al*., 1998).
有跡象顯示溴化消毒副產物可能比氯化類似物更致癌，與流行病學研究中的早期證據裡也給出指示，溴化消毒副產物可能造成生殖與發育的影響

New studies are indicating that iodinated compounds are even more toxic than their brominated analogues (Plewa et al., 2004a; Richardson *et al*., 2007； Richardson *et al*., 2008b).
新研究指示該碘化合物比其它溴化類似物更具毒性。

Moreover, many emerging DBPs are nitrogen containing (the so-called "N-DBPs"), which are generally more genotoxic and cytotoxic than those without nitrogen (Plewa et al., 2008).
此外，許多新興的消毒副產物都有含氮（所謂的"N-DBP"），通常比沒有氮的那些更具遺傳毒性和細胞毒性。

Specific DBPs that are of current interest include iodo-acids, bromonitromethanes, iodo-THMs, haloamides, halofuranones, halopyrroles, haloquinones, haloaldehydes, halonitriles, and nitrosamines.
目前具體的消毒副產物包括碘酸，溴硝基甲烷，碘-三鹵甲烷，鹵代酰胺，鹵呋喃酮，鹵代吡咯，鹵代醌，鹵代醛，鹵代腈和亞硝胺。

Several of these DBPs are carcinogenic, including MX (3-chloro-4-(dichloromethyl)-5-hydroxy-2(*5H*)-furanone) and several of the nitrosamines including N-nitrosodimethylamine (NDMA).
這些消毒副產物，其中幾種是致癌的，這些消毒副產物中的幾種是致癌的，包括微核（3-氯-4-（二氯甲基）-5-羥基-2（5H） - 呋喃酮）、幾種亞硝胺與 N 亞硝基二甲胺（NDMA）。

Many emerging DBPs show stronger genotoxic or cytotoxic effects in mammalian or human cells (in vitro) than DBPs that are currently regulated (Attene-Ramos *et al*., 2010； Plewa *et al*., 2008).
許多新興的消毒副產物在哺乳動物或人類體外細胞中，顯示出比當前調節的消毒副產物有更強的基因毒性或細胞毒性作用。

For example, iodoacetic acid, the most genotoxic DBP studied to-date, is two times more genotoxic than bromoacetic acid (Plewa et al., 2004a), which is regulated.

例如，到目前為止研究的最基因毒性、經調節後的消毒副產物中的碘乙酸，是溴代乙酸的基因毒性的兩倍。

Throughout the series of haloacetic acids, the toxic potency increases from chloro- to bromo- to iodo-derivatives (Plewa et al., 2010).
在整個系列的滷代乙酸中，毒性效應從氯 - 溴 - 碘衍著生物增加上去。

Recently published research revealed an association between the toxicity of monohaloacetic acids and their capacity to induce oxidative stress (Pals et al., 2013).
最近發表的研究顯示，其誘導氧化應激的能力，單鹵代乙酸與毒性之間有關聯。

Iodoacetic acid also caused neural tube defects in mouse embryos (Hunter and Tugman, 1995), and recent data shows that it is also tumorigenic in mice (Wei et al., 2013).
碘代乙酸也引起小鼠胚胎的神經管缺陷，最近的數據顯示，它也是小鼠致瘤性的。

While most toxicity studies to-date have been conducted on individual chemicals only, DBPs in treated water are always present as mixtures.
然而，至今大多數的毒性研究，僅針對個別化學品著手，但處理水中的消毒副產物，總是作為混合物。

As a consequence, a collaborative study of the four national laboratories and centres of the U.S.
因此，對美國四個國家實驗室和中心的合作研究。

EPA was conducted to investigate the toxicity of these complex DBP mixtures, as well as defined mixtures containing regulated DBPs (Pressman *et al*., 2010； Simmons *et al*., 2008).
EPA 研究調查這些複雜消毒副產物混合物的毒性，以及含有調節消毒副產物的混合物。

A battery of in vitro and in vivo assays was used to investigate the toxicity, with an emphasis on reproductive and developmental effects.
一批體外和體內測定被用來調查毒性，重點著重在生殖與發育的影響方面。

Seventy priority DBPs were quantified, and more than 100 were comprehensively identified.
七十個優先級消毒副產物被量化，且全面確定了 100 多個。

In the tested concentrates (~136× drinking water concentrations), major in vivo effects were not observed, but a number of more subtle effects (such as lower sperm counts, and delayed puberty) were found.
在測試濃縮物（～136×飲用水濃度）中，未觀察到主要的體內反應，但發現了一些更微妙的影響（如精子數量減少與青春期延遲）。

Complete toxicology results for this work have recently been published (Narotsky et al., 2013).
這項工作完成毒理學結果，且最近已經發表了。

In Europe, the HIWATE project combined chemical analysis of DBPs in drinking water samples from five different countries with both in vitro cytotoxicity tests and epidemiological studies on adverse pregnancy outcomes (Jeong et al., 2012).
在歐洲，長期暴露於飲用水消毒副產物對健康影響(HIWATE)的項目中，採自五個不同國家的飲用水樣品，進行消毒副產物的組合化學分析，也同時進行體外細胞毒性試驗與對不良妊娠結果的流行病學研究。

Poor correlation between chemical analyses and genotoxic responses observed in this study indicates an unidentified influence and emphasizes the need to further evaluate the toxicity of complex mixtures.
在本研究中觀察到，化學分析與基因毒性反應之間的相關性不佳，表明不明確的影響，並強調需要進一步評估複雜混合物的毒性。

In view of the multitude of potentially occurring DBPs, a biotest-based test strategy might be a feasible alternative or addition to chemical analysis for the hazard assessment of treated water.
鑑於許多潛在的消毒副產物中，以生物為主的測試策略，都有可能是一個可行的選擇或補充化學分析處理水的危害評估。

A number of comparatively simple in vitro tests may already give important indications of the toxicological properties of most concern.
一些比較簡單的體外試驗，可能已經給出對最憂心的毒理特性的重要跡象。

(Kirkland et al.(2011)) have shown that none of the known genotoxic carcinogens would have remained undetected by a simple combination of a bacterial gene mutation assay (Ames test) and an in vitro micronucleus test.
(Kirkland 等人(2011)) 已經表明，透過細菌基因突變測定（Ames 測試）與體外微核試驗的簡單組合，沒有已知的基因毒性致癌物質未被檢測到。

Both assays are already applied for regulatory purposes in the German waste water regulation (German Federal Ministry of Justice, 1997).
這兩種測定法都已經在德國廢水管理中應用於監管。

3.2. Implications for natural biota 對天然生物群的影響

Given the universal make-up and functionality of DNA, it is generally accepted that qualitatively the induction of genetic damage following exposure to environmental contaminants across phylogenetically disparate groups of organisms is the same (Dixon *et al*., 2002； Jha, 2004).
鑑於 DNA 的普遍組成與功能，普遍接受的是，定性地在與系統發育不同的生物群體接觸環境污染物後，誘導遺傳損傷是相同的。

Genotoxic effects are considered to be important for the initiation and promotion of carcinogenesis, and several studies have linked the induction of pre-neoplastic and neoplastic lesions in fish and invertebrates with genotoxic effects (e.g. DNA adducts, DNA strand breaks, induction of micronuclei) following exposure to a range of contaminants in the natural environment (Myers *et al*., 1998; Lyons *et al*., 2004; Frenzilli *et al*., 2004; Vogelbein *et al*., 1990; Hesselman *et al*., 1988; Gardner *et al*., 1991; Bolognesi and Hayashi, 2011； Theodorakis *et al*., 2012).
遺傳毒性作用被認為對致癌作用的起始與促進是重要的，且幾項研究將魚與無脊椎動物中的前腫瘤和腫瘤病變的誘導與基因毒性作用（例如 DNA 加合物，DNA 鏈斷裂，微核誘導）聯繫在一起暴露於自然環境中的一系列污染物。

Whilst cancer is one of the major health concerns in the human health arena, this disease until now has not been considered important for natural biota - despite the fact that under the microscope neoplasia whether in humans or in natural biota (e.g., fish or mussels) have similar mechanisms of induction and pathological features.
雖然癌症是人類健康領域的主要健康問題之一，但到目前為止，這種疾病對於天然生物群尚未被認為是重要的-儘管事實上，在顯微鏡下，無論是人類還是天然生物群（例如魚或貽貝），瘤形成機制都具有誘導和病理特徵相似的機制。

In natural biota, with enormous reproductive surplus, the occurrence of neoplasia has in the past not been considered relevant for environmental risk assessment.
在具有極大繁殖過剩的天然生物群中，過去並沒有認識到有關惡性腫瘤的發生與環境風險評估相關。

This paradigm is however being scientifically challenged for two reasons (a) induction of genetic damage in natural biota could serve as a sentinel for risks to human health by environmental contamination and (b) induction of genetic damage (whether in somatic or germ cells) indicates a potential threat to biodiversity (Jha, 2004; Jha, 2008 ; Bickham *et al*., 2000).
然而，這種範例受到科學挑戰有兩個原因（a）天然生物區域的遺傳損傷的誘導可以作為對環境污染對人類健康造成風險的哨兵，（b）誘導遺傳損傷（無論是體細胞或生殖細胞）是否表示對生物多樣性的潛在威脅。

Even the fixation of mildly deleterious mutations could significantly contribute to a loss of Darwinian fitness and could eventually lead to the extinction of small populations (Lynch *et al*., 1995 ; Lande, 1998).
即使是固定的輕度有害突變，也有可能導致達爾文式適應度的喪失，最終可能導致小群體的滅絕。

Whilst there is a large number of studies using bacterial systems (e.g., Ames test, SOS chromo test, etc.) to determine the intrinsic genotoxic potential of DBPs, there have been very few studies to determine expressed genotoxic effects on natural biota in vivo, taking into account the environmentally realistic routes of exposure, metabolism, excretion and DNA repair capabilities of the organisms.
雖然有大量使用細菌系統的研究（例如，Ames 測試，SOS 色度測試等）來確定 DBP 的內在遺傳毒性潛力，但是很少有研究來確定在體內對天然生物群表達基因毒性作用，考慮到生物體的環境實際的接觸途徑，新陳代謝、排泄與 DNA 修復能力。

In freshwater, erythrocytes from the larvae of urodele amphibian (newt), *Pleurodeles waltl*, suggested that chlorine levels of 0.125 and 0.25 ppm in water disinfected with sodium hypochlorite led to significant elevations in micronuclei (Mn).

在淡水中，來自有尾類的兩棲動物(蠑螈)的幼蟲歐非肋突螈的紅細胞，建議在次氯酸鈉消毒水中氯含量為 0.125 和 0.25 ppm，導致微核(Mn)顯著升高。

The level of Mn also increased with an increasing concentration of monochloramine (Gauthier et al., 1989).
微核的含量隨著一氯胺濃度的增加而增加。

While evaluating the genotoxicity of five chlorinated propanones identified in several chlorinated waters, the newt Mn assay detected clastogenic/aneugenic effects only for two compounds - 1,3-dichloropanone and 1,1,3-trichloropropanone (Curieux et al., 1994).
在評估幾種氯化水中，五種氯化丙酮的遺傳毒性的同時，新錳測定僅針對兩種化合物，即 1,3-二氯苯酮與 1,1,3-三氯丙酮，檢測到致突變/起效作用。

In order to compare the relative genotoxicity of classic disinfectants (e.g., sodium hypochlorite and chlorine dioxide) and an alternative disinfectant (e.g., peracetic acid), induction of DNA damage (using the comet assay) and micronuclei was carried out in the haemocytes of zebra mussels, *Dreissena polymorpha* under *in situ* conditions.
為了比較經典消毒劑（例如次氯酸鈉和二氧化氯）和替代消毒劑（例如過乙酸）的相對遺傳毒性，在斑馬貽貝原位條件下，在斑馬魚血細胞中進行 DNA 損傷（使用彗星測定）和微核的誘導。

Results suggested the two chlorinated compounds to be positive for the endpoints whereas peracetic acid did not show any genotoxic effects (Bolognesi et al., 2004).
結果表明兩種氯化合物端點為陽性，而過乙酸沒有顯示任何基因毒性作用。

Examination of kinetics, tissue specific concentrations and effects on enzyme systems has been carried out for dichloroacetic acid, a product of chlorine disinfection, in rainbow trout, *Oncorhynchus mykiss* showing differential tissue specific responses (Fitzsimmons et al., 2009) but more work is required to further elucidate these mechanistic aspects.
已經對二氯乙酸（氯消毒產品，虹鱒魚，顯示差異組織特異性反應）進行動力學，組織特異性濃度與對酶體系的影響，但需要更多的工作來進一步闡明這些機械方面。

Incorporation of biomarkers into regulatory environmental risk assessment is lacking and the focus continues to be on chemical measurements in the context of environmental quality standards, although some of the international treaties (e.g., the Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR) recommend the use of biomarkers for environmental monitoring programmes (Hagger et al., 2006).
將生物標誌物納入監管環境風險評估是不足的，在環境質量標準的背景下，重點仍然在化學測量，儘管一些國際條約（例如“保護東北大西洋海洋環境公約”，奧斯陸公約）建議使用生物標誌物進行環境監測方案。

Similarly, the water framework directive of the European Union (Directive 2000/60/EC) emphasizes the need for biological elements as well as physicochemical and hydromorphological components for the determination of good ecological status.
同樣，歐盟的水框架指令也強調需要生物元素以及物理化學與水形態成分，來確定良好的生態狀況。

Sub-lethal effects inadvertently affect the Darwinian fitness, including reproductive success of the organisms (Jha, 2008), which will ultimately impact short- and long-term survival of the exposed species and hence environmental sustainability.
亞致死效應無意中影響達爾文式適應，包括生物的繁殖成功，這將最終影響暴露物種的短期和長期生存，從而影響環境的可持續性。

Therefore, there is a growing need to develop a strategy to determine the sub-lethal toxicity (including genotoxicity) of environmental contaminants in a range of ecologically relevant species at different trophic levels.
因此，越來越需要制定一種策略，以確定不同營養級別的一系列生態相關物種中的環境污染物的致命毒性（包括遺傳毒性）。

4. Exposure 暴露

Human and environmental exposure to ballast water related chemicals is first and foremost determined by the quantities of chemicals that may be released by BWMS.
暴露在人與環境的壓艙水相關化學品，首先要合乎壓艙水管理系統發布的化學品數量標準。

While quantities of active substances applied are defined in the operational schedule of BWMS, quantities of generated DBPs need to be determined analytically in treated water during BWMS testing.
雖然在壓艙水管理系統的運行計劃中，定義了所需的活性物質的數量，但在壓艙水管理系統測試期間，需要在處理過的水中分析確定生成的消毒副產物的數量。

As indicated above, most data available at the present comes from land-based testing and is at least summarily published in the course of the IMO procedure G9 for the approval of BWMS that make use of active substances.
如上所述，目前大多數數據來自陸上測試，至少要在國際海事組織程序 G9 期間，簡要發布批准壓艙水管理系統使用活性物質。

A recent review article summarizes the DBP data reported for ten internationally approved BWMS based on chlorine or ozone as active substance (Werschkun et al., 2012b).
目前綜述文章總結了十個國際認可的以氯或臭氧作為活性物質的壓艙水管理系統報告中，消毒副產物數據。

As can be expected in marine waters (see Section 2.1), brominated compounds are predominately formed.
如在海水中可以預期的那樣，主要形成溴化物。

The dominating individual substances detected in treated ballast water are bromoform (up to 670 μg L^{-1}), dibromoacetic acid (up to 120 μg L^{-1}), tribromoacetic acid (up to 99 μg L^{-1}), bromoacetic acid (up to 86 μg L^{-1}), bromate (up to 70 μg L^{-1}), dibromochloromethane and dibromoacetonitrile (each up to 21 μg L^{-1}).
在經處理的壓艙水中，檢測到主要單獨物質是溴仿（高達 670μgL-1），二溴乙酸（高達 120μgL-1），三溴乙酸（高達 99μgL-1），溴乙酸（直至 86μgL-1），溴酸鹽（高達 70μgL-1），二溴氯甲烷和二溴乙腈（各自高達 21μgL-1）。

Only a limited range of substances has so far been investigated, mainly chlorinated and brominated methanes, phenols, acetic acids, and acetonitriles.
目前僅對有限範圍的物質進行調查，主要是氯化、溴化甲烷、酚類、乙酸與乙腈。

The available database suffers from a number of information gaps and uncertainties, and systematic investigations of DBP formation in sea water in relation to water quality or operational parameters are missing.

可用的數據裡，存在許多信息差距與不確定性，缺少與水質或操作參數有關的海水，消毒副產物形成的系統調查。

4.1. Environmental exposure 環境暴露

For the assessment of environmental acceptability of a BWMS the predicted environmental concentration (PEC) of all discharged substances needs to be determined.
為了評估壓艙水管理系統的環境可接受性，需要確定所有排放物質的預測環境濃度（PEC）。

The PEC needs to account for different harbour types worldwide and should be a realistic worst case representation of the harbour properties, the processes causing renewal of the harbour water masses, the average treated ballast water emissions and the environmental fate of the different released substances.
預測環境濃度需要在全球範圍內考慮不同的港口類型，應該是港口物業的實際最壞的情況，造成港口水域更新的過程，平均處理的壓載水排放量和不同釋放物質的環境命運。

For this purpose, the software MAMPEC (Marine Antifoulant Model to Predict Environmental Concentrations), originally developed for the exposure calculation of leaching antifoulants, was adapted to the specific requirements of ballast water assessment and includes a specified model harbour.
為此，最初開發用於浸出防污劑暴露計算的軟件 MAMPEC（海洋防污劑預測環境濃度模型）適應壓艙水評估的具體要求，並包括指定的型號港口。

A systematic sensitivity analysis (Zipperle et al., 2011) determined that the original MAMPEC assumption of constant and homogeneous emissions underestimates the maximum concentrations of fast decaying substances as compared to the more realistic assumption of spatial and temporal heterogeneity of ballast water discharges.
系統敏感性分析確定，與壓艙水排放的空間和時間異質性更實際假設相比，原始的海洋防污劑預測環境濃度模型中，假定恆定與均勻排放低估了快速衰減物質的最大濃度。

In particular for the calculation of maximum exposure to substances with half-lives shorter than 1 d near-field analysis is therefore proposed as a more fitting approach.
特別是對於半衰期短於 1 天的物質之最大暴露量進行計算，因此提出了更為合適的方法。

In the ‘near-field’, which addresses an individual discharge and ship rather than an entire harbour, discharge characteristics control the mixing behavior (Doneker, 2002).
在近的領域裡，它解決了個體排放與船舶而不是整個港口，排放特性控制混合行為。

Modelling of different case studies showed that the dilution factor at the end of the near-field zone increases (i.e. the maximum concentration of substances decreases) with increasing ambient current velocities, increasing discharge depths, and decreasing ballast water discharges.
不同案例研究的塑造表明，近領域末端的稀釋因子增加（即物質的最大濃度降低），隨著環境電流速度的增加，排放深度增加，會減少壓艙水排放。

Under stagnant conditions, e.g., in a confined harbour basin, a dilution factor as low as 5 may result.
在停滯的條件下，如在密閉的港區，可能導致低至 5 的稀釋因子。

In all environmental assessments of rapidly reacting substances, e.g., oxidants, it is important to apply the same consideration of decay for exposure calculation as for the assessment of toxicity values used in risk assessment (see also Section 5).
在快速反應物質（如氧化劑）的所有環境評估中，對風險評估中使用的毒性值的評估（參見第 5 節）應用與暴露計算相同的考量因素是重要的。

At the moment, there are no field data for ballast water related chemicals to verify the validity of exposure models, since the substances in question (see Table 2) are not currently included in established monitoring programmes for the marine environment, which mainly target persistent organic pollutants (POPs), such as polychlorinated and polybrominated hydrocarbons, dibenzodioxins and -furans, or perfluorinated compounds.
目前，沒有關於壓艙水相關化學品的實際數據，以驗證曝光模型的有效性，因為有關物質（見表 2）目前不包括在海洋環境的現行監測計劃中，主要針對持久性

有機物污染物（POPs），如多氯代和多溴烴，二苯並二噁英和 - 呋喃，或全氟化合物。

Classical POPs are semi-volatile to non-volatile and evaporate slowly in air.
經典的持久性有機污染物，在空氣中緩慢蒸發，從揮發性到非揮發性。

As they are predominantly non-polar they show a high bioaccumulation tendency and are concentrated at solid phases of suspended matter or sediments.
由於它們主要是非極性的，它們顯示出高的生物蓄積傾向，並且集中在懸浮物或沉積物的固體階段中。

Therefore, they are eliminated quite rapidly from the water phase by sedimentation.
因此，藉由沉降從水階段中相當迅速地消除它們。

In contrast, most BWMS compounds are either rather volatile (halogenated hydrocarbons, acetonitriles, and amines) or non-volatile and polar (halogenated phenols and acetic acids).
相比之下，大多數壓艙水管理系統化合物是相當易揮發的（鹵代烴，乙腈和胺）或非揮發性和極性（鹵代苯酚和乙酸）。

Compounds of the first category evaporate quite readily from the water, whereas the polar group members remain in the water column.
第一類的化合物在水中很容易蒸發，而極性群體成員保留在水柱中。

They do not accumulate on suspended matter or sediments and exhibit little bioaccumulation potential.
它們不會積累在懸浮物或沉積物上，且表現出很小的生物累積潛力。

Thus, they can be transported by currents over large distances if they are persistent.
因此，如果持久生存著，它們可以透過大量的距離傳輸。

The different chemical and environmental characteristics of classical POPs and ballast water treatment chemicals have significant effects on monitoring parameters such as the monitoring matrix, concentration ranges, and spatial objectives.

經典持久性有機污染物與壓艙水處理化學品的不同化學和環境特徵對監測參數如監測基質，濃度範圍和空間目標具有顯著影響。

Classical POPs are often monitored in sediments and biota because they have a tendency to accumulate in these matrices.
經典的持久性有機污染物通常在沉積物和生物群中進行監測，因為它們有累積在這些基質中的趨勢。

Due to this accumulation, a safety margin is often applied to water concentrations and to the evaluation of effect levels.
由於這種累積，安全幅度通常用於水分濃度與效果水平的評估。

The monitoring of ballast water treatment chemicals, on the other hand, will concentrate on the water phase, with medium to low concentrations, and on local and regional distribution.
另一方面，壓艙水處理化學品的監測將集中在中至低濃度的水階段，以及局部與區域分佈上。

Concentrations of the most important DBPs produced in BWMS (THMs and HAAs) were calculated as up to 100 μg L^{-1} for 5-times dilution from the ship outlet and as up to 5 μg L^{-1} for 100-times dilution (Zipperle et al., 2011).
在壓艙水管理系統（三鹵甲烷和鹵代乙酸）中產生的最重要的消毒副產物濃度計算為高達 100μgL-1，從船上出口進行 5 次稀釋，最高為 5μgL-1，100 次稀釋。

These concentrations are about 2–4 orders of magnitude higher than those of classical POPs in the marine environment.
這些濃度比海洋環境中的經典持久性有機污染物高出約 2-4 個數量級。

Within the dense plume from the emitting ship (5-fold dilution) direct analysis, e.g. gas or liquid chromatography coupled with mass spectrometry, without a pre-concentration step will be possible for major constituents.
在發射船的密集羽流（5 倍稀釋）內直接分析，如氣相色譜、液相色譜與質譜聯用，無需預濃縮步驟，對於主要成分是可能的。

However, with increasing distance and increasing dilution, the analysis will become more and more difficult and additional enrichment and pre-concentration steps will be necessary.

然而，隨著距離的增加與稀釋度的增加，分析變得越來越困難，且需要額外的濃縮與預濃縮步驟。

The most challenging problem of future monitoring strategies for ballast water compounds will be sampling at locations other than the immediate point of discharge because of the temporal and spatial variability of emissions.
未來的壓艙水化合物監測策略是最具挑戰性的問題，因為時間和排放的空間變異性，將在直達點以外的地點進行採樣。

Time-integrated sampling using passive samplers might be a promising approach.
使用被動採樣器於時間整合抽樣可能是一個有希望的方法。

With increasing distance from the land, i.e. along shipping routes or in open sea areas, even this may only be feasible for persistent compounds in the higher concentration ranges.
隨著與陸地的距離，即航運路線或公海地區的距離不斷增加，即使是對於濃度較高的持久化合物也是如此。

A differentiation from background concentrations arising from natural or other anthropogenic sources will be important, in order to properly distinguish contributions from BWMS.
與自然或人為來源產生的本濃度分化是重要的，為了正確區分壓艙水管理系統的貢獻。

4.2. Human exposure 人類暴露

Potential exposure to chemicals from BWMS can be anticipated in particular for the ship's crew and for port state inspectors, but also for the general public.
可以預期壓艙水管理系統對化學品的潛在暴露，也可以為公眾，特別是對於船員和港口國檢查員。

The GESAMP BWWG (IMO, 2012) and Banerji et al.(2012) compiled comprehensive lists of exposure scenarios and equations for the quantification of exposure.
聯合國海洋環境科學方面專家兼壓艙水工作小組與(Banerji 等人（2012）) 編制了暴露情景與量化暴露方程的綜合清單。

The most important information is summarized in Table 3.

最重要的資訊總結在表 3 中。

Many specific details depend on the type of system, e.g., whether it requires the storage of chemicals on board, or whether it involves frequent cleaning and maintenance procedures.
許多具體細節取決於系統的類型，例如，是否需要在船上儲存化學品，或者是否涉及頻繁的清潔和維護程序。

Occupational exposure to BWMS related chemicals may occur through dermal contact, which can be prevented by appropriate protective clothing and equipment, or through inhalation of volatile substances, e.g. THMs, emitted from treated ballast water into the surrounding atmosphere.
與壓艙水管理系統有關的化學物質的暴露可能通過皮膚接觸發生，這可以藉由適當的防護服與設備或藉由吸入從被處理的壓艙水排放到周圍環境中的揮發性物質（如三鹵甲烷）來防止。

For the quantitative estimation of exposure, reliable data on the concentrations of substances, in particular DBPs, in treated water are essential.
對於暴露的定量估計，關於處理水中物質濃度，特別是消毒副產物的可靠數據極為重要。

As calculations based on concentrations measured during land-based testing show, inhalation of bromoform in the confined space of the ballast tank during inspection or cleaning may reach toxicologically relevant levels in the case of inadequate ventilation.
根據在陸上測試中測量的濃度計算顯示，在檢查或清潔過程中，在壓艙裡通風不足、密閉空間情況下，吸入溴仿量可能達到毒理學的標準。

In order to help ship owners to protect their crews from chemicals associated with ballast water treatment, the IMO published a guidance document detailing the potential exposure situations that should be addressed when installing a BWMS on board a specific ship (IMO, 2009).
為了幫助船東保護船員避免受到壓艙水有關的化學物質的影響，海事組織發布了一份指導性文件，詳細說明了在特定船舶上安裝壓艙水管理系統時，應解決潛在暴露情況。

Non-occupational exposure scenarios also include oral intake of chemicals by swallowing diluted ballast water during swimming or by the consumption of seafood from ballast water discharge areas.
非暴露方式還包括，在游泳期間吞食稀釋的壓艙水，或藉由從壓載水排放區域買的海產品口服攝入化學品。

While substance concentrations in the water can be calculated with MAMPEC (see above), the calculation of concentrations in seafood requires substance-specific data on bioconcentration, which are mostly lacking for the substances of concern.
雖然水中的物質濃度可以用海洋防污劑預測環境濃度模型計算（見上文），但海產品濃度的計算需要生物濃縮的物質特異性數據，這些數據主要缺乏考慮的物質。

Estimations based on physical–chemical properties, although a common practice in environmental risk assessment, may be significantly flawed, as exemplified by Taylor (2006), who reported an experimentally determined bioconcentration factor of bromoform in sea bass that exceeded the value calculated from its octanol–water partition coefficient by more than a factor of 10.
基於物理化學性質的估算雖然是環境風險評估中的常見做法，但可能會有明顯的缺陷，泰勒在 2006 發表的例子說明了，一種實驗確定的鱸魚中溴仿形式的生物濃縮因子超過了其辛醇計算值 - 水分配係數超過 10 倍。

5. Risk assessment 風險評估

IMO procedure G9 outlines the risk assessment to be performed for BWMS that make use of active substances (IMO, 2008b).
國際海事組織程序 G9 概述，對使用活性物質的壓艙水管理系統，進行的風險評估。

A more detailed description of the risk assessment process can be found in the "Methodology for information gathering and the conduct of work of the GESAMP Ballast Water Working Group" (IMO, 2012).
風險評估過程的更詳細的描述可參見"資訊收集與聯合國海洋環境科學方面專家兼壓艙水工作小組工作方法"。

Risks are evaluated with regard to the aquatic environment, human health and the safety of the ship itself.
對水的環境、人體健康以及船舶本身的安全性進行評估。

Risk assessment for human health and the environment is based on information provided by the manufacturer of the BWMS and follows the general principles of established regulatory frameworks for the evaluation of chemicals or biocides (see Fig. 2, centre).
對於人體健康與環境的風險評估，是基於壓艙水管理系統製造商提供的資訊，並遵循已建立的化學品或殺生物劑評估法規框架一般原則（見圖 2 中間）。

In fact, key provisions of IMO procedure G9 were modelled on the former EU directive for biocidal products (EU, 1998).
事實上，海事組織程序 G9 的關鍵規定是根據前歐盟殺蟲劑產品指令。

Generally, the risk assessment for both the environment and human health consists of a comparison between the calculated exposure (see Section 4) and the exposure for which no adverse effect is assumed based on laboratory tests.
一般來說，環境與人體健康的風險評估包括計算暴露（參見第 4 節）與根據實驗室測試不承擔且不利影響的暴露之間的比較。

Toxicity tests for the environment should consider short-term and long-term effects for at least three taxonomic groups of different trophic levels, i.e., algae, invertebrates, and fish.
對環境的毒性試驗應考慮至少三種不同營養級別的分類群體，即藻類、無脊椎動物與魚類的短期和長期影響。

Human health effects are estimated from in vitro or animal studies on short-term and long-term toxicity, local effects on skin and eye, mutagenicity, and effects on reproduction and development.
從體外或動物研究中估計人體健康影響短期與長期毒性，對皮膚與眼睛的局部作用、致突變性以及對繁殖與發育的影響。

Assessment factors account for inherent uncertainties of the effects assessment.
評估因素考慮到影響評估的內在不確定性。

Ecotoxicity tests are also conducted with the treated ballast water, providing information on the mixture of substances present in the discharge as compared to single substances.
對處理過的壓艙水進行生態毒性試驗，提供與單一物質相比，排放物中存在的物質混合物的資訊。

Whole effluent tests for mammalian toxicity endpoints are not part of the G9 procedure.
用於哺乳動物毒性端點的全流出物測試，不是 G9 程序的一部分。

A frequent point of criticism towards regulatory risk assessment is its simplification and standardisation, which may not adequately reflect the complex reality, in particular with regard to multiple exposures or long-term population effects.
對監管風險評估的一個常見點是其簡化與標準化，這可能不能充分反映複雜的實際面，特別是在多重風險或長期人口影響方面。
While the risk assessment of BWMS focuses on the future discharge of substances from a discrete source (ship), the established conventions for the protection of the marine environment, e.g., OSPAR for the North Atlantic or HELCOM for the Baltic Sea, are concerned with the status of substances present in the environment today (Fig. 2, bottom).
然而壓艙水管理統的風險評估著重在從離散源（船）的未來物質排放量，且保護海洋環境的既定公約，如北大西洋的奧斯陸和波羅的海的海洋法委員會，都關切當今環境中存在的物質的狀況。

The initial step of this assessment also includes the derivation of effect levels, which are considered safe, from toxicity testing of single substances.
該評估的初始步驟還包括從單一物質的毒性測試中，推導出被認為是安全的效應標準。

In this regard, regulatory risk assessment and environmental monitoring schemes are complimentary.
在這方面，監管風險評估與環境監測計劃是免費的。

Spatial integration of the assessment for a single substance followed by the integration of status classifications obtained for different substances give a more complete picture of the status of the aquatic environment with regard to hazardous substances.

對單一物質的評估進行空間整合，然後整合獲得的不同物質的狀態分類，可以更全面地了解有害物質對水生環境的狀況。

This may be complemented by assessments of different ecological aspects, such as biodiversity.
這可以補充不同生態方面的評估，如生物多樣性。

A different kind of holistic approach, which includes and at the same time transcends the assessment of chemical hazards from BWMS, is provided by Basurko and Mesbahi (2014) with their proposed sustainability assessment of marine technologies (Fig. 2, top).
Basurko 和 Mesbahi 提出了一種不同的整體方法，其中包括超越了壓艙水管理系統的化學危害評估，並提出了對海洋技術的可持續性評估（圖 2，上圖）。

Based on life-cycle methodologies (Klöpffer, 2003; Dreyer *et al*., 2006； UNEP, 2009), assessment schemes were developed for three different dimensions of sustainability – environment, economy and social impact.
基於生命週期方法，開發了可持續性-環境、經濟與社會影響，三個不同層面的評估方法。

In addition to the toxicity of treated water and the chemicals used on board, the sustainability assessment of the technology as a whole also needs to consider factors like the materials used in the construction of the BWMS, energy consumption and related air pollution, or waste generation and management.
除了處理的水與船上使用的化學品的毒性之外，整個技術的可持續性評估還需要考慮如在建造壓艙水管理系統，能源消耗與相關空氣污染或廢物產生中，使用的材料等因素與管理。

The integration of the different dimensions of sustainability allows comparisons between different technologies or scenarios with regard to their overall impact, as well as specific variables.
關於他們的整體影響，以及具體的變數，整合可持續發展的不同層面中，允許不同技術或場景之間的比較。