Guidelines for RV eco-design

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1. Contents

Introduction

International regulations limiting the environmental impact of vessels and vessel operations exist since the late seventies and are in constant development. These conventions have initiated and fostered the development of new and innovative technologies to meet the legislative requirements. In recent years the whole shipping industry - from ship designing, ship building to ship operators - has also been creative to design green ships, to test and to implement the new technologies and to create environmental awareness amongst crew and shore staff.

Green ship concepts and projects have emerged on a global scale but have largely focused on the larger merchant ships (containers, tankers, bulk carriers, cruise ships...). Many technologies can be applied to smaller vessels and a multitude of isolated examples exist where ship operators/owners have implemented green technologies on smaller ships.

The EuroFleets workpackage on ecodesign of research vessels reported on the current eco-performance of the European research fleet (Cattrijsse 2011) and demonstrated that the aging fleet can improve substantially on greening of the research vessels and the science operations at sea.

This report lists green ship technologies and green ship operational measures that exist or that are in development today. For each technology the report mentions its potential or applicability to (smaller) research vessels. The report does not inform on cost effects or technical issues for the installation of these techniques on existing vessels or the budgetary implications for new builds. The list merely informs the research vessel operators on the available technical and ship operational opportunities.

A number of examples have been identified where new builds and refits have received a green design.

Both this report and the report on the current performance of the European Research Fleet form the basis for the final guidelines to eco-responsibility of existing research ships and eco-design for new build vessels.

2. Green ship designs

2.1. A greener ship

Preparatory to this deliverable, in the deliverable D3.4 (Cattrijsse et. al. 2011) the beneficiaries of the Eurofleets workpackage 3.4 "Eco-design for regional vessels" defined technologies or operational measures improving a ship's environmental impact beyond the legal requisites of international conventions as "*green*". All efforts aiming at meeting the legal requirements were not considered "*green*" even though they are implemented to make a vessel and/or its activities environmentally friendlier.

One needs however to understand that "green" is a fashionable term. The "green ship" does not exist and a total environmental impact free vessel is yet to be build. The term "greener" ship is probably a better wording. There exist too many aspects where ships and their operations can reduce their environmental footprint. Additionally, the continuous development and improvement of technologies to evolve into better performing versions gradually narrows the definition of the definition and the perception of "*green*". A flashy green ship today will likely be a pitch black one by the end of its lifetime.

Applying whatever sweep of green technologies onboard a vessel does also not suffice. Reaching a total green status necessitates full consideration to be given to the cradle-to-grave concept (Rogers, et al. 2011a) and the implementation of environmental policies into management plans and management systems (Rogers, et al. 2011b).
The cradle-to-grave concept considers all phases in the lifecycle; from design, over production and usage to decommissioning. As an extension to this, a cradle-to-cradle approach also includes the recyclability of the used materials. In both the C2G and C2C approach the impact of emissions during the operational phase is significant.

Creating environmental awareness amongst shore staff and crew by continued training and follow-up is paramount. ISM and ISO9001 & ISO14001 certification all are options to achieve green accreditation of the ship operator's environmental management system.
Next to operational procedures the German "Blaue Engel" and the Clean/Green ship certifications of some classification bureaus are options to focus on both the vessel and/or the operations.
Much like the international shipping industry, the research vessel community could benefit from a clear definition of the green ship concept and a auditing of such.

2.2. Emerging and new green technologies

About ten to fifteen years ago the green or clean ship concept was introduced as significant advances in shipping technology had emerged. New technologies like innovative anti-fouling systems and ballast and waste water treatment technologies help in further reducing the environmental impact of shipping activity.

The European Marine Equipment Council (EMEC) has identified seven topics where currently existing green technologies can when integrated make today's ships 15-20% cleaner. EMEC anticipates that if these technologies could be further developed in the near future, ships could even be made 30% more eco-friendly (Green Ship Technology Book, 2010).

The seven issues that according to EMEC should be taken into account to reduce the environmental impact of ships are

- Reduction of air emissions
- Ship waste disposal
- Bilge water treatment
- Black waste water treatment
- Grey waste water treatment
- Ballast water treatment
- Innovative anti-fouling systems

Next to these this report considers optimised hull and rudder design and LNG as fuel as major points of potential improvement. Also reducing the underwater radiated noise and waste heat recovery systems are listed.

2.3. Existing green ship designs

A relative long list of green ship designs exist to date. Some of these designs have effectively been realised while some only exist on paper. Yet, some of these designs have been approved by classification bureau's (DNV, NYK, BV, LR and GL) and are therefore quite real. Other designs do exist but owners often keep their information hidden or strongly limit details for economic reasons.
A recent and ongoing discussion on the LinkedIn forum "Green Ship Technology" and further searches in open sources resulted in a list of available green ship designs. A non-exhaustive list of green ship designs can be consulted in annex to this report. Information on these and other projects can easily be found on the internet.
The list exemplifies that most existing green ship designs are not totally relevant for research vessels. All but a few designs concern larger merchant vessels (especially tankers and container vessels.

Each green/clean ship design focuses on a number of environmentally friendly technologies. Decreasing fuel consumption features as the most prominent aspect. Reduced fuel consumption can be obtained in various ways and hull optimisation and propeller design appear to be an almost constant aspect. Wind aided navigation and air lubrication are also often applied in the designs to further decrease fuel consumption and thus engine exhaust gases. Heat recovery systems and optimisation of auxiliary machinery (cooling & pump systems) are also promising techniques to aid in this respect.

Other techniques include ballast free ship designs and ballast water treatment systems, hybrid and auxiliary power generation (wind, solar power, batteries & fuel cells) and gas exhaust cleaning systems to comply with MARPOL Annex VI. LNG as a new maritime fuel is receiving increasing attention and ships operating on LNG are being taken into operation relatively frequently.

The list exemplifies that most existing green ship designs are not totally relevant for research vessels. Some aspects can be incorporated into (regional) research vessels but the proposed systems can only be implemented on larger vessels.

Two research vessels have been designed to be environmentally better performing than conventional vessels. The University of New Castle is replacing the RV Bernicia with a vessel with an improved hull design that makes it 40% more power efficient compared to existing hulls. Canadian universities and BMT Fleet Technology are currently outfitting the former Canadian Coastguard vessel 'Tsekoa II' with a hybrid propulsion after which the vessel will serve as a coastal research ship.

The NOOA research centre of the Great Lakes – GLERL- achieved a total petroleum free operation of its three smaller research boats/ships in 2006 via the Green Ship Initiative. It took NOOA 5 years from effective start to accomplish.

Yet, even traditional ship designs are nowadays often equipped with a number of green technologies that have become almost standard in the ship building. The RV Simon Stevin, a 2012 new build for VLIZ, will be equipped with waste heat recovery, vacuum toilets, silicone based and active anti-fouling. The vessel will be ISO14001 accredited. The Norwegian IMR is currently building a larger arctic research vessel that will be able to run on LNG for limited periods of time. The Spanish Ramòn Margalef also contains a number of green features: use of biocide free silicon hull paints, ozone treatment of ballast water, use bio-hydraulic oil, a power management system and a BV cleanship notation.

Both 'Ramòn Margalef' and 'Simon Stevin' will be silent vessels. Most new build research vessels are designed to operate in silent mode. The main reason to use low noise engine installations is science and not environmental concern. Yet, as the goal reached is environmental more performing than legally asked by conventions and the attained effect prevails above the underlying reasons this report does consider silent research vessels as green in this aspect.

2.4. Structure and scope of the report

Eurofleets deliverable D3.4 (Cattrijsse et al. 2011) builds upon a set of issues where research vessels and their operators can make efforts to green the vessel, the scientific operations and the management of the research fleet. These issues includes the relevant MARPOL annexes, IMO international conventions on biofouling and ballast water, the EC convention for low sulphur marine fuels, low underwater radiated noise, the code of conduct on marine science operations at sea, training of personnel and the available management tools.

This report applies the same set of issues and lists for each of those the identified new and available technologies to green vessels and their operations. The applicability of each for greening research vessels is shortly discussed.

The report does not evaluate financial implications for retrofit or implementation on new builds. Cost/benefit calculations are left for the individual research vessel operator.

Finally a smaller number of examples of existing greener research ships and designs are reviewed in more detail.

2.5. General remark on available information on technology

Information on new technologies is in almost all cases supplied by manufacturers. The authors could not find any independent source where any new technologies were evaluated by an independent source for their application on (smaller) research vessels.

3. MARPOL Annex I Pollution by Oil

Operational oil pollution from shipping activities remains an important environmental impact. Oils and oily residuals continuously enter the environment through either direct release via oil lubricated propeller shafts or from deck run off. The yearly amount of oily substances that enters the marine environment through simple ship operations is larger than caused by incidents or accidents (EMEC 2010). Operational oil loss from stern tubes would amount annually to over 80 million litres (Carter 2009). MARPOL also still allows discharge of bilge water at concentrations below 15ppm and under strict circumstances.

High speed centrifuges or membrane microfiltration technologies may clean bilge water to much lower concentrations than required by MARPOL. Yet, operators can choose not to discharge under any circumstance and keep oil residues and bilge water in separate tanks to be disposed of at shore. This likely constitutes the most cost effective approach and many RV operators have indicated that they dispose of oil wastes on shore (Cattrijsse et al. 2011).

The use of biodegradable oils and lubes is also a technique that has been widely available and used. Biodegradable oils and lubes have been applied in many other industries and their use in the maritime sector is still growing (Lundquist 2011). By standard a biodegradable oil/lube is a product that is degraded by 60% over a period of 28 days, which is three to four times faster than conventional oil break down (Honary 2001).
The advantages of bio-oils include excellent lubricity, stabile viscosity, higher flashpoint and lowered toxicity. They do lack oxidative stability but this is tackled by growing genetically modified plants (Honary 2001).
While bio-oils will degrade faster than mineral oils they still are considered pollution as they leave a sheen on the water surface and have similar negative physical effects on biota as conventional oils. One ship operator reported that serious skin burns have been caused by biodegradable oils. Others claim a high water content of bio-oils causes problems.

Since 2006 NOAA has, through the effort of the “Green Ship Initiative”, three smaller research vessels in operation on the Great Lakes that run totally on petroleum free fuels (NOAA 2007). Some research vessel operators report that when using biofuels or low sulphur fuels which are blended with bio-fuels, tanks may get contaminated with bacterial growth oa. causing problems with filters and quality of the fuel.

A water lubed stern tube is not a novel technique but as technology of bearings for water lubricated shafts has improved recently, water lubed propeller shafts are being installed on vessels and this almost totally eliminates operational oil loss (Carter 2009). Some operators report that biofouling in such systems can be problematic.

4. MARPOL Annex IV - Pollution by Sewage

Ships may discharge sewage (black water) at an appropriate distance to shore. To ensure less impact sewage treatment systems can be installed onboard vessels. When the ship carries an approved treatment plant or a comminuting and disinfecting system discharge may occur closer to shore.
Holding tanks are the best option as delivery to shore will prevent direct impact on the marine environment. While most regional research vessels will often operate beyond the minimum distances to shore dictated by MARPOL, operators can still choose to install membrane bioreactors to clean their discharge and thus minimize impact. The remaining sludge of the bioreactor needs to be disposed of in harbors (EMEC 2010). When seawater is being used to flush toilets, the biological treatment of sewage waters will become problematic.
It is anticipated that future MARPOL IV amendments will further strengthen the conditions under which sewage can be discharged at sea, even up to no discharge if no treatment installation is available onboard. Vacuum toilets are an elegant way to reduce the amount of black water that is produced making storage onboard easier (EMEC 2010).

5. MARPOL Annex V – Pollution by Garbage

Currently MARPOL V allows discharging garbage at sea under specific circumstances. Recently the Marine Environment Protection Committee (MEPC62) has amended MARPOL Annex V. All wastes, not only plastic as before but also glass, packing materials, metal, and paper can no longer be discarded at sea. The total ban on dumping of ship born wastes at sea, some exceptions like food wastes still exist, will go into force on 1 January 2013.

To avoid such impact on the marine environment operators can reduce or exclude discharge at sea by installing waste compressors and/or MARPOL certified incinerators (EMEC 2010). Garbage should be compressed carefully as disposal costs on land will increase as recycling becomes troublesome when various fractions cannot be separated. Heat produced by incinerators should be recycled and used for electric power production with turbines.

European research vessel operators have expressed their preference for stowing garbage regardless of issues involved (smell & hygiene).

6. MARPOL Annex VI – Air Pollution

Reducing the environmental impact of burning fossil fuels constitutes the major issue where ship operations can improve and where most efforts have been made to develop systems reducing fuel consumption and/or cleaning exhausts.
The options and techniques available have been listed here in decreasing order of importance for implementation on (smaller, regional) research vessels.

6.1. Slow steaming and engine performance monitoring

The easiest and likely today the most important way to cut back emissions of CO_2, NO_x, SO_x and soot is reducing sailing speed. In commercial shipping this approach to clean ship operations is a hot item as it does not only significantly reduce emissions and fuel consumption but meanwhile also reduces operational costs at a similar pace. This slow steaming includes a prudent operational "style" of the crew, ie. smooth accelerations and de-accelerations.

6.2. Low Sulphur fuels

To comply with European regulations and in advance of the MARPOL VI deadline low sulphur distillate marine fuels are generally available in Europe. New editions of two ISO standards on marine fuels have been developed to meet higher international requirements for air quality, ship safety, engine performance and crew health (ISO 2010). Further improvements on marine fuels with a lowered sulphur and low ash content are studied.

6.3. Cold ironing

For most regional research vessels shore power supply is not a difficult issue. In many cases smaller ships are even lying cold while in the harbor and will therefore in both cases not add to air pollution in port areas. If the vessel is equipped with a dual fuel harbor generator it would be possible to run on LNG from a storage tank on the pier to minimize air pollution and emission of particles.

6.4. Improved ship hull design

Retrofitting existing ship hulls to a better design requires considerable effort. Incorporating an optimum hull design into a new build is a relatively straightforward process and in most cases standard approach. Improved hull designs can add up to significantly increase fuel efficiency and thus reduced emissions (Morse et. al. 2009). It will also help in improving sea behavior and optimalise the hull shape for the entire operational profile of the vessel. In relation to this, the

design speed, if aiming at slower operational profiles, determines the hull's shape and dimensions.
Innovative hulls like trimaran or SWATH forms can further reduce drag while maintaining stability and reducing the need for ballast water. A SWATH design can have higher drag at low speeds, due to their increase in wetted area but they tend to have better resistance at higher speeds as they displace less water and produce less wave resistance. Other innovative hull designs that increase efficiency and improve seakeeping behavior include the prolonged bow types developed by Damen (axe-bow), Ulstein shipyards (X-bow) and Groot Ship Design (Groot Cross-Bow).

MBARI recently commissioned a study for the design of a new research ship where three hull forms were considered. The conventional monohull concept was found to deliver an advantage to trimaran or SWATH designs when balancing performance and green operations (Moon 2011).
Additionally, improved hull design may reduce or even eliminate the need for ballast water. This would not only 'release' considerable amounts of energy which is required to transport the ballast water but also free the costs for treating ballast water and stop the transfer of species through ballast water.
Over the entire life cycle of a ship a steel hull may compared to an aluminum hull have a slightly lowered total environmental impact. Aluminum will have a higher impact during construction and disposal phases and a lower impact during the use phase (de Vos-Effting & van Gijswijk 2008).

6.5. Improved propeller and rudder design

Like optimised hull design, choosing the proper propeller/rudder system will also help in improving propulsive efficiency and consequently decrease exhaust emissions (EMEC 2010). In case the operational profile of a vessel changes or the propeller was not designed using CFD the retrofit of a better propeller design can greatly add in fuel consumption decrease. Reblading propellers has been reported to reduce fuel consumption an average to about 10%, with a maximum of 17% (Morse et. al. 2009)
Novel propeller designs like the Contracted Loaded Tip (CLT) propeller have been effective in reducing fuel consumption and noise/vibrations. Counter Rotating Propellers (CRP) have the highest documented power savings of up to 15% (Morse et. al. 2009). Another recent development that increases propeller efficiency are Boss Cap fins which remove the vortex behind a propeller.

6.6. Engine performance monitoring

Several commercially available software tools allow crew to enhance fuel consumption and thus reduce exhaust pollution. Based on individual ship engine rooms and 'historical' data, benchmarking and reference information such techniques may also allow for improved maintenance schemes of the engines and auxiliary systems and thus cleaner exhausts.

6.7. Waste Heat Recovery

The energy stored in the main engine exhaust can be recuperated and thus provide savings in primary energy consumption and hence in a reduction of emissions. Modern diesel engines have superior heat efficiency to older engines but not exceeding 50%. Using this wasted energy with the new breed of heat recovery systems allows generating electricity (turbo chargers) to supplement propulsion or other energy requirements like heating accommodations or for generating electricity. It may reduce the number of generators needed on board.
Heat can be recuperated from cooling water and exhaust. The latter will need larger installations and may compromise exhaust cleaning systems. These techniques would also help in reducing SO_x, NO_x and particulate matter from the exhausts (EMEC 2010).

6.8. LNG as fuel

The first LNG powered vessel, a ferry, was taken into operation in 2000 and since then a continuously growing number of vessels sail on LNG. Legislation and certification of vessels has evolved such that international voyages are now possible. The new Norwegian arctic research vessel will be equipped with the capacity to run on LNG for limited periods of time. Designs for implementing LNG on smaller vessels are being developed.

LNG not only provides a SO_x free and significantly reduced NO_x and CO_2 emissions but also an economically interesting fuel at today's oil prices. The major drawbacks for using LNG as fuel are found in need for space for the holding tanks and a supply chain that is not always fully and/or region wide operational (currently depending on presence of LNG terminals). There are strong efforts made to solve that issue (Schröder Bech 2011).
LNG should be a very interesting fuel for relative small vessels with a limited number of days of operation between port calls which enables bunkering at regular intervals. Regional research vessels could be equipped with dual fuel engines and a combination of diesel and LNG tanks in order to run on LNG to the extent possible, taking into consideration refuelling opportunities, port calls, station work etc.

6.9. Exhaust gas cleaning - NO_x

The EMEC green book (EMEC 2010) mentions a number of techniques that may aid in reducing the NO_x content of emissions. There are two options for reducing NO_x.
The first method is to reduce combustion temperatures which can be accomplished by lower engine loads (slow steaming) or by adding water to fuel. Technologies to reduce combustion temperature include humid air motors, direct water injection, exhaust gas recirculation and fuel-water emulsification. These would lead to greater fuel consumption (May, SFA international). Such modifications to the engines fuel system probably need ad hoc evaluation for retrofitting on specific engines.
Combustion catalysts reduce NO_x formation during the combustion process up to 75% with a minimum of investment (May, SFA international). Selective Catalytic Reduction is an exhaust treatment system where the fumes pass over a catalyst bed where urea or ammonia is injected to reduce the nitrogen oxides to atmospheric nitrogen. These are relative expensive installations

that need extra maintenance and supply of the catalyst substance. SCR systems become more compact and cheaper. As most modern trucks have SCR's installed on their engines such systems can offer a viable solution for regional research vessels. (Weaver 2009).

6.10. Exhaust gas cleaning – Particulate matter

Distillate fuels produce much less particulate matter than residual fuels. Marine engines running on low sulphur distillate fuels are therefore emitting less particulate matter than engines running on conventional fuels. Applying sulphur removal or gas scrubbing techniques will automatically positively impact the particulate matter content of the exhaust fume.
Additional removal of particulate matter can be achieved by installation of particulate filters (cyclone separators, wall flow filters or electrostatic precipitators) or by increasing the fuel injection pressure (EMEC 2010). The cheapest method to reduce particulate matter is to keep the engines in good condition (May, SFA International).
Diesel Particle Filter technologies, which are almost becoming standard in the automobile industry, have been successfully applied onboard smaller vessels (Schwarz et. al. 2009). Often PM filters are housed together with SCR and Diesel Oxidation Catalyst technology in one unit to clean diesel engine exhausts from the total spectrum of polluents.

6.11. Hybrid propulsion and auxiliary power generation

Hybrid propulsion systems take advantage of the best of both mechanical and electric power generation. Fuel cells or battery systems offer the possibility to provide propulsion power under limited conditions for restricted periods of time.
The former Canadian coastguard vessel “Tsekoa II” is currently being equipped with fuel cells and the vessel should in near future enter service as a regional and coastal research vessel off the coast of British Columbia for several Canadian Universities. Other examples exist where smaller vessels use fuel cells.
Energy can also be stored in batteries to aid both propulsion and hotel loads. The Green Tug designs by Foss Maritime and Offshore Ship Designers proof that batteries can be installed for propulsion of smaller vessels (Stratton 2009).
But fuel cells or batteries definitely may power auxiliary systems and thus aid in reducing total fuel consumption. Wärtsilä is experimenting with fuel cells for auxiliary power generation onboard vessels. Batteries may also be fueled by solar power.

6.12. Solar power

Solar panels installed on ships have demonstrated that this technology holds potential for reduced fuel consumption or power supply for shore consumption. A number of pilot projects exist where solar panels provide auxiliary power to small fast ferries (BMT designs) and even on large merchant vessels (eg. car carrier of Mitsui OSK Lines). Like fuel cells solar panels can currently only aid in reducing energy consumption by providing power for hotel loads or auxiliary systems.

In general solar power generation is not cost effective yet. For most research vessels there is not enough available deck space to generate much power. The potential of using solar power onboard ships depends on future developments in efficiency.

6.13. Wind aided navigation

Several pilot projects exist where merchant vessels are equipped with sails, kites or Flettner rotors to reduce exhaust and fuel consumption. As these wind aided propulsion is only advantageous during transit the use for regional research vessels will likely be limited. Ocean going vessels could benefit during long passage times.

Using sailing vessels as research platforms is not utopic. A fair number of sailing ships and boats are being used as research vessels but these perform merely research on sea mammals. A few cases clearly demonstrate that the capacity of a sailing research ship does not need to be limited to one or two science tasks.
The Polish RV OCEANIA has used it sailing capacity over more than two decades. The French sailing ship TARA supports various research tasks around the world and the US Derek M Baylis also demonstrates that different research tools can be performed using a sail powered vessel, up to ROV work and acoustic surveying techniques. The operational costs of Derek M Baylis were found to be three times cheaper than using a conventional coastal research vessel (Goldfinger 2012). The success of this vessel has resulted in the design of an Ocean Class Research Ship by Wiley Design Group and the University of Oregon.

6.14. Air lubrication

The concept of pumping air under the hull of a vessel to reduce drag and thus decrease fuel consumption is implemented on a small number of large merchant ships. Results from existing projects proof potential and designers of such systems claim a maximum of 15% reduction in fuel consumption. The installation of such a system requires a large amount of tubing and thus space which is not always available in existing smaller vessels. As air bubbles block signals of acoustic equipment the application of such technology onboard research vessels may only be useful during transit. The technology also is only effective on longer vessels.

6.15. Exhaust gas cleaning - SO_x

Installations to remove SO_x from the exhaust are being installed on ships to comply with MARPOL regulations. Scrubbers can reduce SO_x above 80%. Installing such systems on existing vessels is an engineering challenge as the demand for space and the weight of the installations do limit options. A typical regional research vessel will run on distillate fuel (MDO or MGO). Sulphur content of the exhaust from such fuels is much lower than when burning residual fuels. Most European research vessel operators run their vessels on low sulphur fuels to comply with EC regulations. Consequently installing scrubbers is not a necessity. Further, if running on residual fuel (HFO) the SOCP report on EGC systems (SOCP 2011) advocates that a merchant vessel needs to burn 4000ton/yr heavy fuel in a MARPOL VI Emission Control Area to financially benefit from the installation of a scrubber. Most regional and ocean class research vessels will not meet this requirement.

7. IMO Convention on Control of Harmful Anti-fouling Systems

Clean biofoul-free hulls reduce drag and aid substantially in controlling fuel consumption. Periodic cleaning of the hull should be standard practice as this will indirectly help in reducing exhaust pollutants.
Epoxy resin coatings last longer than conventional paints but due to their low friction with water, helps in reducing fuel consumption. These coatings still release chemical compounds that kill organisms (mostly copper or zinc). Anti-fouling paints containing biocides are to be avoided. Only biocide free antifouling mechanisms are environmental friendly. The technology of applying natural biocides is still under development.

Instead of using toxins some techniques use physical instability as growth inhibitor. Surface Treated Coatings (STC) involves frequent hull cleaning that does not release any toxins but does release small amounts of polymer (Candries 2009). Silicon based paints slowly grind off under friction during sailing inhibiting settlement of biota. This slow grinding also releases polymer microparticles. Science has recently drawn the attention to the presence and possible negative effects of microplastics in the environment.
Non-stick coatings provide a very smooth surface preventing settlement of organisms and providing easier cleaning. Such coating is only most suitable for vessels that operate above 30knots and repairing damaged surfaces is difficult.
Photoactive paints that release hydrogen peroxide under light have proven to be effective. Another innovative technology possibly consists of slime producing coatings that continuously sloughs off of the hull and helps in reducing drag (Marks 2009).
Active anti-biofouling systems that create an electric potential difference between the hull and water and thereby help in preventing growth on the hull, are regularly and successfully installed on larger and smaller vessels.

8. IMO Convention for the Control and Management of Ships' Ballast Water and Sediments

Exchanging ballast water is not a very common operational procedure for smaller vessels where cargo loads are relatively stable, like research vessels. In most cases (regional) research vessels will also not often cross significant biological ‘provinces’ where other fauna/flora occur. Releasing ballast water may therefore not affect the local fauna and flora as no major differences will exist in the aquatic communities of the different places visited by the regional vessel. While changing ballast water, regional vessels may contribute to a further, accelerated distribution of exotic/alien organisms already present.

The IMO Convention on ballast water that will come into force in future applies to all ships so future smaller research vessels will need to have a ballast water treatment system. Such installations are available on the market. Depending on the age of the vessel and its ballast water capacity, compliance with IMO treatment requirements shall be met by 2016 at the latest.
Designing a zero ballast ship is however possible and future research vessels should therefore preferably be designed as such.

9. Hazardous materials for experimental work in labs or preservation of biological samples.

The adoption of an Environmental Management Plan (EMP) and System (EMS) may prevent incidents with noxious substances and safeguard serious environmental impact in case incidents occur. Rogers et. al. (2011b) explain how such an EMP may be particularly suited for research vessels. The code of conduct of marine science adopted by the International Research Ship Operators group (IRSO) and the European Research Vessel Operators (ERVO) demonstrates that the research community is concerned and adopts mechanisms to prevent impact.

10. Underwater radiated noise

There are two main reasons for reducing underwater radiated noise. To reduce the impact on marine life and to improve the signal-to-noise ratio during acoustic surveys
Mitigating avoidance behavior and scaring effects on marine life is in general applicable for frequencies up to about 5 kHz. Some sea mammals can hear frequencies far above this. (Mitson & Knudsen 2003). Acoustic instruments operate mostly at frequencies above 1 kHz.
With proper noise reduction efforts it is possible to build vessels with a spectrum level 20 dB (1μPa 1Hz 1m) lower (99% reduction) compared to "conventional" vessels with diesel engine, reduction gear and controllable pitch propeller.
The only proven method is to use diesel-electric propulsion with resilient mounted generator sets, DC propulsion motors and fixed pitch propeller with 5 blades (Mitson 1995). CLT propellers are known to reduce underwater noise. AC motors are also used and they normally need some precautions to reduce the noise peak at the drive frequency, 10 – 100 Hz.
It is believed that an all-electric propulsion aids in maintaining a cleaner engine exhaust and lowering fuel consumption but this can be contested as the efficiency of electric motors drops seriously under low loads. Modern diesel engines remain quite efficient under low loads.
DNV and BV can issue a Silent Class Notation for vessels with different purposes; hydro acoustics, seismic, fishery, research and others.
It should be mentioned that maintaining low noise levels is an ongoing process. Without proper maintenance, systems will get noisier and vessels may no longer meet their noise goals.

11. Conduct of Marine Science

OSPAR has established a code of conduct for responsible marine research in the deep seas and high seas of the OSPAR maritime area. Members of both IRSO and ERVO have established very similar guidelines for marine science operations.
Additionally, UNCLOS also stipulates that marine scientific research shall be conducted in compliance with all relevant regulations adopted in conformity with the convention including those for the protection and preservation of the marine environment.
The implementation of such guidelines should be assured through the research vessel EMP & EMS (Rogers et. al. 2011b).

12. Administrative tools for ship operators regarding environment related management

Det Norske Veritas, Bureau Veritas and Germanisher Lloyd issue Green Class notations. Operators may opt to classify their vessel according to these. As explained by Rogers et. al. (2011) other international standards such as ISO9001, the ISO14001 and the ISM code include environmental management systems for use onboard vessels.
Other "environmental awareness labels" eg. 'Der Blaue Engel' may also be applied to vessels and help operators and crew to maintain a high level of environmental friendly operations.
All these management systems recognize the importance of continued training and instruction of both crew and shore staff into their schemes.

13. Examples of greener research vessels

13.1. Canadian Coastal Research Vessel

The University of Columbia is currently refitting a smaller vessel to use as a coastal research vessel. The former Canadian Coast Guard vessel "Tsekoa II" will be equipped with all electric propulsion that will be powered by batteries, fuel cells and low emission diesel generators. The generators will only be used during transit and use of submersible operations.

13.2. NOAA Green Ship Initiative

Back in 2000, NOAA's Great Lakes Environmental Research Laboratory, converted its former RV "Shenehon" (24m, build 1953) to 100% biodiesel fuelled. In 2006 all three smaller research ships of GLERL operated totally petroleum free using biodiesel, bio-lubes and bio-oils in engines and hydraulics and currently continue to do so.

13.3. The Princess Royal

The hull, rudder and propellers of the new coastal catamaran research vessel “The Princess Royal” (University of Newcastle) has been fully optimised to keep fuel consumption low and thus reduce engine exhausts. A Power Management System was installed to keep track of its performance and fuel consumption. The vessel systems have been optimised for reduced environmental impact. A high-tech inverter battery system will minimise generator running time, solar panels will be integrated into the electrical system to maintain the batteries in a carbon-free manner, the hydraulic system will be optimised for minimum energy usage, and the use of bio fuels and other 'environmental' systems are being explored.

13.4. Simon Stevin

This 36m regional RV sailing for the Flanders Marine Institute (VLIZ) has been equipped with a diesel-electric propulsion and a number of technologies that will make it greener than conventional regional research vessels. Waste heat recovery supports heating power while vacuum toilets will reduce the amount of black water produced. The hull, propeller & rudder have been optimised for both resistance and silent operations. Next to applying silicon paints an active anti-fouling system has been installed.

13.5. Ramon Margalef

The new 41 m regional research vessel of Instituto Espanol d’Oceanografia (IEO) also bears a number of features that makes it environmentally friendly. The hull is covered with a biocide free anti-fouling paint and an ozone treatment is used to clean both ballast water and effluent of the fish cleaning process. The Ramon Margalef is also a silent vessel, ICES209 compliant and is equipped with a PMS that guarantees minimized fuel consumption. The vessel bears the Clean Ship notation of Bureau Veritas.

13.6. RV Oceania, Tara Oceans & Derek M Baylis

These three vessel demonstrate that sails are an option for research vessels without compromising the research capacity and performance while reducing environmental impact and operational cost dramatically. The Oceania has served the Polish Academy of Sciences since 1985. The Tara Oceans has performed worldwide research cruises (Karp-Boss & Troublé 2012) and the Derek M Baylis is often used for inshore science cruises (Goldfinger 2012).

13.7. RV Western Flyer replacement design study

The Montery Bay Aquarium Research Institute commissioned a design study to Glosten Associates Inc. to develop a low environmental impact research vessel. The study evaluated three hull forms and concluded that the monohull design offered the best option to produce a ship that reaches the best environmental performance while maintaining a high standard for research capability (Moon 2011).

13.8. Design of the Rachel Carson

A sailing ocean class research ship was designed on behalf the Oregon State University that possess the same capacity as the current operating UNOLS RV Wecoma. The ship is designed such that it can accommodate containers and is capable of performing all possible research tasks. Fishing and towing heavy equipment would still demand diesel engines but as all other research equipment can be performed under sail the operational costs and the environmental impact will doubtless decrease significantly.
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16. Addendum –Selection of Green Ship Designs

Knud E. Hansen A/& ABB
- new design of 2000 TEU Container Feeder Vessel.

Det Norske Veritas
- Momentum RoRo
- Triality Tanker
- Quantum Container Vessel
- Ecore Bulker (joint with FKAB)

Germanischer Lloyd
- Best-Plus Aframax
- Zero-emissions Container Vessel

NYK designs
- Eco Ship 2030

Wallenius Wilhelmsen
- E/S Orcelle

Innovacion Logistica
- CargoXpress

Fair Transport
- Ecoliner

Mitsui O.S.K. Lines (MOL), Mitsubishi Heavy Industries (MHI) & Sanyo Electric Group.
- Zero harbour emissions car carrier

Mitsubishi Heavy Industries
- Mitsubishi Air Lubircated System (MALS) on bulk carriers

Maersk
- Triple E Container Carrier

Stenabulk
- E-MaxAir Tanker

Danish Green Ship initiative (GrontMij & Odense Steel Shipyard)
- Seahorse 35 Bulk Carrier (LR classified)

Offshore Ship Designers (in cooperation with BakkerSliedrecht)
- Green Tug

Foss
- Hybrid Tug

DAMEN Shipyard Group
- E3-Tug (hybrif propulsion)
- ACES air lubricated inland ship

BMT Fleet Technology
- All electric passenger ferry
- Coastal hybrid RV (CCG Tsekoa II)
- Hornblower ferry (Hornblower Cruises)