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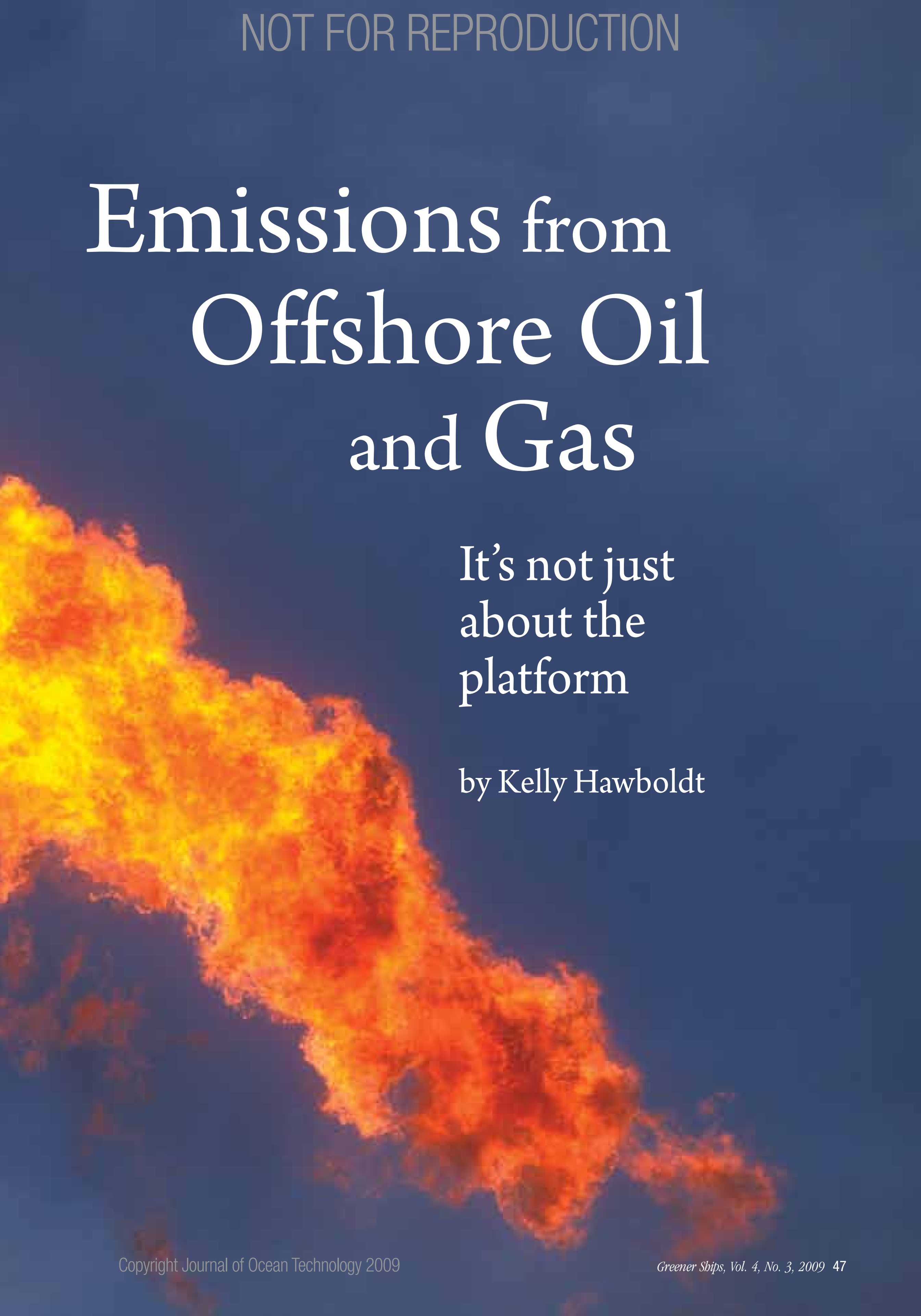

Emissions from Offshore Oil and Gas

It's not just about the platform

by Kelly Hawboldt

Natural gas or oil fired equipment (e.g. compressors, utility boilers, etc.) and the flare from offshore oil and gas production platforms both generate some form of gaseous emissions. In addition, there are the fugitive emissions associated with the production process. The targeted compounds are typically nitrogen oxides (NO_x), sulphur dioxide, hydrogen sulphide, particulate matter (PM), non-methane volatile organic hydrocarbons (NMVOCs), methane, carbon monoxide, and carbon dioxide. Carbon dioxide is targeted not for any toxicity but rather its greenhouse gas effect, while methane is both a greenhouse gas and represents an explosion and toxin hazard. Sulphur dioxide, NO_x, NMVOCs, carbon monoxide, and PM are regulated in various degrees around the world. For offshore platforms, the emission regulations are set by the region.

For marine transport, the International Maritime Organization (IMO) has adopted a set of regulations for sulphur oxides, NO_x, and volatile organic hydrocarbons (VOCs). The IMO is also proposing greenhouse gas emission reduction strategies, such as levies on carbon emissions.

Onshore emissions are relatively straightforward to both control and regulate. Offshore emissions present significant challenges. In addition to all the variables that determine the type of emissions associated with fuel combustion (outlined in more detail below), in marine transport and offshore oil and gas platforms there is the added complexity of the transient nature of the vessels and the transport of the pollutants over sea and into international waters.

In onshore and offshore oil and gas operations, the quantity and nature of the gaseous emissions will be a function of the fuel type, type of reservoir, and regulations. In offshore operations, at least two additional parameters can be added: distance to market and degree of platform processing. The discussion below will focus on offshore platforms:

- Fuel type used in the combustion equipment: Fuels with high hydrogen to carbon ratio (e.g. natural gas) combust to form lower levels of carbon dioxide, particulate matter, and polycyclic aromatic hydrocarbons and other incomplete combustion products. Sulphur dioxide emissions are a function of the sulphur in the fuel while NO_x levels are typically lower; gasoline has shown lower NO_x emissions in some types of engines when compared to natural gas. Carbon dioxide is the major emission (with water) and is not typically regulated. However, some jurisdictions do regulate in the form of carbon emitted. There are several published sources for determining the emission factors.

- Type of platform: Offshore platforms in Canada are almost all oil and gas producing with the exception of Sable Island development offshore Nova Scotia, which is a gas platform. The associated gas produced with the oil in offshore Newfoundland and Labrador (NL) is referred to as "stranded." That is, due to climatic conditions (high iceberg traffic, etc.) and distance to market, recovery of the gas by traditional pipeline is not economically feasible and storage on the platform is not possible. However, other forms of transport are being considered such as Liquefied Natural Gas carriers and Compressed Natural Gas carriers. Currently the associated gas is re-injected for pressure maintenance at 87% of total gas for 2008, as platform fuel at 8% in 2008, and flared at 5% of total gas volume for 2008. The gas produced is significant: the three operating platforms offshore NL produced 7800 m^3 of gas in 2008 or approximately 7500 MW.

- Composition of the produced gas: Gas co-produced with oil or alone can vary widely in composition. Condensate reservoirs contain high levels of hydrocarbon liquids (propane, butane, pentanes, and heavier hydrocarbons), while

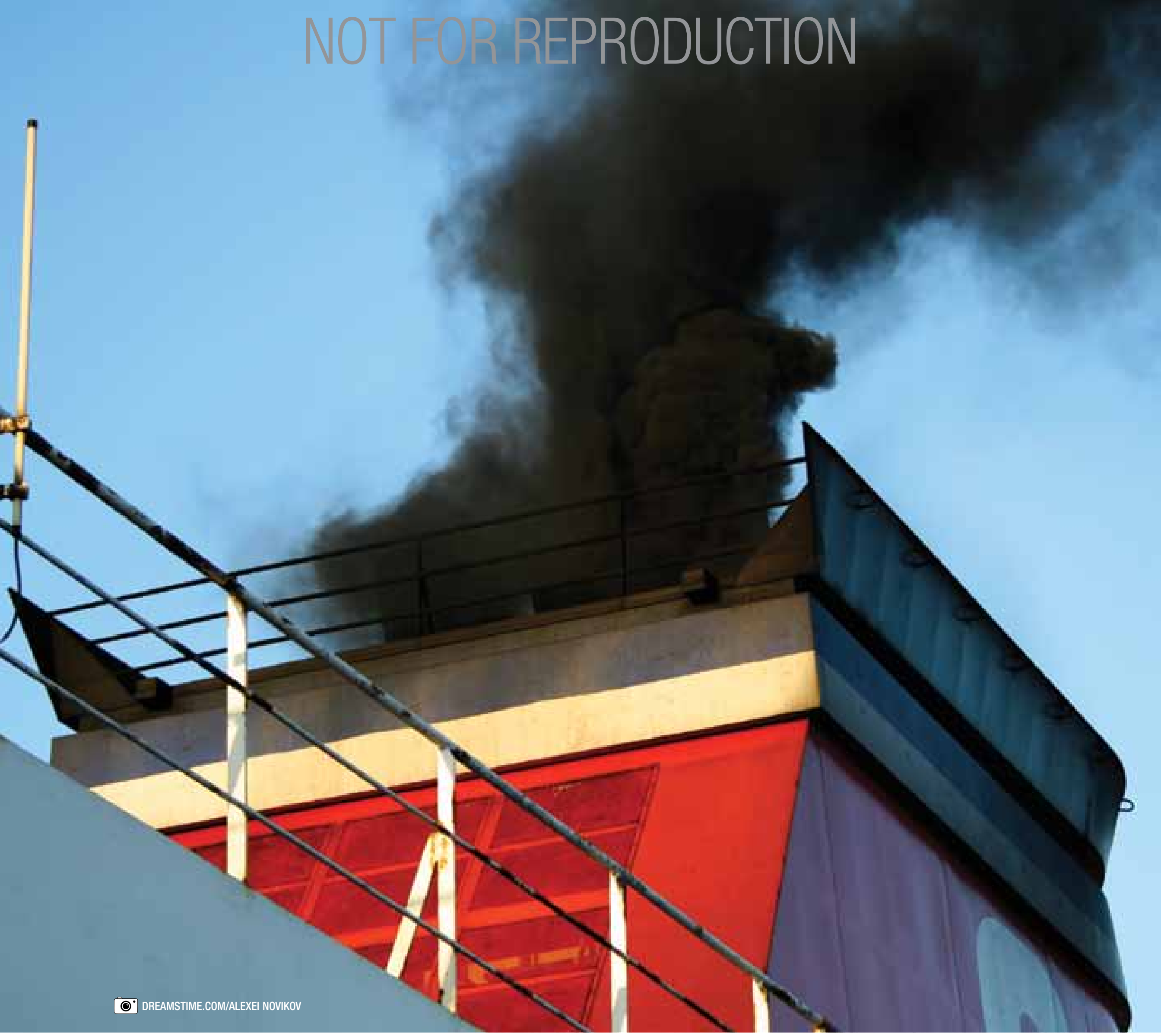

Figure 1: Offshore emissions present significant challenges with respect to control and regulation. There is the added complexity of the transient nature of the vessels and the transport of the pollutants over sea and into international waters.

lean natural gas reservoirs can be 90% plus methane. If the gas is used as fuel or is flared, the nature of the emitted combustion products will be a function of the composition. For instance, when flared, pure methane has a much higher combustion efficiency than methane mixed with propanes and butanes. This results in lower levels of polycyclic aromatic hydrocarbons (PAHs) and other incomplete combustion products in the flared gas. In addition, sour gas (gas containing hydrogen sulphide) will produce sulphur dioxide when flared or used as fuel. As such most regions require hydrogen sulphide removal prior to use/flare.

- Flaring regulations: As indicated above, most regions have tight regulations on the composition of flared gas (reduction in hydrogen sulphide content and/or hydrocarbon liquids) and the volumes that may be flared in a given period. However, the enforcement and tightness of the regulations vary considerably.

- Distance to market: Platforms close to shore or to market will have significantly lower emissions associated with the transport of the product and, if the platform co-produces oil and gas, lower emissions associated with the associated gas. As previously mentioned, stranded gas is re-injected, used as a fuel, and/or flared. If the gas is heavy in liquids and not properly treated prior to flaring or use as a fuel, the resulting emissions will be higher PM, NO_x, and NMVOCs.

- Degree of processing: Due to space and weight limitations, the extent of processing of oil and gas on platforms is limited for platforms in harsh or remote environments. Again, this means if gas is flared or used as fuel, it may not be as extensively processing where heavier hydrocarbons are removed to improve combustion efficiency. This will impact the nature of the emissions outlined above.

In the above discussion, we have not included the emissions associated with the transport of the oil and/or gas from the platform. Gaseous emissions associated with energy use in marine transport have been extensively studied. Most of these studies have focused on greenhouse gases, NO_x, sulphur oxides, and, to a lesser extent, hydrocarbons. There are also published studies on the energy use and emissions from marine vessels using life cycle analyses where not only are operating emissions included in the assessment but also emissions associated with the production and processing of the fuel. Obviously the type of fuel, operating conditions, type of engine and loads, and vessel will determine the nature of emissions associated with fuel consumption.

In order to determine the impact of offshore platforms' gaseous emissions on the marine environment, one needs to determine the quantity and nature of the emissions and fate once released. Various institutions and researchers have calculated emission factors for vessel energy use under a variety of conditions and fuel types. In 2005, the European Commission contracted Entec to determine ship emissions in the European Union. In the Entec report, they compiled the many emission factors for various vessels and fuel types and produced a set of emission factors based on fuel type, vessel, and operation of vessel. Table 1 shows the factors that were determined for tankers using different types of fuel.

The United States Environmental Protection Agency (EPA) and other regulatory agencies have also published emission factors for stationary sources such as natural gas

Emission	**Slow speed diesel engine using residual oil (g/kWh)**	**Medium speed diesel engine, residual oil (g/kWh)**	**Steam turbine, residual oil (g/kWh)**
CO_2	682.44	748.37	719.59
CO	1.59	1.75	1.68
SO_2	11.63	12.75	2.27
NO_x	19.67	14.13	12.94
VOC	0.58	0.64	0.61
PM	1.64	1.79	0.27

Table 1: Emission factors for tankers modified from Entec Report, 2005.

Figure 2: Most regions have tight regulations on the composition of flared gas and the volumes that may be flared in any given period. However, the enforcement and tightness of the regulations vary considerably.

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compressors, boilers, etc. used on the platform itself. The least studied emission source is the flare.

The composition of flared gas is a function of the combustion efficiency (CE), which in turn is a function of a number of parameters, most predominantly flare design and gas composition. Specifically, flammability limits of the gas, auto-ignition temperature, heating value, density, and degree of mixing will affect flare performance. However, meteorological conditions and liquid hydrocarbon levels will also impact CE. Until recently, the combustion efficiency of a flare has been assumed to be 98% as long as the flare is properly operated with sufficient heating value of the flared gas. A study by the Alberta Research Council (ARC) in 1996 showed that combustion efficiencies from a flare at a battery can vary from 62 to 84% depending on the composition of the flared gas.

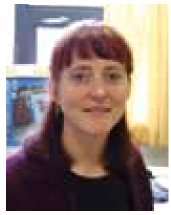
It is not typical to assess nitrogen oxide emissions from flares; however, estimates have been made. Typical emission factors of NO_x for flares have been estimated at 0.0015 tonnes/tonne gas burned to 0.068lb/10^6BTU. It should be noted that if one takes the U.S. EPA emission factor (EF) and uses the heating value of the gas used to determine the EF (1030 MMBTU/MMscf) and converts, the resulting EF of 0.001427 tonnes/tonne gas burned is very close to the exploration and production value. However, it also shows the EF when using the U.S. EPA value is a strong function of the assumed or calculated heating value.

The actual number of contaminants released in measureable amounts from a flare is significant. One of the most comprehensive was performed at ARC where various natural and solution gas compositions were flared in a lab, pilot scale, and field scale. In the pilot scale experiment, of the 188 hydrocarbons detected in the emitted plume, many were PAHs, which are major constituents of particulate matter. Further, in lab through to field studies, the presence of liquid hydrocarbons decreased CE by 10 to 12%. Thirty-one volatile hydrocarbons were identified and fifty-four non-volatile hydrocarbons (e.g. PAHs) in the emitted plume. Nine of the volatile were sulphur hydrocarbons such as thiophene and benzothiophene. There were measureable levels of PAHs as well; of the sixteen priority PAHs identified by the U.S. EPA, five were present in the sampled flared gas at combined levels of 250 mg/m^3.

Again, offshore flaring is strictly controlled in most jurisdictions; however, when assessing the overall impact of offshore operations, the flare cannot be ignored. In the same breath, it is difficult to quantify the emissions due to lack of data. A further complication is the transport of emissions offshore.

Dispersion and transport models for stacks, regions, cities, etc. are well established onshore. In the offshore environment, the modelling of gaseous transport and impact on the environment is complicated. First of all, tankers typically travel long distances and therefore their emissions tend to have a much wider impact than onshore transport emissions or even offshore vessels such as ferries. In addition, gaseous emissions are transported long distances; pollutants produced in industrial and other human activities in southern areas have been shown to be transported all the way up to the Arctic. In 2000, a comprehensive review of transport of pollutants from the south to the Arctic showed evidence between the global emission of contaminants from industrial and agricultural activities and the Arctic. The partitioning of contaminants between the gaseous and water phase further complicates predicting the impact and fate of contaminants. This complicates analysis on two levels: incorporating partition coefficients, which are in turn a function of the composition of both the air and water, which is transient by nature; and effect of other marine activities. Surrounding vessels will also discharge bilge water and other emissions to the water. There may be hydrocarbons in this water, so the impact of these streams should be "decoupled" from the gaseous streams if possible or included in a "water-shed" approach to determining impacts. Finally, the application of dispersion models to predict the fate of point sources of emissions (e.g. compressor stacks) is complex, especially when applied to flares. The aforementioned partitioning between phases should be included as part of the model. The models require complete sets of meteorological data, which may not be available in some regions or highly transient. In particular, the flare presents a problem as it is transient in nature; that is, due to regulations, it is an emergency gas control option and therefore not a continuous source. Most commercially available dispersion models assume the source is continuous, such as a compressor or gas turbine.

Many different issues have been brought up in this discussion indicating how complex even a simple greenhouse gas inventory for an operating platform (including transport) may be. However, as discussed, there are tools in the literature and with regulators to make some determinations. The key is to clearly outline the assumptions and possible limitations in any emission inventory. In determining the impact of these emissions, the marine environment as a whole must be considered. Several researchers are addressing this area, but it is still evolving.



Dr. Kelly Hawboldt received her undergraduate degree from the University of Saskatchewan and both her MSc and PhD from the University of Calgary; she has worked in the energy and environmental industry. Her areas of research include natural gas recovery and treatment from remote/frontier areas, environmental monitoring and impacts of offshore oil and gas, control and management of combustion gases, industrial wastewater treatment/ mitigation, and sustainable processing. Currently Dr. Hawboldt is an Associate Professor in Process Engineering at Memorial University of Newfoundland.

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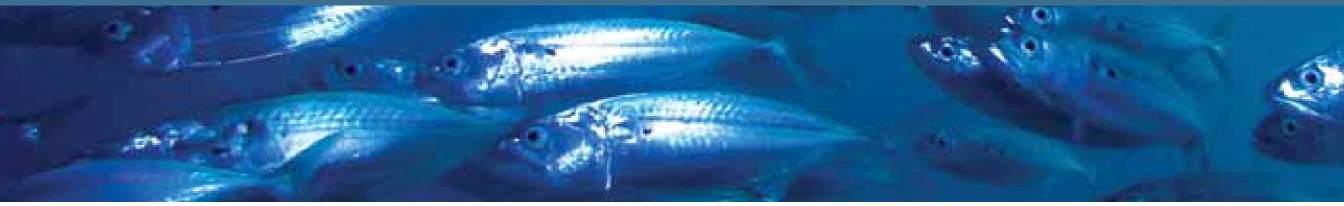

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