Energy Sources, Part B, 3:121–132, 2008

ISSN: 1556-7249 print/1556-7257 online
DOI: 10.1080/15567240600815026

Sustainable Management Techniques for Offshore Oil and Gas Operations

M. I. KHAN[1] and M. R. ISLAM[2]

[1]Faculty of Engineering, Dalhousie University, Halifax, Nova Scotia, Canada
[2]Institute for Sustainable Energy, Environment, and Economy, University of Calgary, Calgary, Alberta, Canada

Abstract *This paper addresses the present environmental misconceptions common in the oil and gas development sector. Some innovative solutions are proposed to solve the problems caused by oil and gas development activities in the marine environment. These solutions are based on the holistic environmental approach, which takes into account the complexity of natural processes and also takes advantage of these processes, rather than working against them. Some of the proposed models are marine protected areas in oil sites (MPAOS), ocean fertilization and CO_2 utilization (OFCU), integrated coastal pollution balancing (ICPB), artificial recruitment in fisheries (ARFS), and artificial rigs from oil rigs (AROR). The main goal of the proposed approach is to maintain and restore ecological sustainability and ecosystem integrity. As a result, each solution will not only stop destruction of the environment but also improve the productivity, biodiversity, and fisheries in the marine ecosystem.*

Keywords ecosystem-based management, innovative management techniques, sustainable management

Introduction

Petroleum hydrocarbons are the lifeblood of modern industrialized society. To date, there has been no other suitable alternative to this energy source. Adequate supplies of reasonably priced oil and gas are required for the economic growth of a country. Despite the hydrocarbon sector's great economic and social benefit, it draws enormous public attention due to its environmental consequences (Smith and Garcia, 1995; Khan and Islam, 2003, 2004, 2005, 2006). All stages of oil and gas operations generate a variety of solid, liquid, and gaseous wastes (Khan and Islam, 2006; Khan et al., 2006). These offshore oil and gas development activities reportedly have devastating impacts in the marine environment and its flora and fauna (Joint Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP), 1993; Khan and Islam, 2007; Khan et al., 2006).

Following the extensive scientific research and knowledge gained in marine ecology, oceanography, and oil and gas technology, scientists are now in a better position to understand ocean science and technology. At the same time, technological development is also creating new and complex problems at an ever-increasing rate. The conventional way to manage the marine resources especially offshore oil and gas operations no longer works adequately. The present management strategies in offshore oil and gas development are based on the traditional sectoral as well as chemical approach rather than

Address correspondence to M. R. Islam, Faculty of Engineering, Dalhousie University, D510-1360 Barrington St., Halifax, NS B3J 2X4, Canada. E-mail: Rafiqul.Islam@dal.ca

taking into consideration the whole ecosystem. In this research, an alternative sustainable management approach is introduced to solve the existing problems of offshore oil and gas development. The main goal of the proposed approach is to maintain and restore ecological sustainability and ecosystem integrity in the operations of the offshore oil and gas development. This article provides a brief description of present environmental status of offshore operations. It is followed by the detailed description of all alternative modes.

The Environmental Status of Offshore Oil and Gas

Offshore oil and gas development operations and their impacts are different from the land-based oil and gas activities. The offshore operations were divided into four phases. These phases are seismic exploration, exploratory drilling and installation of structures, production, and decommissioning of the platforms. The technological details and scale involved for each of these phases were significantly different and generated different effluents and impact, as shown in Table 1.

In offshore oil and gas operations, different types of wastes are studied (Khan and Islam, 2003, 2007) which are drilling wastes, human-generated wastes, and other industrial wastes. A detailed list of wastes generated in different phases of offshore operations is shown in Table 2. There are also accidental discharges—for example, via air emission, oil spills, chemical spills, and blowouts. CO_2 emissions are one of the most pressing issues in the hydrocarbon sector. There are direct emissions from production sites through flaring and from burning fossil fuels. The oil sector contributes a major portion of CO_2 emission. About 29 billion tons of CO_2 are released into the air every year by human activities: 23 billion tons come from burning fossil fuels and industry (Intergovernmental Panel on Climate Change (IPCC), 2001; Jean-Baptiste and Ducroux, 2003), which is why this sector is blamed for global warming. The question is: How might these problems best be solved? Is a solution possible?

Crude oil is one of the major toxic elements released in the marine environment (Figure 1) by the oil industry. On average, from offshore oil and gas operation, 15 million gallons of crude oil are released yearly into the marine environment. There are in total 700 million gallons of oil discharges into the sea from other sources (United States Coast Guard, 1990; Khan and Islam, 2004). Other sources of oil release are routine maintenance of shipping, domestic/urban runoff, up in smoke, and natural seepages.

Table 1

Different technological phases of offshore oil and gas development and related wastes

Seismic exploration	Drilling and installation	Production	Decommissioning
When a license is issued, the proponent is given 5 years to explore the resources. The actual process may be 20–30 days.	Generally 3–5 years, including onshore fabrication, installation, and commissioning.	Depending on the size of the reserve, the production phase can last between 25–35 years.	Proponents require preparing a decommissioning plan for offshore petroleum development; however, no information on time frame of decommissioning activities was found.

Table 2
Different technological phases of offshore oil and gas development and related wastes

Seismic exploration	Drilling and installation	Production	Decommissioning
Sounds Associated wastes Human generated wastes: sanitary wastes, kitchen and food wastes, laundry wastes, and sink and shower drainage, and trash	Drilling muds Drillings cuttings Produce sands Storage displacement water Bilge and ballast water Deck drainage Well treatment fluids Naturally occurring radioactive materials Cooling water, desalination brine Water for testing fire control Other assorted wastes: Accidental discharges: air emission: oil spills, chemical spills, blowout Human generates wastes: sanitary wastes, kitchen wastes, and sink and shower drainage, laundry wastes, and trash Other industrial wastes: cardboard, empty container, scrap metal, wood pallets, used chemicals and paint, sandblasting grit and paint, and cooling water	Produced water Treatment, and completion fluids Deck drainage Produced sand Storage displacement water Bilge and ballast water Deck drainage Well treatment fluids Naturally occurring radioactive materials Cooling water, desalination brine Water for testing fire control Accidental discharges: air emission: oil spills, chemical spills, blowout Other assorted wastes Human generated wastes: sanitary wastes, kitchen wastes, and sink and shower drainage, laundry wastes, and trash Other industrial wastes	Abandoned structures

Alternative Environmental Management Techniques

Present management techniques in offshore oil and gas create numerous problems in the marine ecosystem, which have been well studied (Patin, 1999; Khan and Islam, 2003, 2004, 2005, 2006; Khan et al., 2006). There is clearly a need to develop measures in this sector that stop adverse impacts on the marine environment. Managers, scientists, and engineers have tirelessly sought to develop different strategies, techniques, and management guidelines to solve the problems. Yet, in solving these problems, misconceptions have appended in the present "environmentally absolutely correct" attempts made in oil and gas operations which cause further damage to the environment. To solve these problems, some new management techniques are proposed for the offshore oil and gas operations, which are pictorially shown in Figure 2. The figure shows the five different models, namely MPAOS, OFCU, ICPB, ARFS, and AROR.

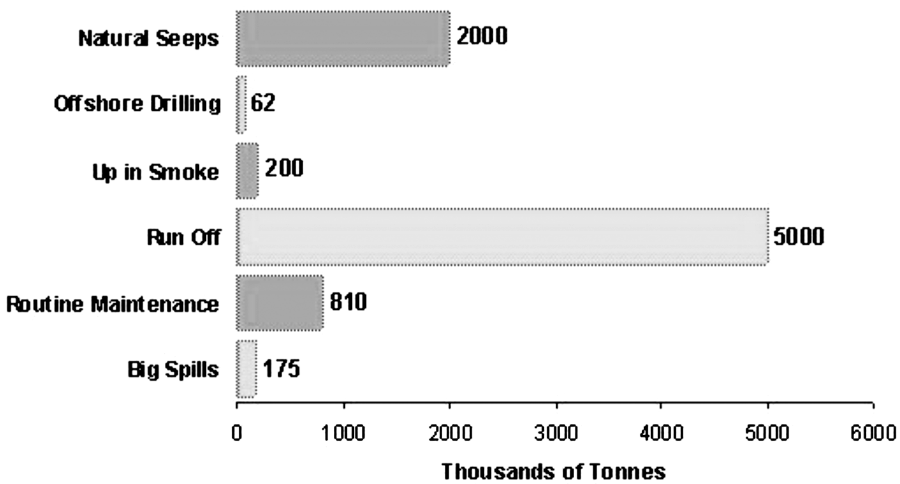

Figure 1. Annual total amount of oil release in the marine environment (Khan and Islam, 2004).

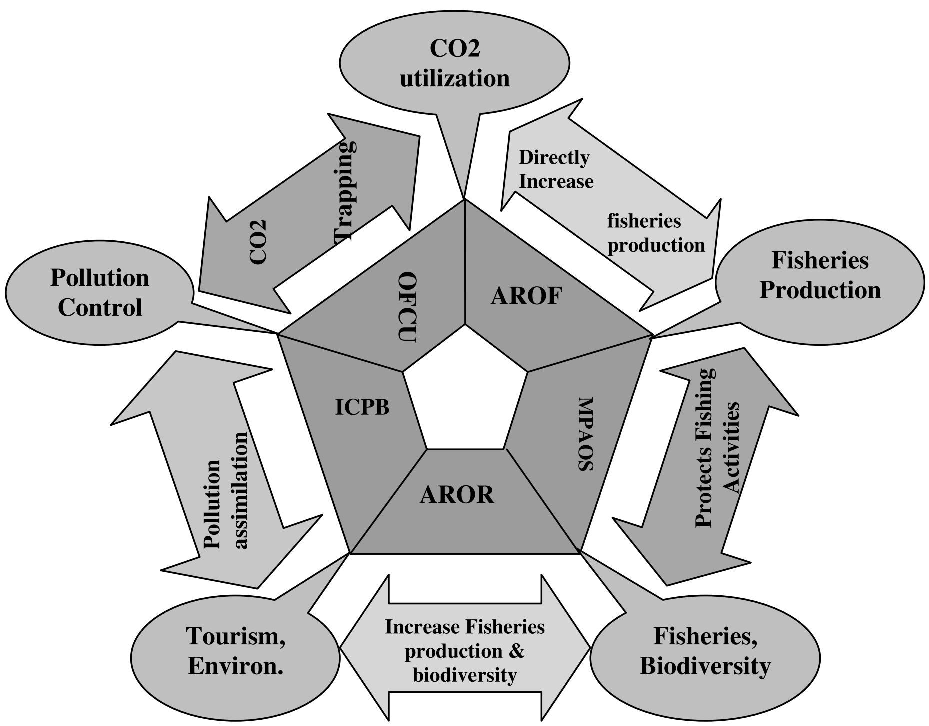

Figure 2. Proposed different sustainable management models of offshore oil and gas operations.

Marine Protected Areas in Oil Sites (MPAOS)

Offshore oil and gas development sites can also be designated as protected areas, or MPAOS. Due to the huge structural development in the oil operation, these sites represent obstacles to fishing, maritime transport, and other activities, which in turn provide undesignated restricted areas or protected areas. It is reported that 500 m from the oil rig is rarely polluted, and a 1,000-m distance is safe from waste discharges. There is no harm in creating protected areas in the oil development sites. Currently, marine protected areas are being introduced as part of fisheries management, as a legally designated area necessary to maintain biodiversity and to protect resources and cultural value.

In current general practice, marine protected areas are developed in the particular habitat by considering the special characteristics needed to preserve biodiversity. The proposed MPAOS can be designated in any place where oil rigs are operating, such as tidal lagoons, mudflats, salt marshes, mangroves, rock platforms, underwater areas on the coast, and seabed in deep water. Details of MPAOS are presented in Figure 3. Community-based approaches can also be introduced in long-term maintenance of the MPAOS, where different stakeholders and local communities of the surrounding areas can be involved in planning, developing, and managing the MPAOS. The oil and gas companies can play a major role by becoming involved in these conservation activities. For the success of the MPAOS, there needs to be considerable cooperation and involvement among all levels of government, industry, and the community.

In the MPAOS, all activities should be controlled, and only activity which does not harm the area's biodiversity may be permitted. Recreational and commercial activities such as sports fishing and eco-tourism may continue but should be sensitively managed to prevent adverse disturbances to the natural attributes of designated areas. Conserving the environment should be the main objective in MPAOS (Figure 3).

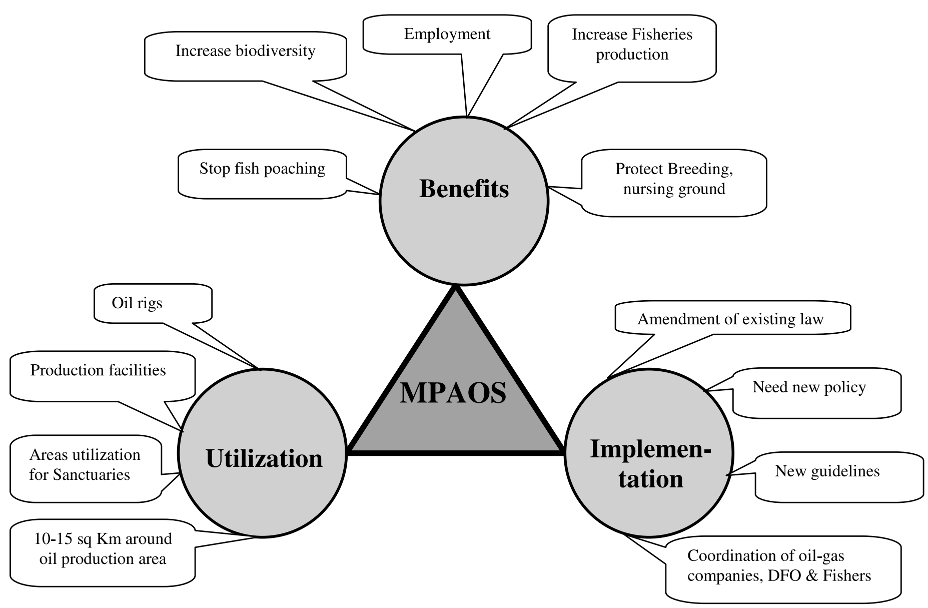

Figure 3. Pictorial view of marine protected area in oil sites and its method of implementation, requirements, and benefits.

By designating an oil site as a protected area, numerous ecological and environmental benefits can be achieved, some of which are discussed in this article. MPAOS can improve fisheries production by protecting fish nursing and breeding grounds. They may maintain a good fish stock for the natural recruitment of fisheries, and they will improve and maintain undisturbed biodiversity. Fishing activities will be limited or controlled in the MPAOS. As a result, the other organisms will not be destroyed as "by-catch" during fishing periods. MPAOS can also protect endangered or threatened species from further destruction. The protected area will stop the poaching of valuable species from the designated areas.

Ocean Fertilization and CO_2 Utilization (OFCU)

The main objective of this proposed approach is the fixation of the CO_2 by bacterio-plankton following fertilization with enriched industrial and domestic wastes. Ecological and planktonic studies of Barber and Chai (2001), Coale (2001), Hutchings and Bruland (1998), and Coale et al. (1996) reveal that phytoplankton growth can be significantly increased by providing iron as a fertilizer (Figure 4). As a result, plankton may produce a bloom in which optimum number of plankton grow in the environment (Cooper et al., 1996; Boyd et al., 2000; Coale, 2001). This plankton bloom can play a significant role in CO_2 utilization. A pictorial image of the proposed model is given the Figure 5.

For experimenting, abandoned, semi-enclosed bodies of water can be selected. The enclosed water body will be helpful in controlling the ecosystem parameters to maintain optimum growth of phytoplankton. Desirable industrial or organic wastes containing increased iron, silicon, nitrogen, phosphorus, and potassium may all be used as fertilizers. The targeted fertilizer has iron and silicon. This will also help with accumulation of the wastes, which will be utilized as the nutrient sources of marine phytoplankton. These nutrients can be applied through semi-submersible boxes or can be spread through tankers, barges, or aerial application. The targeted species for iron fertilization are photosynthesis species or chlorophyll pigmented species, some of which are known as cyanobacteria, diatoms, blue-green algae, bacterioplankton, and seaweeds.

The most intriguing aspect of the proposed OFCU model is its potential to minimize atmospheric CO_2 levels, which may ultimately slow down global warming. The idea is to balance CO_2 emissions by sinking enough organic carbon in the ocean bottom by applying the IFCU models. Considering the larger ocean scale, one can estimate how much CO_2 can be fixed if the model is successful. There are also ecological

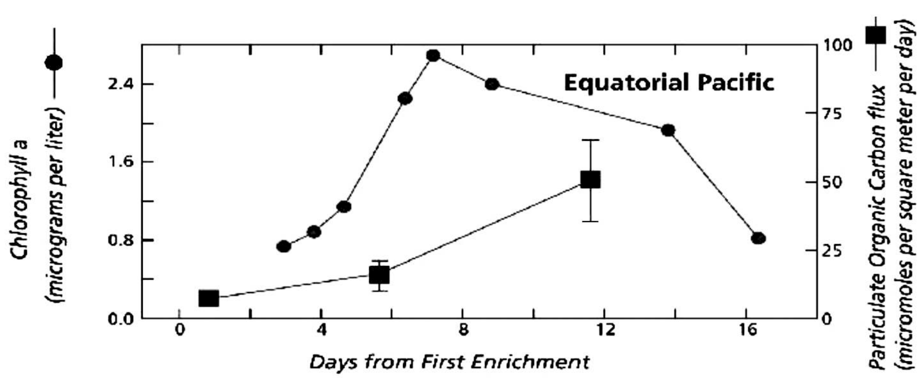

Figure 4. Effects of iron fertilizer in the plankton growth (adapted from Buesseler, 1999).

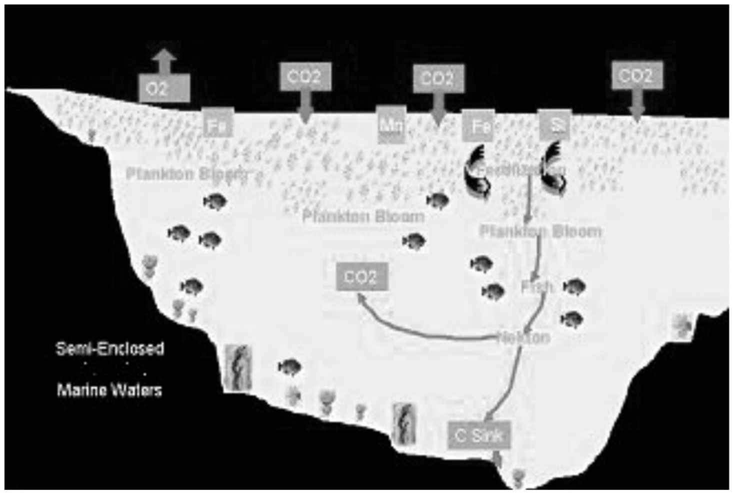

Figure 5. A proposed model of iron fertilization and carbon dioxide utilization.

benefits from this model. For example, plankton growth will develop associated plankton feeding organisms, which will ultimately increase fisheries as well as ecosystem productivity.

Integrated Coastal Pollution Balancing (ICPB)

As mentioned earlier, more than 700 million gallons of oil enter the marine environment annually (Oil in the Sea, 2003; Khan and Islam, 2004). The major portion (55%) enters coastal areas through runoff (Figure 4). The proposed ICPB models utilize the runoff oils and pollution through balancing ecosystem components. This is also a highly ambitious idea. The principle of bioremediation, fisheries, food web enhancement, aquacultures, and seaweed plantation will be utilized in the ICPB model.

To experiment with this model, sites can be selected in coastal inlets and river mouths. This will require ecological planning for the implementation of this project; for example, nutrient utilization rate and oil remediation rate by microorganisms or algae. The total pollutants input will be estimated in the selected area, such as runoff oil, agricultural waste releases, municipal waste releases, and other industrial pollution. Ecosystem models would then be developed to utilize those pollutants. For example, after considering the quantity of total nitrate and phosphate discharges, plants such as seaweeds and other algae will be introduced. These algae and seaweeds will be planted in such a way that they play a role in the phytoremediation of drainage oil as well as oil (or oil product) released from nearby sources. If agricultural or industrial pollution increases, this might lead to excessive production of the seaweeds and other plankton. To control phytoplankton growth, herbivorous fish can then be introduced. Mussel farming can also be set up to control the number of plankton particles in the water. In this way, an overall ecosystem can be developed in the selected coastal areas.

Oil degrades in the natural environment fairly quickly (GESAMP, 1993). Most oil compounds are found to degrade within a year in the natural environment. In the Exxon-Valdez report, it was found that within the first few years most of the spill oil was degraded (GESAMP, 1993). Through implementing the ICPB method, the runoff oils can be biodegraded and other ecological benefits such as fisheries and aquaculture production can be achieved. This may be a good option both for the ecosystem and by improving its productivity, which will bring social and economic benefit for the community.

Artificial Recruitment in Fisheries (ARFS)

Offshore oil and gas development is primarily criticized for its impact on the fisheries. The impact of offshore operations on fisheries depends on where the oil and gas development sites are. Studying the stock assessment of the developing sites, the status of the fisheries can be estimated, and it is possible to estimate how many negative interactions would have happened in that area. The main principle of the proposed ARFS method is to compensate the fisheries production if anything happens as a result of oil and gas development. The ARFS will help to increase the existing fish stocks and transplantation of species in the targeted areas. Here, targeted areas might include development sites or an alternative site where fisherman can extend their fishing activities into open waters, e.g., lakes, reservoirs, rivers, seas, and oceans.

The main objective of the ARFS is to increase the stocks of selected species in targeted areas and to resuscitate the stocks of over-fished or environmentally altered bodies of water. It will also fill ecological niches, utilize more fully certain biological resources, and compensate for the effects of barriers on the migratory routes to spawning grounds. This objective is achieved through artificial propagation of seed (fish larvae) and their release into open waters, stocking of adults into open waters and spawning streams, and the construction of fish ways and artificial spawning channels. The amount of fish fries should be added to achieve the maximum sustainable yield (MSY). Figure 6 shows the amount of fish that should be compensated to achieve the MSY.

The seed would be produced by establishing hatcheries, which induce hormonal treatment for the artificial propagation. This sort of hatchery technique is well established for commercial aquaculture development. After producing fish larvae, they will be stocked in the targeted areas. The stocking density, or how much to stock, would be determined by studying the carrying capacity of the targeted areas. Species selection would be done

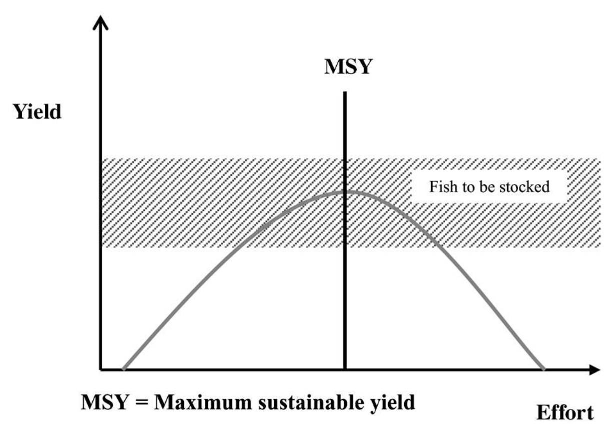

Figure 6. Maximum sustainable fisheries yield and direct recruitment of fish by oil and gas operators.

according to the hydrobiological condition of the site. Generally, species are selected based on the need to utilize available food or the objectives of culture. It is a good idea to select omnivorous, plankton feeding, and herbivorous or predator species to optimally utilize the available food. Indigenous species should be selected rather than exotic species. Otherwise, possible effects of exotic fish interaction on the indigenous fauna and general ecology of the receiving waters, including rapid increase of introduced species and possible elimination of indigenous species, will cause the destructive effects of transplanted fish and the introduction of new pests, etc. Different species such as fish, crustaceans, and mollusks can be stocked in the proposed ARFS.

By implementing ARFS, some direct fisheries benefits can be obtained. Some of these are discussed in this article. The natural fisheries production in the open water depends on the natural spawning in the ocean, but the success of ARFS is not dependents on natural spawning and recruitment. This significantly increases harvest and survival rates. It can also, therefore, utilize the optimum amount of natural food produced and establish productive fisheries in the targeted areas.

Artificial Reefs from Oil Rigs (AROR)

In the offshore operations, different types of oil rigs are installed according to water depth. Oil rigs are huge structures, thousands of tons in weight. By law, abandoned rigs must be decommissioned and removed from marine waters. Generally, these rigs are cut down to manageable size and brought back to the shore. The AROR model is proposing to use these rigs as artificial rigs. The main objectives of the AROR are to utilize the abandoned structures for fisheries yield and production, for recreational activities, to prevent trawling, to repair degraded marine habitats, and overall economic and social benefits (Cripps and Ababel, 2002; Baine, 2001).

In the proposed AROR models, the abandoned rigs can be kept in their original sites to establish a reef community or it can be transported to another planned site, giving a choice of type of seafloor conditions; for example, sand or muddy bottom or shallow or deep water areas. It is reported that wherever artificial reefs are established, benthic communities become productive. For example, the sand and mud habitat areas may not be as diverse as an original reef community, but often they can produce the productive benthic flora and fauna in establishing AROR.

It was recently reported that existing oil rigs have spawned lush marine habitats that are home to a profusion of rare corals and 10,000 to 30,000 fish per rig (Dybas, 2005). According to Dybas (2005), oil companies can save between $400 and $600 million per rig by converting them into artificial reefs instead of offshore decommissioning. Therefore, the conversion of AROR as well as other proposed models are economically profitable and can be implemented with coordination of other governmental agencies and NGOs. Figure 7 shows the detailed coordination process of the proposed models.

Conclusions

Present environmental management in the offshore oil and gas sectors is based on technological/engineering solutions, which consider only sectoral benefit in an unsustainable way. To achieve the sustainability in this sector, an alternative management approach is proposed. Based on this approach, five sustainable management models are developed; namely, MPAOS, OFCU, ICPB, ARFS, and AROR. These models follow the principle of natural functions in marine environment and take into account ecological, biological,

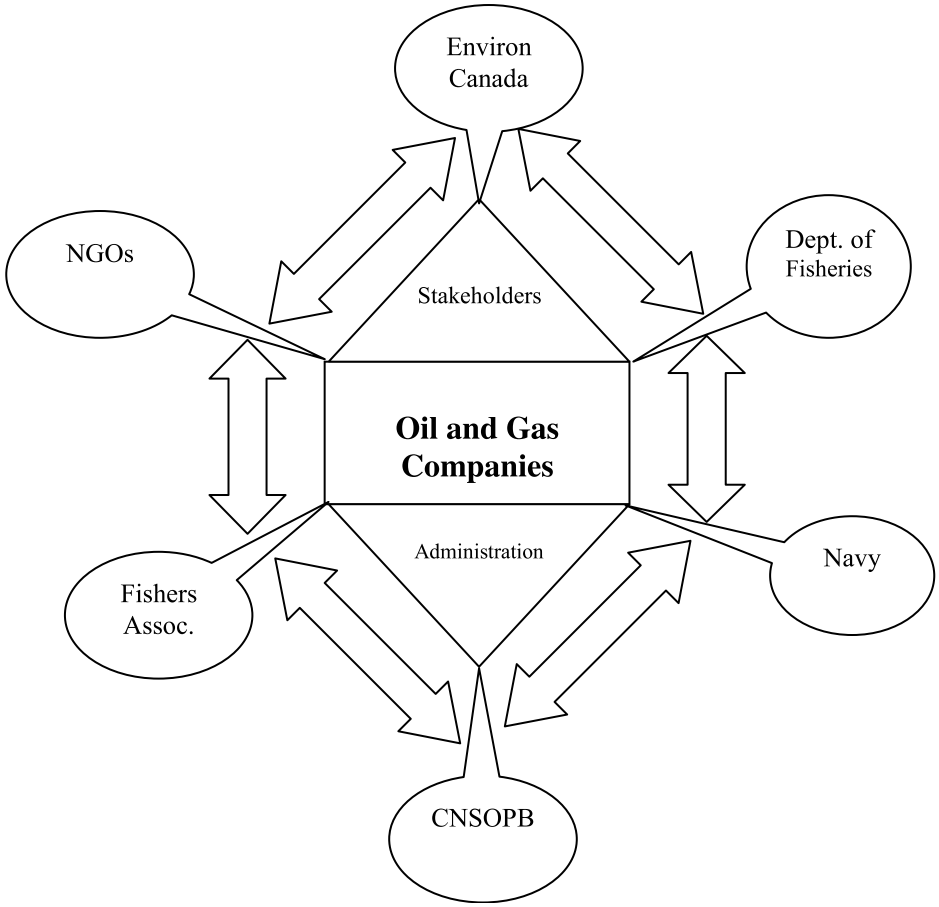

Figure 7. Implanting agencies of sustainable management models.

and technological factors. The MPAOS model protects and increases fisheries production. It also preserves biodiversity and improves ecological quality in the designated oil site. The OFCU model naturally utilizes CO_2 through increasing primary productivity (food chain) and sinks carbon in the sea bottom. This is a proposal for a natural way of CO_2 utilization. The ICPB model utilizes or traps pollutants biologically through assimilation. The ARFS model is designed to compensate the fisheries production by oil and gas operations. It directly increases fisheries production by stocking fish fry in the oil and gas operation sites. The AROR is modeled to utilize enormous amounts of abandoned oil structures and convert them to artificial rigs. It also increases fisheries production, biodiversity, and ecotourism activity.

The main goals of these models have been to maintain and restore ecological sustainability and ecosystem integrity, while managing offshore oil and gas operations. As a result, these models will not only stop destruction of the environment but also improve the ecological quality, productivity, biodiversity, and fisheries in the marine ecosystem. The existing solutions to these problems involve focusing on the individual problems without integrating the total ecosystem. As noted, this may benefit the oil sector but harm the whole ecosystem. The proposed sustainable management techniques are based on theoretical concepts. Therefore, to implement these techniques, it will require elaborative research and experimental study to understand how these proposals will function in a larger and real ecosystem context.

References

Baine, M. 2001. Artificial reefs: A review of their design, application, management and performance. *Ocean & Coastal Management,* 44:241–259.

Barber, R. T., and Chai, F. 2001. Using modeling to design and evaluate transient open iron enrichment for carbon sequestration. *2001 Conference Proceedings, First National Conference on Carbon Sequestration*. NETL Publications, United States Department of Energy, May 15.

Boyd, P. W., Watson, A. J., Law, C. S., Abraham, E. R., Trull, T., Murdoch, R., Bakker, D. C. E., Bowie, B. K. O., Chang, H., Charette, H., Croot, P., et al. 2000. A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization. *Nature* 407:695–702.

Buesseler, K. O. 1999. Fertilizing the ocean with iron [on-line]. Woods Hole Oceanographic Institution 1999 Annual Report, http://cafethorium.whoi.edu/Fe/1999-Annualreport.html (accessed 12 September 2005).

Coale, K. H., Johnson, K. S., Fitzwater, S. E., Gordon, R. M., Tanner, S., Chavez, F. P., Ferioli, L., Sakamoto, C., Rogers, P., Millero, F., Steinberg, P., Nightingale, P., Cooper, D., Cochlan, W. P., Landry, M. R., Constantinou, J., Rollwagen, G., Trasvina, A., and Kudela, R. 1996. A massive phytoplankton bloom induced by an ecosystem-scale iron fertilization experiment in the equatorial Pacific Ocean. *Nature* 383:495–501.

Coale, K. 2001. Open ocean fertilization for scientific study and carbon sequestration. *2001 Conference Proceedings, First National Conference on Carbon Sequestration*. NETL Publications, United States Department of Energy, May 15.

Cooper, D. J, Watson, A. J., and Nightingale, P. D. 1996. Large decrease in ocean-surface CO_2 fugacity in response to in situ iron fertilization. *Nature* 383:511–513.

Cripps, S. P., and Ababel, J. P. 2002. Environmental and socio-economic impact assessment of reef, a multiple platform rigs-to-reefs development. *ICES J. Mar. Sci.* 59:S300.

Dybas, C. L. 2005. Marine Life Complicates Removal of Old Oil Rigs, *The Washington Post*, Monday, April 11, 2005, p. A10.

GESAMP. 1993. (IMP/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution): Impact of Oil and Related Chemicals and Wastes on the Marine Environment. *Rep. Stud. GESAMP* 50:180.

Hutchings, D. A., and Bruland, K. W. 1998. Iron-limited diatom growth and Si:N uptake ratios in a coastal upwelling regime. *Nature* 393:561–564.

IPCC. 2001. *Climate Change 2001: The Scientific Basis*. (Contribution of the working group I to the third assessment report of the Intergovernmental Panel on Climate Change). Cambridge: Cambridge University Press.

Jean-Baptiste, P., and Ducroux, R. 2003. Energy policy and climate change. *Energy Policy* 31:155–166.

Khan, M. I., and Islam, M. R. 2003. Ecosystem-based approaches to offshore oil and gas operation: An Alternative Environmental Management Technique. Annual Technical Conference and exhibition, *Society of Petroleum Engineer,* Denver, CO, USA. October 6–8. SPE Paper 84058.

Khan, M. I., and Islam, M. R. 2004. Assessing environmental fate and behaviour of oil discharges in marine ecosystem: Using fugacity model. In: *Proceedings of the Offshore Oil and Gas Environmental Effects Monitoring Workshop: Approaches and Technologies*, Bedford Institute of Oceanography, May 26–30, 2003. Armsworthy, S. L., Cranford, P. J., and Lee, K. (Eds.). Columbus, Ohio, USA: Battelle Press, pp. 145–165.

Khan, M. I., and Islam, M. R. 2005. Assessing sustainability of technological developments: An alternative approach of selecting indicators in the case of offshore operations. *ASME Congress*, Orlando, Florida, Nov. 5–11. Paper no. IMECE2005-82999.

Khan, M. I., and Islam, M. R. 2007. *True Sustainability in Technological Development and Natural Resources Management,* NY, USA: Nova Science Publishers, 381 pp.

Khan, M. I., Lakhal, S. Y., Satish, M., and Islam, M. R. 2006. Towards achieving sustainability: Application of green supply chain model in offshore oil and gas operations. *Int. J. Risk Assess. Manage*. 8:23.

Oil in the Sea. 2003. Committee on Oil in the Sea: Inputs, Fates, and Effects, Ocean Studies Board and Marine Board, Divisions of Earth and Life Studies and Transportation Research Board, National Research Council. The National Academies Press, Washington, D.C.

Patin, S. 1999. *Environmental Impact of the Offshore Oil and Gas Industry.* East Northport, NY: EcoMonitor Publishing, 425 pp.

Smith, E. R. A. N., and Garcia, S. R. 1995. Evolving California opinion on offshore oil and development. *Ocean & Coastal Manage.* 26:41.

United States Coast Guard. 1990. *Update of Inputs of Petroleum Hydrocarbons into the Oceans due to Marine Transportation Activities.* National Research Council, National Academy Press, Washington, D.C.