# Ecological Consequences *of* Artificial Night Lighting

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*Chapter 5*

# Influences of Artificial Light on Marine Birds

The nocturnal activities of many animals have been changed by artificial lighting. Ambient light influences the reproductive physiology, migration, foraging, and hence parental behavior of many species. Perhaps more than any other vertebrates, birds are intimately and inextricably linked with the light features of their environments (e.g., Farner 1964).

Nocturnal oceans are essentially flat, dark environments in which marine birds negotiate their lives. Some seabirds exploit coastal and nearshore habitats, and others are pelagic, ranging over vast ocean expanses. Many seabirds are nocturnally active, in part to avoid diurnal avian predators, primarily gulls. Many of these nocturnal birds also prey on vertically migrating and bioluminescent prey.

Somewhat paradoxically perhaps, many nocturnal seabird species are highly attracted to artificial light. The attraction to light by nocturnal-feeding petrels has been hypothesized to result from their adaptations and predisposition to exploit bioluminescent prey (Imber 1975) and from a predilection to orient to specific star patterns (Reed et al. 1985). In these instances, artificial light sources might be perceived as attractive "supernormal" stimuli. Well before the age of electric lighting, humans used light from fires to attract nocturnal birds for exploitation (Maillard 1898, Murphy 1936, Murie 1959).

Migratory birds move seasonally over tens of degrees of latitude and longitude, often exhibiting movements of hemispheric proportions. These creatures are especially vulnerable to increasing sources and extents of artificial lighting. Light-associated mortality of nocturnal avian migrants involving collisions of hundreds or thousands or more birds with lights and lighted structures has been well documented for well more than a century (Allen 1880, Brewster 1886, Kumlien 1888, Johnston and Haines 1957, Evans 1968; see Chapter 4, this volume). Considering that mortality during migration is more than an order of magnitude higher than during energy-demanding breeding and winter seasons (Sillett and Holmes 2002), the population effects of additive mortality associated with artificial lighting could be profound.

Increasing risks associated with artificial lighting cumulate with other sources of environmental modification, degradation, and change, including deforestation, pollution, overfishing, and global climate change (e.g., Vitousek et al. 1997, Hughes 2000). For example, because global fish stocks are being overexploited, more fishery effort is directed at invertebrates on lower levels of marine food webs (Pauly et al. 1998). As a consequence, light-induced fisheries for squid are increasing in capacity and ocean coverage, with unknown influences on marine ecosystems (Rodhouse et al. 2001).

Given the dramatic influence of artificial lighting on marine organisms in the instances that have been documented, a general effect on marine birds, mammals, fishes, and invertebrates can be expected. Birds that spend most of their lives at sea are often highly influenced by artificial lighting in coastal areas and in dark, two-dimensional ocean environments. Except for coastal areas, oceanscapes tend to have less artificial lighting than terrestrial environments. Much artificial lighting on the ocean occurs at intense source points that can attract marine birds from very large catchment areas (Rodhouse et al. 2001, Wiese et al. 2001).

This chapter reviews the major sources of artificial illumination in the marine environment and their direct and indirect influences on seabirds. The cumulative effects of artificial lighting with other sources of environmental risk are considered. Different species and age classes of marine birds exhibit different degrees of attraction, and hence vulnerability, to artificial lighting. Mortality associated with artificial lighting threatens populations of endangered and rare species. Current levels of mitigative action are nonexistent or inadequate to address problems posed by artificial lighting for marine organisms. Environmentally sound and ecologically precautionary broad-scale and long-term adaptive planning programs are needed to address current and future problems.

## Sources of Artificial Light in the Marine Environment

The major sources of artificial light in marine environments include vessels, lighthouses, light-induced fisheries, and oil and gas platforms. Vessels have plied the seas for as long as humans have inhabited coastal environments, though most widely and prolifically during the last few centuries. Vessel numbers, sizes, and lights have increased exponentially throughout this period. Yet the more recent changes associated with lighthouses, marine gas and oil platforms, and light-induced fisheries are likely having the most significant influences on marine birds.

### *Lighthouses and Coastal Lighting*

Lighthouse beacons have been an important aspect of coastal navigation for centuries, with their proliferation probably peaking in the late nineteenth century. Rotational beams identified landfall and specific sites for mariners. At times, lightships have been moored at sea and at coastal sites with treacherous navigation. Because of improved navigational aids such as sonar and global positioning systems aboard vessels, the number of active lighthouses decreased dramatically in the late twentieth century, a trend that will continue over the next decades.

As large segments of human populations moved to coastal areas for housing, recreation, and leisure, the extent of artificial lighting along coasts spread throughout the twentieth century. Moreover, artificial illumination increased in power and intensity, as well as proliferating during this period.

### *Oil and Gas Platforms at Sea*

The intense flares at offshore hydrocarbon platforms, undoubtedly the most lethal light there is (Terres 1956, Bourne 1979, Sage 1979, Hope-Jones 1980, Wallis 1981), can be detected easily on satellite images (Muirhead and Cracknell 1984). These flares relieve pressures associated with natural gas from drilled wells and can reach up to 40 m (131 ft). Flares tend to burn most intensely during the initial operational phases of drilling and when hydrocarbon is not offloaded to vessels during extreme sea conditions (Burke et al. 2005). Hydrocarbon platforms are being constructed and deployed at remote ocean sites, where they impose novel artificial light sources, such as the shelf edge of the Grand Banks of eastern Canada. Both the intensity and oceanographic novelty of the light source could have a cumulative effect on the attraction and mortality of seabirds.

### *Light-Induced Fisheries*

Many fisheries use intense artificial lighting to attract, concentrate, and facilitate prey capture (e.g., Vojkovich 1998, Arcos and Oro 2002; see Chapter 11, this volume). Rodhouse et al. (2001) estimated that 63–89% of the world catch of squid is caught using lights that can be mapped using satellite imagery. Small artisanal vessels fishing squid often use a single light, whereas large vessels may use 150 lamps, with about 300 kW of illumination power (Rodhouse et al. 2001), and several vessels often work in the same area. Squid species that have large, well-developed eyes are attracted to the intense lights. The highest concentrations of light-induced fisheries for squid (also octopus and cuttlefish) are pursued in the Kuroshio Current on the China Sea Shelf southwest of Japan and along the Sunda–Arafura Shelf primarily in the Gulf of Thailand. Other major light-induced fisheries for squid are carried out around New Zealand, in the southwest Atlantic, and in the California and Humboldt currents.

## Influences of Ambient Light, Lunar Phase, and Season on Avian Attraction to Artificial Lighting

Attraction to and mortality at lighted structures is influenced by visibility, ambient light conditions, and lunar phase. Birds are more attracted to light during low cloud cover and overcast skies, especially foggy, drizzly conditions that are pervasive in many ocean regions (Brewster 1886, Kemper 1964, Aldrich et al. 1966, Weir 1976, Hope-Jones 1980, Wallis 1981, Telfer et al. 1987). Moisture droplets in the air refract light and greatly increase illuminated volumes (i.e., catchment basins), whereas concentrated beams of light act as bright corridors in the darkness into which birds fly (Weir 1976). Birds entrained in intense artificial light often circle the source for hours to days, especially during overcast conditions, when they are reluctant to fly outside of the sphere of illumination into darkness (Avery et al. 1976, Wallis 1981). Also, seabirds and marine waterfowl fly closer to land during foggy conditions (Chaffey

2003; see also Weir 1976, Blomqvist and Peterz 1984), increasing their chances of encountering and being affected by coastal lighting.

Seabird vulnerability to artificial light is influenced by lunar cycles. There is significantly less attraction to artificial lighting on bright, clear nights with a full moon (Verheijen 1980, 1981, Telfer et al. 1987). In these conditions, breeding nocturnal seabirds exhibit less activity at colonies (Warham 1960, Harris 1966, Boersma et al. 1980, Watanuki 1986, 2002, Bryant 1994). Conversely, more birds are attracted to, stranded at, and killed at artificial lights during new moon phases, when activity at breeding colonies is also greater.

Autumn and spring migratory periods are critical times for mortality associated with artificial lighting at coastal and offshore sources. In autumn high proportions of relatively easily disoriented young-of-the-year are on the wing, and during both spring and autumn seabirds move in large numbers across oceans and hemispheres. In the northwest Atlantic, for example, tens of millions of birds move into the region from breeding areas in the Arctic in the fall and the Southern Hemisphere in the spring.

## Direct Influences of Artificial Light on Seabirds

Marine birds are attracted to and often collide with lighthouses (Evans 1968, Crawford 1981, Verheijen 1981, Roberts 1982), coastal resorts (Reed et al. 1985), offshore hydrocarbon platforms (Ortego 1978, Hope-Jones 1980, Tasker et al. 1986, Baird 1990, Wiese et al. 2001, Burke et al. 2005), and vessels that use intense artificial lighting to attract and catch squid and other fish (Dick and Davidson 1978, Arcos and Oro 2002).

Mass collisions of birds with lighted structures can result in high levels of mortality. In one documented incident, the lights of a fishing vessel were estimated to attract about 6,000 crested auklets (*Aethia cristatella*) weighing 1.5 metric tons, which nearly capsized the boat (Dick and Davidson 1978). Mass collisions and incidences of hundreds, thousands, and tens of thousands of circling birds have been reported at coastal and offshore artificial light sources (Bourne 1979, Wiese et al. 2001). Seabirds are attracted to the flares of offshore oil and gas platforms and can be killed by intense heat, by collisions with structures, and by oil on and around brightly lit platforms (Figure 5.1; Wood 1999, Wiese et al. 2001, Burke et al. 2005; see also Newman 1960).

Mortality associated with flaring and artificial lighting is episodic, which probably explains why some observers report hundreds and even tens of thousands of birds killed by flares (Sage 1979), and others report

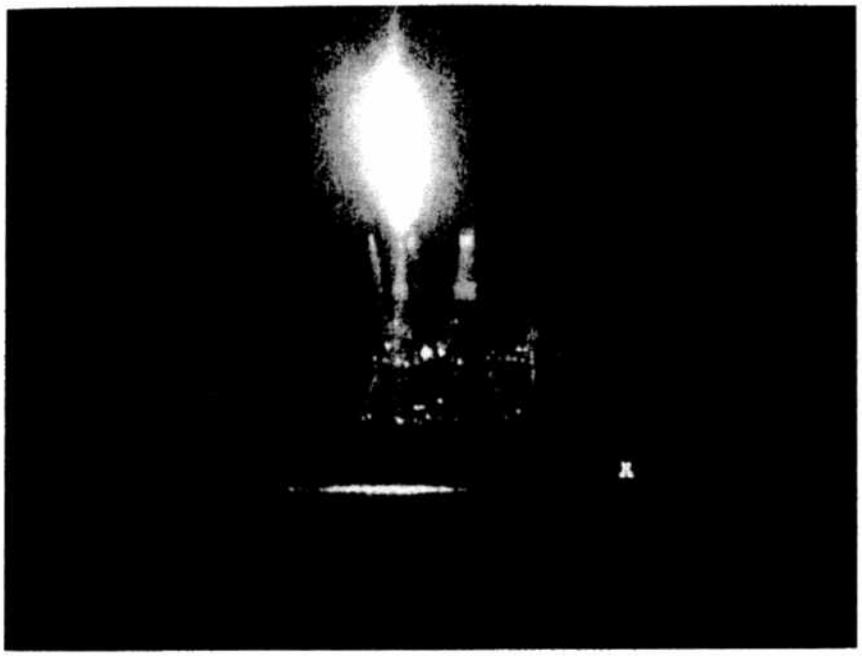

**Figure 5.1.** Hibernia oil platform and its flare by night on the edge of the Grand Banks of eastern Canada on February 18, 2003. Photo courtesy of C. Burke.

many birds attracted to platforms with little or no associated mortality (Hope-Jones 1980, Wallis 1981). These apparently discrepant findings also provide a rationale for the necessity of having dedicated independent observers rather than casual industry observers on offshore hydrocarbon facilities (Wiese et al. 2001) and on light-induced nocturnal fishing boats. Observer independence is needed to ensure validity and transparency of the process, as is true for observers on fishing vessels to monitor catches and bycatches (Weimerskirch et al. 2000, Melvin and Parrish 2001).

## Indirect Influences of Artificial Light on Seabirds

Much of the mortality associated with artificial lighting is indirect and difficult to document. For instance, migrating passerines have been observed to circle platforms continuously for hours to days and to fall on the ocean or, less often, to land on platforms exhausted and emaciated (Hope-Jones 1980, Wallis 1981). This holding or trapping effect (Verheijen 1981) of intense light can deplete the energy reserves of migrating birds, rendering them incapable of making it to nearest landfalls. Although migratory seabirds do not use landfalls, the energetic costs associated with such diversions could have severe consequences for winter survival or subsequent reproduction.

Offshore hydrocarbon platforms develop rapidly into artificial reefs that create marine communities. These reefs attract, concentrate, and proliferate flora, crustaceans, fishes, and squids (Carlisle et al. 1964, Duffy 1975, Sonnier et al. 1976, Ortego 1978, Wolfson et al. 1979, Hope-Jones 1980, de Groot 1996). Lighting attracts invertebrates, fishes, and birds, and organisms at higher trophic levels are in turn attracted to lower ones as well as to the lighting.

Many species of marine birds have been recorded feeding in artificial nocturnal lighting. Most of these events have been recorded in coastal situations, but feeding at lights has also been observed for terrestrial waterbirds (e.g., Brown et al. 1982) and at offshore fishing vessels and hydrocarbon platforms (Hope-Jones 1980, Burke et al. 2005). Conversely, some nocturnally migrating crustaceans and associated predators might be less likely to migrate toward surface waters that are artificially illuminated.

Purse seine fisheries for small clupeids in the Mediterranean Sea use lights to attract and concentrate fishes (Arcos and Oro 2002). These nocturnal fisheries also attract threatened Audouin's gulls (*Larus audouinii*) that capture fish during hauling. The fisheries thus might be considered as providing a short-term benefit for the gulls but could also be changing their distributions at sea and potentially depleting their prey.

Many of the squids taken by albatrosses are dead ones that are scavenged (Weimerskirch et al. 1986). Squid species that have positive buoyancy after death ("floaters"; Lipinski and Jackson 1989, McNeil et al. 1993) are the ones most often scavenged by procellariiform seabird species (e.g., Rodhouse et al. 1987). Some of the dead squid contain hooks that can injure or kill avian scavengers. Albatrosses and other procellariid avian species may be those most attracted to offshore squid fisheries.

Light-induced nocturnal fisheries at times are conducted near islands where nocturnal seabirds nest. These light levels could facilitate predation by night-hunting gulls and could also reduce visitation rates by burrow-nesting seabirds to mates, eggs, and chicks (Keitt 1998).

## Cumulative Effects

The most complex indirect influences on populations often are those associated with cumulative effects that represent the interaction of a multiplicity of diverse causes (Clark and Leppert-Slack 1994, Duinker 1994). In such circumstances, a negative environmental or population effect might not be attributable to any single factor but rather to a multiplicity of cumulative interactions that are obscured from a causal analysis (e.g., Burke et al. 2005).

Many cumulative effects probably are associated with artificial lighting. For example, light and heat that facilitate marine plant growth attract invertebrates and fishes, and these in turn attract and concentrate feeding gulls and other seabirds at offshore hydrocarbon installations (Wiese et al. 2001, Burke et al. 2005). Wastewater discharged on site at these platforms fertilizes the artificial reefs and provides feeding opportunities that attract scavenging gulls, just as coastal sewage outflows do. Spilled oil and discharged oily drilling fluids at platforms also contaminate birds on site (Burke et al. 2005). Together, the cumulative attractive effects are likely synergistic and greater than the sum of the influences of light, food availability, heat, and structural effects.

Globally, cumulative natural (e.g., oceanographic and climate change) and anthropogenic changes (e.g., greenhouse gas emissions, overfishing) are having profound, long-term effects on the Earth's ecosystems (Vitousek et al. 1997). The proliferation of artificial light throughout the biosphere could act in synergistic and unknown ways with these other large-scale environmental changes. For example, overfishing of the world's fish stocks in recent decades has led to much fishing effort being directed at invertebrate prey, that is, fishing down marine food webs (Pauly et al. 1998). Consequently, light-induced squid fisheries are increasing in effort and extent (Rodhouse et al. 2001). Furthermore, as the fishing and oceanographic influences in particular areas of squid concentration produce stock collapse, such as off eastern Canada in the 1980s (Black et al. 1987, Montevecchi 1993), fishery efforts are concentrated in other hotspots, such as the southwestern Atlantic (Rodhouse et al. 2001).

## Species Vulnerability

Many nocturnal seabirds have a preponderance of rods in their retinas, more rhodopsin, and often larger eyes than related diurnal species (McNeil et al. 1993). These species probably are more susceptible to the influences of artificial light. Many of the smaller planktivorous nocturnal species are highly sensitive to, and attracted to, night light (Imber 1975, Dick and Davidson 1978, Bretagnolle 1990). At least 21 species of procellariiform seabirds are known to be attracted to artificial lighting (Murphy

1936, Reed et al. 1985). For example, Leach's storm-petrels (*Oceanodroma leucorhoa*) are highly attracted to lighthouse beacons and to the illumination of offshore hydrocarbon platforms (Wiese et al. 2001). These storm-petrels have also been observed flying about lights at baseball fields in San Francisco (B. Sydeman, personal communication, 2004) and St. John's, Newfoundland (N. Montevecchi, personal communication, 2004).

Vulnerability to artificial light appears to be greatest among species that feed on bioluminescent prey and could have predispositions for light attraction. Many endangered and threatened species of marine birds therefore are at risk. Even some of the largest of marine birds, such as king penguins (*Aptenodytes patagonicus*), prey on bioluminescent myctophids often at low illumination levels (Cherel and Ridoux 1992). They likely also have keen sensitivity and possibly attraction to ambient and artificial light.

## Age Vulnerability

Fledgling storm-petrels, petrels, shearwaters, and possibly some auks are more attracted to artificial light than are adults. This could result from disorientation associated with environmental inexperience or possibly from predispositions to find bioluminescent prey at sea (Imber 1975). Fledgling band-rumped storm-petrels (*Oceanodroma castro cryptoleucura*), dark-rumped petrels (*Pterodroma phaeopygia sandwichensis*), grey-faced petrels (*Pterodroma macroptera gouldi*), Barau's petrels (*Pterodroma baraui*), Newell's shearwaters (*Puffinus auricularis newelli*), wedge-tailed shearwaters (*Puffinus pacificus*), and Cory's shearwaters (*Calonectris diomedea*) incur considerable mortality as a result of their attraction to artificial lighting (Telfer et al. 1987, Bretagnolle 1990, Whittow 1997, Mougeot and Bretagnolle 2000, Day et al. 2003, J. Valerias, unpublished data). Many of these species are endangered or threatened, including band-rumped storm-petrels, dark-rumped petrels, and Newell's shearwaters. The varying age-class attraction of nocturnal species to light also suggests that some older birds may learn not to approach artificial light sources.

Among nocturnal seabirds, immature and nonbreeding birds appear to be more sensitive and vulnerable to the influences of lunar light than are breeding birds. This could be related to the greater vulnerability of immature and nonbreeding birds to visually hunting nocturnal predators when compared with breeders (Morse and Buchheister 1977, Huntington et al. 1996, Mougeot and Bretagnolle 2000, Stenhouse et al. 2000). In contrast to seabirds, adult passerines are more likely to be attracted to lighted coastal structures than are juveniles (Dunn and Nol 1980; but see Chapter 4, this volume).

## Potential Population Effects

Wiese et al. (2001) suggested that artificial lighting at oil platforms on the Grand Banks could affect long-distance migrants from high latitudes in the Southern Hemisphere (shearwaters) and from the high Arctic (dovekies, murres) as well as from the world's largest populations of Leach's storm-petrels that breed locally. The species that are potentially most vulnerable to attraction to artificial lighting in marine environments, however, are nocturnal species that are at risk and endangered and whose populations are small and fragmented.

### *Endangered Species and Species of Concern*

The small population sizes of some endangered and threatened species that are attracted to nocturnal light make them particularly vulnerable to artificial lighting. Barau's petrel, for example, an endangered endemic species that breeds on Réunion Island in the Indian Ocean, exhibits a very strong attraction to artificial lighting that leads to mortality (Le Corre et al. 2002). Very rare endangered Mascarene petrels (*Pseudobulweria aterrima*) are also killed by attraction to artificial lighting. Fledglings of two endemic Hawaiian seabirds, Newell's shearwater and dark-rumped petrel, suffer high mortality associated with artificial coastal lighting as they depart from inland nesting sites on their way to sea (Telfer et al. 1987, Ainley et al. 1997, 2001, Slotterback 2002, Day et al. 2003). Table 5.1 lists endangered, threatened, and rare species that experience mortality associated with artificial lighting.

Threatened Audouin's gulls feed on small clupeid fishes at nocturnal purse seine operations that use artificial lights to attract and concentrate fishes (Arcos and Oro 2002). Intense artificial lighting associated with commercial fisheries for squid exerted a negative influence on nesting Xantus's murrelets (*Synthliboramphus hypoleucus*; Carter et al. 2000, Pacific Seabird Group 2002), leading in part to their listing as a threatened species in California. The market-driven squid fishery has more than doubled the number of participating vessels from the 1970s to the 1990s, during which period catches increased about 4.5-fold (Vojkovich 1998). The fisheries are carried out just offshore from important nesting islands

**Table 5.1.** Marine bird species that are endangered, threatened, or of special concern and that are attracted to human light sources.

| *Species* | *References* |
|---|---|
| Newell's shearwater (*Puffinus auricularis newelli*) | Telfer et al. 1987, Ainley et al. 1997, 2001, Day et al. 2003 |
| Dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) | Telfer et al. 1987 |
| Cahow (Bermuda petrel) (*Pterodroma cahow*) | Beebe 1935 |
| Grey-faced petrel (*Pterodroma macroptera gouldi*) | Le Corre et al. 2002 |
| Barau's petrel (*Pterodroma baraui*) | Le Corre et al. 2002 |
| Mascarene petrel (*Pseudobulweria aterrima*) | Le Corre et al. 2002 |
| Band-rumped storm-petrel (*Oceanodroma castro cryptoleucura*) | Telfer et al. 1987, Slotterback 2002 |
| Audouin's gull (*Larus audouinii*) | Arcos and Oro 2002 |
| Xantus's murrelet (*Synthliboramphus hypoleucus*) | Pacific Seabird Group 2002 |

for murrelets and black-vented shearwaters (*Puffinus opisthomelas*). Their lights have also facilitated nocturnal predation by barn owls (*Tyto alba*) and western gulls (*Larus californicus*) at colonies and possibly disrupted reproductive behavior, movement, and aggregations on the water, which leads to nest abandonment (Keitt 1998).

## Methods to Reduce Effects of Artificial Light on Seabirds

About twenty-five years ago, Hope-Jones (1980) indicated the need for detailed study of the effects of hydrocarbon platforms on avian behavior and mortality. Despite the phenomenal proliferation of these platforms in the world's oceans and as surprising as it seems, these studies are still necessary (Montevecchi et al. 1999, Burke et al. 2005).

### *Working with Seasonal and Spatial Patterns of Avian Vulnerability*

Peak fledging periods are highly concentrated during a few weeks in late summer in the Northern and Southern hemispheres. Minimizing coastal and offshore lighting at these times could significantly reduce unnecessary avian mortality. Moreover, some sites attract more birds than others. On the Hawaiian island of Kauai, for instance, the mortality of endangered shearwaters and petrels was highest at coastal sections near river mouths, apparently because fledglings of these species follow river valleys from inland mountain nesting sites to sea (Telfer et al. 1987). The Kauai Surf Hotel near the mouth of the Huleia River accounted for almost half of all the avian fallout documented during 1981 (Telfer et al. 1987). By shielding and eliminating skyward lighting at the hotel during fledging times, Reed et al. (1985) produced significant reductions in the mortality of these endangered endemic species. Such temporal mitigative strategies could also be applied profitably during periods of peak migratory movements. The County of Kauai initiated a program of insulating and shielding streetlights in 1980, and a Save Our Shearwaters program, aimed at recovering and releasing stranded young birds, has been in place since 1978 (Day et al. 2003).

The flares on offshore and land-based hydrocarbon facilities are periodically shut down for maintenance and refit. These downtimes should be scheduled to coincide with periods of greatest risk of avian mortality, that is, peak fledging and migration times.

### *Shielding, Extinguishing, and Modifying Light*

Shielding lights to eliminate skyward illumination could greatly reduce the catch basin of light attraction for birds in or passing through a region. By shielding the upward projection of light, Reed et al. (1985) demonstrated experimental reductions of 30–50% of the landings of endangered endemic shearwater and petrel fledglings at a coastal Hawaiian resort. This approach indicates worthwhile opportunities for reducing coastal and offshore light pollution.

Some cites such as Tucson, Arizona and Prague, Czech Republic shield lights in their municipalities to reduce light pollution that interferes with astronomical observation. Light shielding also helps to direct more light downward, where it is intended. This action also benefits birds that are active and migrate at night. Shielding of lights at marine platforms must both eliminate the skyward projection of light and guard against increasing the incidence of light directed at the sea surface to avoid its attractiveness to fishes and invertebrates.

A practical but underused approach to reducing light pollution is simple conservation. Turning off unneeded exterior and interior lighting and covering windows at night could be extremely useful. In 2000, the

California Fish and Game Commission required that squid fishing vessels shield their lights and use no more than 30,000 W per boat. Observers are not required on these vessels, but they should be.

Different wavelengths of light have different attractiveness to animals; for example, red and blue appear to be less attractive than white light (Wiese et al. 2001; see also Weir 1976, Telfer et al. 1987). More compellingly, intermittent lights at lighthouses result in fewer bird losses compared with steady rotating beams (Weir 1976). Lighthouses in Canada and elsewhere still use rotating beams; these should be replaced with strobe or intermittent flashing signals.

### *Flaring at Offshore Hydrocarbon Platforms*

Flaring cannot be shielded to prevent upward illumination, but it can be reduced and eventually eliminated by reinjecting gases into hydrocarbon basins. The technology is available to do this and should be implemented rapidly and universally.

During the initial operation of the Hibernia platform on the continental shelf of eastern Canada in 1998, there were reports of hundreds, thousands, and tens of thousands of seabirds circling the platform for hours. These reports have ceased, but because there are no dedicated independent observers or comprehensive protocols for collecting this type of information on this and other platforms, information is lacking on what has occurred and what is occurring. In the absence of information, it is impossible to assess the consequences of flaring and offshore artificial lighting. About a year after startup, potentially significant levels of seabird mortality were still ongoing at a sufficient level to be documented during a casual visit by a journalist (Wood 1999). Current protocols on offshore platforms are inadequate to detect significant episodic mortality (Burke et al. 2005).

### *Mandating Dedicated Independent Observers on Offshore Hydrocarbon Platforms and Light-Induced Fishery Vessels*

Self-reporting does not always provide accurate or reliable assessments of activity, especially of negative, inappropriate, or illegal activity (Weimerskirch et al. 2000). Independent arm's-length monitoring is widely accepted as a more valid and reliable means of resource and environmental assessment because industries or individuals with vested interests in profits do not always self-regulate unless compelled to do so.

Long-term systematic observations by dedicated independent observers therefore are necessary to reliably document and understand the episodic nature of avian mortality at lighted structures at night (Montevecchi et al. 1999). Without such information, effective mitigation is essentially precluded. A program of independent, systematic observations throughout the year is necessary to detail the species present and times of greatest risk. Risk periods vary widely between species and between oceanographic regions, and an adaptive approach to mitigation is needed to implement different strategies in different circumstances.

Dedicated independent observers should be mandated as a legislative condition of operation of offshore hydrocarbon platforms in all jurisdictions. Observers are already required on fishing vessels because of the potential detrimental effects that biologically unsound fishing practices can have on populations of marine fishes (Stehn et al. 2001). The threats from lights and flares at offshore hydrocarbon platforms appear as severe and necessitate similar regulation.

## *Reducing Cumulative Effects*

Light acts in concert with other environmental factors such as heat, structures, pollutants, and food to augment the risks to birds. For instance, seabirds attracted to offshore lights associated with squid fishing vessels or hydrocarbon platforms might also be killed by ingesting hooked prey or by oil on the water.

An example of an indirect cumulative influence relates to the unnecessary discharge of wastewater at offshore platforms. These wastes fertilize the developing reef below platforms and promote plant and crustacean growth that in turn attracts fish (Duffy 1975, Ortego 1978, Sonnier et al. 1976). The fishes in turn may be attracted to the surface waters by intense lighting, where they may be preyed on by birds at night (Burke et al. 2005). Retaining wastewater at platforms and recycling it at land-based facilities would prevent unnecessary fertilization and reduce the attraction of scavenging gulls.

## *Limiting the Expansion of Light-Induced Fisheries*

Concerns have been expressed about the movement of light-induced squid fisheries into the Antarctic region and the consequences for squid-eating marine birds and mammals (Rodhouse et al. 2001). Quotas for squid in the Antarctic have been set conservatively on the basis of these concerns.

### *Limiting the Construction of New Lighted Structures*

Artificial lighting is increasing globally, including in the marine environment (e.g., *Pipeline and Gas Journal* 2005). The most direct and effective mitigative measures to preserve darkness involve eliminating unnecessary illumination, reducing light intensity, and minimizing the skyward and seaward projection of artificial light.

## Conclusion

Lighthouses, offshore and nearshore squid and other fisheries that use intense lighting to attract prey at night, and offshore oil and gas platforms and their brilliant gas flares are imposing new artificial light sources in heretofore dark nocturnal ocean environments. These developments attract, concentrate, and kill seabirds and other marine animals. The mortality of seabirds associated with these artificial sources is not monitored or studied effectively. To minimize these forms of mortality, it is essential to study their seasonal variation and species vulnerabilities. Some causes of this mortality are indirect (e.g., energy depletion from prolonged circling of light sources, increasing predation on nocturnal species by diurnal gulls hunting at night), and some are embedded in cumulative effects (e.g., offshore platforms create artificial reefs that attract crustaceans and fishes that in turn attract avian predators). Endangered, threatened, and rare species are at especially high risk for negative population effects. Fledglings making their initial flights to sea from nesting areas and migrating flocks are the most critically affected groups. Occurrences of light-associated mortality are episodic, so to document this mortality there is a compelling need to legislatively mandate dedicated independent observers on hydrocarbon platforms and light-enhanced nocturnal fishery vessels.

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