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LITERATURE REVIEW, SYNTHESIS, AND DESIGN OF MONITORING OF AMBIENT ARTIFICIAL LIGHT INTENSITY ON THE OCS REGARDING POTENTIAL EFFECTS ON RESIDENT MARINE FAUNA

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1.0 POTENTIAL EFFECTS ON MARINE FAUNA

1.1 Introduction

In the Final Proposed Outer Continental Shelf Oil and Gas Leasing Program 2002-2007 (USDOI 2002), the Minerals Management Service (MMS) proposed lease sales in the Beaufort Sea, Chukchi Sea/Hope Basin, Norton Basin, and Cook Inlet Planning Areas. A requirement of Stipulation No. 8 of the MMS Final Beaufort Sea Multiple Sale EIS (USDOI 2003) was that all structures associated with offshore drilling must be lighted to avoid avian mortality but that light radiating outward from structures must also be minimized.

Substantial development in the Arctic involving the deployment of artificial light sources already has occurred adjacent to and in the Beaufort Sea. Industrial support facilities in arctic Alaska, such as the buildings and storage areas at West Dock, structures at the Endicott Spur Drilling Island, structures and work areas on Northstar Island, and support vessels and supporting facilities are brightly lighted. More lighted structures can be expected in this area as Outer Continental Shelf (OCS) development proceeds. Light radiating outward from structures is a potential factor affecting the marine environment. Little study has been made of the introduction of artificial light into the formerly dark fall and winter habitats of numerous species of marine invertebrates, fishes, birds, and mammals in the Arctic. These organisms include a number of protected species that live in or migrate through artificially lighted habitat during dark periods and seasons. This study addresses the issue of artificial light in the Arctic by conducting a literature review of lighting impacts on marine organisms and by designing a potential monitoring program for artificial light. It focuses on arctic marine and estuarine species commonly found in Alaska OCS lease areas, primarily in the Beaufort and Chukchi seas. Important trophic components, protected species, and endangered species are highlighted, including spectacled (*Somateria fischeri*) and Steller's (*Polysticta stelleri*) eiders. When applicable, the review includes information on the effects of lighting on related species at other latitudes/longitudes and at other seasons or periods.

The various sources of artificial light, performance characteristics of lamps, physics of light transmission and reflectance, and methods of measurement are reviewed. In addition, potential light-monitoring and -modeling programs are described. Finally, mitigation procedures to reduce lighting impacts, limitations and data gaps in our understanding, and a list of alternative

approaches and sampling strategies are provided. An annotated bibliography also was prepared in a ProCite format.

A technical workshop was held at the MMS Alaska office (Anchorage, AK) on January 25, 2008, to discuss information needs based on the literature search, to identify important areas in which there is limited or no information, to discuss alternative approaches and sampling strategies, and to make recommendations on the preliminary design of an artificial-light monitoring program that potentially could be used in existing Arctic OCS development areas.

1.2 Methods

This study addresses potential effects of lighting on arctic marine and estuarine species commonly found in Alaska OCS lease areas, focusing primarily on the Beaufort and Chukchi seas during normally dark periods or seasons. Sources of information included, but were not limited to, primary scientific literature and books from national and international sources, unpublished reports, and other accessible sources such as internet homepages and in-house databases. Appropriate sources at the U.S. Fish and Wildlife Service, the U.S. National Marine Fisheries Service, the Alaska Department of Fish and Game, the International Dark-Sky Association, and other sources in the scientific and offshore-development community were contacted to identify local information on responses of fauna to artificial light.

The databases used in this literature search included BioOne, Science Citation Index, Cambridge Scientific, Alaska Resources Library and Information Services (ARLIS), and internal catalogues of Golder Associates, Inc., and ABR, Inc.—Environmental Research & Services. The information was entered into ProCite, a bibliographic software program that allows the end-user to gather, manage, and manipulate reference information.

1.3 Results

In the following section, the impacts of artificial light are discussed by species-group: mammals, birds, fishes, and invertebrates. Their abundance and use in the Alaska arctic marine environment, visual properties and optical capabilities, attraction to light, and reported impacts of artificial lighting are presented for each species-group.

1.3.1 Species-group

1.3.1.1 Mammals

Abundance & Use of Area

Two broad taxonomic groups of mammals occur in the Beaufort and Chukchi seas—carnivores (order Carnivora: families Canidae, Odobenidae, Phocidae, and Ursidae) and whales (order Cetacea: families Balaenidae, Eschrichtiidae, Monodontidae, Delphinidae, and Phocoenidae; Lentfer 1988). Although it is not a marine mammal, one species of canid—the arctic fox (*Alopex lagopus*)—occurs regularly in coastal and offshore (on sea ice) arctic Alaska. The walrus (*Odobenus rosmarus*; the single species of odobenid world-wide) is rare in the Beaufort Sea but is abundant in the Chukchi Sea as the ice recedes in the summer and before it expands southward in the fall. The seals (phocids) of Arctic Alaska are pagophilic (ice-loving) species, including the bearded seal (*Erignathus barbatus*), ringed seal (*Phoca hispida*), and spotted seal (*Phoca largha*). The ringed seal is the most numerous species year-round and breeds in the ice of both the Chukchi and Beaufort seas, whereas the bearded seal and (especially) the spotted seal occur in this region more in the summer, as the ice-edge retreats. The single species of bear (ursid) occurring in numbers in the Chukchi and Beaufort seas is the polar bear (*Ursus maritimus*), which lives and forages primarily on the sea ice and comes ashore in coastal areas, where some females den and bear cubs.

Two species of baleen whales (mysticetes)—the bowhead whale (*Balaena mysticetus*) and the gray whale (*Eschrichtius robustus*)—occur in the Chukchi and Beaufort seas. The former species migrates across both regions between summer concentration areas in the eastern Beaufort Sea and winter concentration areas in the western Bering Sea, and the latter species occurs in the Chukchi Sea in summer, migrating far south in winter. Toothed whales (odontocetes) are represented primarily by belugas (*Delphinapterus leucas*; also called white whales), which occur coastally in the Chukchi Sea and, to a lesser extent, in the Beaufort Sea (mainly during seasonal migrations to and from the Canadian Beaufort Sea). Two other species of toothed whales—killer whale (*Orcinus orca*) and harbor porpoise (*Phocoena phocoena*)—occur in the Chukchi Sea in summer, but little is known about their abundance and distribution in the area; it is possible that both reach the Beaufort Sea.

responsive to changes in light levels because of a need to protect the retina from bright light. Because higher vertebrates, and mammals in particular, have lost photomechanical abilities to protect retinas by having pigments migrate within the photoreceptor cells (as occurs in the lower vertebrates), their pupils are extremely controllable and highly responsive to light.

Mammals that are active throughout the entire day and some mammals that are crepuscular or nocturnal have an additional reflective layer, the *tapetum lucidum*, behind the photoreceptive cells in the eye. This layer, which causes the distinctive eye-shine of some mammals in a car's headlights at night, reflects light back into those cells, thus effectively amplifying the amount of light hitting them and increasing night-vision ability. It is found in most carnivores and ungulates but is rare in many other mammalian groups; it also is not found in obligate diurnal species. This layer also occurs in marine mammals that see in both the water and the air. These animals can accommodate to poor vision in the air by stopping down the pupil, thereby reducing the amount of light available for vision (Nagy and Ronald 1970).

Optical Capabilities

Incident light may be reflected at the water's surface, and some is transmitted into the water below. That light that penetrates water is absorbed and scattered. These conditions result in reduced light availability with depth and in shifts in wavelengths of light that are available to underwater animals. Marine mammals in general show optical adaptations that reflect these general patterns seen in mammals as a whole. For example, marine mammals tend to forage under low light conditions (in either turbid water or at night), requiring optical adaptations and/or the development of other means of sensing the environment. The optical system of pinnipeds (phocids and otariids) has adapted to see in low light by increasing pupil size and responsiveness (Levenson and Schusterman 1997) and by increasing rod density (Estes 1989). Both pinnipeds and the fish-eating toothed whales have high visual acuity underwater to enable the capture of fishes while swimming rapidly (Estes 1989). The toothed whales also have developed alternative means of sensing the environment through the development of echolocation, although they use echolocation primarily as a long-distance sensory mechanism and use vision for detection of nearby objects (Griebel and Schmid 2002). Walruses have small eyes with presumably poor vision but also highly sensitive vibrissae (i.e., bristles on the face). There also is evidence that some seals have increased sensitivity of vibrissae, perhaps to aid in close sensing of prey in low light (Dehnhardt and Kaminski 1995).

Most, if not all, pinnipeds forage at night or under low light levels (Hobson 1966, Estes 1989). As a result, they tend to have large eyes and pupils, especially in the deep-diving seals (Walls 1942, Lavigne and Ronald 1972, Estes 1989), and have highly sensitive eyes and retinas (Nagy and Ronald 1970). Along with cetaceans, they also have a *tapetum lucidum* behind the retina that reflects light back through the rods at low light levels (Hobson 1966, Nagy and Ronald 1970, Lavigne and Ronald 1972, Zorn et al. 2000). Morphologically, the *tapetum* in pinnipeds is a *tapetum cellulosum* and the *tapetum* in cetaceans is a *tapetum fibrosum*, each with a different structure (Zorn et al. 2000). The *tapetum* in pinnipeds is highly developed (Walls 1942), and the *tapetum* in cetaceans probably is the most developed of all mammals (Zorn et al. 2000). Cetaceans also have large corneas and pupils, suggesting adaptations for vision generally similar to those of pinnipeds (Griebel and Schmid 2002). Further, the *tapetum* of some cetaceans may have multiple peaks of sensitivity that indicate separate adaptations to wavelengths seen at the surface and wavelengths seen at depth (Young et al. 1988). For pinnipeds, there is some evidence for good daylight visual acuity both underwater and in air (Mauck et al. 2005). However, the resolution ability of the sea lion eye with decreasing ambient light decreases more rapidly in air than in water (Schusterman and Balliet 1971).

Although color vision is mediated by the presence of cones in the retina, the presence of cones does not imply color-vision but instead may reflect the adaptation of the eye to bright light. In fact, some carnivores can detect various colors but apparently do not use the information in foraging (Ewer 1973). Earlier studies suggested that most of those seals that had been examined carefully had only rods in their eyes, suggesting that color vision is rare and that they are adapted to foraging under low light conditions (Nagy and Ronald 1970). Although some authors have found cones in harbor seals, these cones represent only about 1–2% of the photoreceptors (Jamieson and Fisher 1971, Griebel et al. 2006). Recent research indicates that at least some pinnipeds (e.g., harbor seals) have one type of cone, the L-cone, that is most sensitive in longer (green to red) wavelengths (Crognale et al. 1998, Griebel and Schmid 2002). In pinnipeds, the S-cone, which is sensitive to short-wavelength light and which is found in other mammals, has been lost through evolution, resulting in what otherwise would be monochromatic color vision, except for the modification of the activity of rods to produce something akin to dichromatic color vision (Griebel and Schmid 2002, Griebel et al. 2006). This system appears in those pinnipeds in which the pupil shrinks to such a small aperture that rods effectively act as a second cone, even in substantial light (Griebel and Schmid 2002).

Cetaceans show adaptations to color vision similar to those of pinnipeds (Griebel and Schmid 2002). For example, they also have lost the S-cones, resulting in the loss of dichromatic color vision, which is found in terrestrial mammals (Griebel and Schmid 2002). However, a type of dichromatic vision exists and is possible only through increased spectral sensitivity of the rod pigments (Griebel and Schmid 2002).

The eyes of pinnipeds do not focus well in the air because the refractive index of light differs between air and water. The refractive index of their cornea is similar to that of water, rather than that of air; hence, it is optimized (i.e., is emmetropic) for underwater vision by being spherical at the expense of visual acuity in air (Walls 1942, Jamieson and Fisher 1971). In the air, the iris is closed down to a vertical slit so that the eye functions as a pinhole lens, rather than focusing by changing lens shape (Gentry and Peterson 1967). Other authors (e.g., Lavigne and Ronald 1972) however, have indicated that pupil size and shape are determined by ambient light, rather than the medium in which the seal is seeing. However, the iris always is partially open underwater because that light is filtered (attenuated) at some wavelengths. In the air, astigmatism caused by irregular corneal shape also is corrected by stopping down the iris (Nagy and Ronald 1970), although visual acuity in the air is reduced under low light levels because the pupil has to be partially opened (Lavigne and Ronald 1972, Mauck et al. 2005). At least some small dolphins and other small cetaceans also have an ability to see in air to varying degrees, although they have no ability of accommodation (i.e., focusing) and have no ciliary muscles to stop down the pupil to a pinhole (Watkins and Wartzok 1985).

Some pinnipeds, especially deep-diving ones such as northern elephant seals (*Mirounga augustirostris*), have additional adaptations in that their eyes develop scotopic vision (i.e., ability to see under low light conditions) rapidly (Levenson and Schusterman 1999). This adaptation, which takes about 6 minutes to become effective, is believed to be more rapid than that of shallower-diving pinnipeds because the elephant seals achieve foraging depths of 200–1,000+ m in only about 6 minutes. As a result, their eyes become dark adapted in a similar period, rather than the 15–40 minutes required for eyes of shallower divers (Levenson and Schusterman 1999).

Photopigments of pinnipeds also may be specialized for particular light regimes and appear to be most sensitive to wavelengths of light found in their environment (Levenson and Schusterman 1999); in general, they are shifted in sensitivity more toward the shorter (more blue) wavelengths (Griebel and Schmid 2002). For example, in seals, the vision-sensitivity curve matches the

wavelengths of light found in seawater, and the eye contains a dense concentration of rods, suggesting that they have excellent underwater visual sensitivity in dim light (Nagy and Ronald 1970). Although biochemical studies indicate that the visual systems of marine mammals are adapted for maximal sensitivity in the water in which they forage (the sensitivity hypothesis), behavioral studies indicate that the visual systems are adapted to maximize the amount of contrast between the prey and their environment (the contrast hypothesis; Watkins and Wartzok 1985). Hence, although their eyes can detect only certain wavelengths that are available to them, the animals themselves are more responsive to certain parts of the wavelength-sensitivity spectrum, making prey stand out more clearly against their environmental background. In fact, some researchers have suggested that marine mammals have developed two pigment systems and color vision to maximize both sensitivity and contrast-based methods for the detection of objects (Watkins and Wartzok 1985).

In general, pinnipeds that are deeper divers (e.g., elephant seals) tend to have eyes that are shifted more toward shorter (more blue) wavelengths than do pinnipeds that are shallower divers (e.g., harbor seal *Phoca vitulina*, California sea lion *Zalophus californianus*; Griebel and Schmid 2002). For example, Weddell seals (*Leptonychotes weddellii*), which forage in fairly clear Antarctic water on non-bioluminescent fishes, have photopigments that peak in sensitivity around 495 nm (i.e., blue-green), similar to that of coastal fishes and terrestrial mammals (Lythgoe and Dartnall 1970). In contrast, elephant seals, which feed in very dark water on mostly bioluminescent prey, have photopigments that peak in sensitivity around 485 nm (towards blue), similar to that of deep-sea fishes (Lythgoe and Dartnall 1970, Levenson and Schusterman 1999). These animals actually use background bioluminescent light to see prey at depth, feeding on prey that are bioluminescent or that concentrate at the highly bioluminescent deep-scattering layer (Levenson and Schusterman 1999).

Harp seals (*Phoca groenlandica*) have photopigments that peak in sensitivity around 500–525 nm which is the green part of the spectrum and similar to that of green coastal waters (Lavigne and Ronald 1972). In addition, the presence of a Purkinje shift in this species implies that harp seals have at least two types of photopigments with different absorption spectra (Lavigne and Ronald 1972).

Cetaceans show similar optical adaptations to those of pinnipeds, in that the vision is shifted to greater sensitivity at shorter (more blue) wavelengths, presumably because the underwater light

field becomes shifted toward shorter wavelengths at depth (Griebel and Schmid 2002, Griebel et al. 2006). Spectral absorption maxima range from 481 nm in the deep-diving beaked whales to 486 nm in the coastally feeding bottlenose dolphin to 496 nm in the bottom-feeding gray whale (Griebel and Schmid 2002).

In general, marine-mammal eyes show little change in sensitivities from dark-adapted to light-adapted eyes (the Purkinje shift), in contrast to those for terrestrial mammals (Watkins and Wartzok 1985). For example, the Purkinje shift in terrestrial mammals from dark-adapted to light-adapted eyes generally is on the order of 45–59 nm toward longer (more red) wavelengths. In contrast, the Purkinje shift in marine mammals typically is on the order of only 4 nm toward longer wavelengths. This reduction in the degree of shift from scotopic to photopic eyes in marine mammals probably reflects the reduced wavelengths of light that are available underwater.

Behavior

Migration/Movements

Marine mammal migration and movement may be influenced by light levels. Movements of sperm whales (*Physeter catodon*) have been shown to be affected by light *via* lunar phases (Wright 2005). An analysis of mass strandings of sperm whales in the British Isles indicates a significant lunar periodicity in strandings, with the highest number occurring during the New Moon and First Quarter and the fewest strandings occurring during the Full Moon and Third Quarter (Wright 2005). Surprisingly, this pattern was opposite that seen in eastern Canada, where the highest number of strandings occurred during the Full Moon; however, the sample size for Canada was much smaller than that for the British Isles. Wright (2005) speculated that these strandings somehow are related to the vertical migration of their prey, which in turn is affected by light levels *via* lunar cycles. Higher light levels near the Full Moon would make prey stay deeper in the water column, perhaps making foraging more difficult for calves in particular. However, such a proposed model would result in more dead strandings near the Full Moon (as was seen in Canada), rather than the New Moon (as was seen in the British Isles).

The behavior of Galápagos fur seals (*Arctocephalus galapagoensis*) also has been shown to be affected by lunar phases, suggesting an effect of natural light (Trillmich and Mohren 1981, Horning and Trillmich 1999). These authors found that those fur seals hauled out in greater numbers near the Full Moon than at other times.

Harbor seals, in at least some locations, also show lunar effects on some aspects of activity patterns (Watts 1993). In British Columbia, harbor seals hauled out at night in significantly smaller numbers (i.e., they stayed at sea more) near the Full Moon during the summer; however, no lunar pattern was evident during the winter. This lack of a wintertime lunar effect on activity patterns may reflect the fact that this area is considerably cloudier at that time than it is during the summer. The fact that more harbor seals stay at sea at night during the Full Moon in the summer suggests that they are using moonlight as an aid in foraging.

Research by Elsner et al. (1989) indicates that ringed and spotted seals use a variety of cues to find breathing holes in ice while swimming underwater. The first method involves using visual cues to locate holes while swimming underwater in an exploratory fashion; secondary cues involve auditory and vibrissal sense. The seals were able to see distant breathing holes at distances of up to ~40 m, depending on the incident light. The primacy of vision in locating breathing holes is supported by studies showing that blindfolded seals could not find new breathing holes without auditory aids and that some light always is visible to underwater eyes looking upward, even in apparent darkness. Pinnipeds also employ noises ("click trails") under water for a variety of reasons, one of which is foraging in reduced light levels (Renouf and Davis 1982). Steller sea lions (*Eumetopias jubatus*) and harbor seals have been shown to use click trails to help catch fish in total darkness (Renouf and Davis 1982). Ringed seals are another species that lives and forages for a large part of the year in total darkness (Kelly and Wartzok 1996), suggesting the use of additional cues for foraging and migration.

Circadian and Circannual Clocks

Terrestrial mammals have well-regulated circadian clocks (Beier 2006). These circadian body clocks are about 23–25 h for most vertebrates, with a few species ranging between 21 and 27 h. Because they are not exactly 24 h long, circadian clocks must be reset daily through environmental cues, usually daylight. This daily resetting of circadian clocks is called entrainment, the daily cue is called a *Zeitgeber*, and the stimulus itself appears to be the change in the quantity and perhaps spectral quality of twilight (light levels characteristic of dawn and dusk; Foster and Provencio 1999). In vertebrates, the circadian clock is not entrained by the rods and cones on the retina, but instead by a special photoreceptor system that is separate. It also lies in the retina but sends signals to a different part of the brain (the suprachiasmatic nuclei) via a separate neural system. Resetting of circadian clocks requires both more light (1–100 lux) and

longer exposure to light (0.5–100 min) than is required to form a visual image. However, the circadian clock is more sensitive to twilight-level intensities of light than it is to full sunlight. As a result, artificial lights that have illumination levels and durations similar to those of twilight have the potential to disrupt circadian clocks in mammals (Foster and Provencio 1999). Light levels and entrainment also affect the production of some hormones, most notably melatonin, which mediates most activity patterns and behavioral/physiological rhythms in mammals and suppresses the growth of tumors. Even a very small amount of light may suppress the production of melatonin in mammals, thereby negatively affecting their circadian patterns.

Circadian rhythms and the effects of various lighting regimes on activity patterns of various mammals have been studied. Kavanau and Ramos (1975) found that, under 24-hour "normal" light regimes (i.e., ~12 h of daylight and ~12 h of darkness), red foxes (*Vulpes vulpes*) were over 90% nocturnal, suggesting that their visual system was best adapted for dim light, although they also can see well in bright light. The arctic fox was mostly nocturnal, being active late at night and early into the day, a result that differs from studies that suggest that the species is arrhythmic in the wild (Kavanau and Ramos 1975). These authors suggest that being arrhythmic is an adaptive behavior in this species because of the extremes of day length to which this species is exposed and suggested that it is adapted to both high and low light levels. Carnivores may have the most adaptable visual system of all vertebrate groups because it would be to their advantage to be able to forage throughout the day and night (Kavanau and Ramos 1975). Hence, they commonly have both rods and cones in their retinas, allowing them to be active at any time.

In North America, black bears (*Ursus americanus*) are primarily diurnal and crepuscular in activity patterns (Ayres et al. 1986, Bridges et al. 2004), suggesting that vision is extremely important in foraging. However, when there is human-caused disturbance or when brown bears are present, black bears become nocturnal (Reimchen 1998). Studies of activity patterns of black bears foraging on salmon streams found that most (98%) foraging activity occurred at night rather than the daytime (Reimchen 1998). There were two possible reasons given for this pattern. First, black bears foraging during the daytime tended to avoid visual contact with other foraging bears, whereas they often foraged near each other at night. Second, salmon showed a greater avoidance of activity on the shoreline during the daytime, thus increasing the bears' foraging success rate at night. The author concluded that brown bears have some effect on black bear activity patterns but that increased foraging success is the primary reason for higher nocturnal activity in black bears on salmon streams.

In North America, brown bears (*Ursus arctos*) also are primarily diurnal in activity patterns (Klinka and Reimchen 2002). However, a study of brown bears foraging on a salmon stream found that, although they foraged primarily during the late afternoon, these bears also foraged throughout the entire day and night. Further, foraging efficiency was significantly higher at night than during the day. Such a shift in foraging patterns suggests that bears switch from visually-driven foraging during daylight hours to other sensory modes at night.

Pinnipeds also vary in time of day for foraging. For example, Antarctic fur seals generally are nocturnal foragers (Croxall et al. 1985, Boyd and Croxall 1992, Watanabe et al. 2004), whereas some pinnipeds (harbor seals, Weddell seals, northern elephant seals, California sea lions) appear to forage both in the day and at night (Kooyman 1975, Leboeuf et al. 1988, Feldkamp et al. 1989, Coltman et al. 1997). Baikal seals (*Phoca sibirica*) also forage throughout the day and night, probably because their prey undergoes diel vertical migrations (Watanabe et al. 2004). Instrumented wild seals studied during the summer exhibited deeper dives near dusk and dawn and shallower dives in the middle of the night. During the daytime, they exhibited mostly uniform dives, suggesting that they were foraging in a deep layer where the prey was concentrated. Haulout activities of ringed seals also exhibit circadian patterns, although these patterns vary seasonally (Kelly and Quakenbush 1990). Radio-tagged seals studied in March and April had mean haulout times between 1800 and 0230 (i.e., during the evening and much of the night), whereas seals studied in May and June had mean haulout times from 1030 to 1630 (i.e., during the daytime).

Little study of activity patterns of arctic whales has been conducted. One study of diving activities in bowhead whales indicated that there is no consistent diel pattern of diving duration and depth and in other aspects of diving (Krutzikowsky and Mate 2000). The authors speculated that this lack of diel patterns reflected the lack of vertical migration in the whales' prey during the arctic summer. In contrast, sperm whales have a pronounced circadian pattern of feeding by initiating a regular series of dives that begin around sunset and continue throughout most of the night (Watkins et al. 1993), suggesting that they feed on vertically-migrating prey that move toward the surface at night. Another pattern is observed in transient killer whales (i.e., those that prey on marine mammals), which commonly forage during the daytime (Baird and Stacy 1988, Ljungblad and Moore 1983, Lowry et al. 1987).

Circadian rhythms of activity also are common in antarctic species. For example, Crabeater seals (*Lobodon carcinophagus*) in the Antarctic also show diel patterns of dive times and diving depths, with a clear preference for foraging and deeper diving during crepuscular periods than at night (Bengtson and Stewart 1992). This distinctive diel pattern of foraging activity has been explained as a response to diel movements and predator avoidance in their principal prey, the Antarctic krill.

Circannual clocks reflect an endogenous clock that has a periodicity of about 1 year (Beier 2006). These circannual clocks affect a variety of life-history parameters, including reproduction, hibernation, migration, hormones, body mass, and variations in circadian activity patterns throughout the year. Unfortunately, these clocks are poorly understood and poorly studied, primarily because the length of time required for such studies is great. To date, the effects of light have been examined for only three species. Light appears to be the only *Zeitgeber* or daily cue for circannual clocks for the two domesticated/inbred species (domestic sheep and golden hamster), whereas temperature and, to a lesser extent, light regulate circannual patterns in the wild golden-mantled ground squirrels (*Spermophilus lateralis*). Hence, light is a cue, but probably not the only clue, in regulating circannual cycles (Beier 2006).

Feeding

Experiments on captive California sea lions indicate that they swim on their backs beneath their prey and then suddenly change course and hit the prey from below at a high rate of speed (Hobson 1966). This suggests that they are visually aided by the silhouette of the prey against a lighter sky. At the same time, the sea lion would appear dark against a dark background, making it difficult for their prey to detect them.

Yurk and Trites (2000) described a similar pattern of swimming on their backs by harbor seals under artificial lights at a bridge and indicate that a similar use of backlighting occurs in Weddell seals (Davis et al. 1999). Hence, it appears that pinnipeds may generally use backlighting for locating dark prey against a lighter background. Research by Wartzok et al. (1989) and Davis et al. (1999) on Weddell seals found that they were attracted to under-ice areas with greater light caused by less snow cover. Seals preferentially fed on under-ice fishes in those areas, suggesting that they were using backlighting to locate the prey. This use of available patches of light and backlighting suggests that arctic seals may employ similar techniques when foraging on under-ice fish species such as Arctic cod (*Boreogadus saida*) or in locating breathing holes. This attraction

to light patches, however, may cause ringed seals to swim to locations that are not available as breathing holes (Wartzok et al. 1992).

Responses of foraging ringed seals to light levels have been shown to be highly variable within the species (Kelly and Wartzok 1996). Collectively, various seals studied together foraged throughout the day and night, but the frequency and/or depth of foraging varied with light levels for four of the five animals studied. For example, two of the four seals responding to light levels dove more often in daylight than in twilight or darkness, whereas one dove more often in darkness and twilight than in daylight. Likewise, one seal dove more shallowly during darkness than during other light levels, whereas another one dove more shallowly during twilight than during other light levels. Hence, although individual animals showed significant periodicity in aspects of diving behavior, ringed seals as a whole showed no periodicity, suggesting that activity patterns are under endogenous, rather than exogenous, control.

Fristrup and Harbison (2002) presented multiple lines of evidence for two hypotheses about foraging of sperm whales. First, they presented evidence that sperm whales use vision, rather than echolocation, to locate and capture prey at mesopelagic depths. Second, they presented evidence that sperm whales use stimulated bioluminescence to lure prey into their mouths.

Hobson (1966) also indicated that otariids such as northern fur seals (*Callorhinus ursinus*) forage at night on bioluminescent prey species such as lanternfishes and squids. He suggested that bioluminescent plankton sometimes light up the water sufficiently for predators to identify prey species simply based on shape in the luminescent water.

Effects of Artificial Light

Influence of Ambient Illumination

Moonlight has been shown to have an effect on activities of a variety of nocturnal terrestrial mammals, including arctic lagomorphs (rabbits/hares), fruit bats and predatory bats, and temperate rodents (Beier 2006). Under bright moonlight, nocturnal mammals reduce their use of open areas, reduce foraging activity, restrict movements, and concentrate most movements (especially those involving foraging) during the darkest periods of the night. This latter behavioral change is possible because the moon does not rise and set at the same time every night, resulting in at least some periods of darkness every night. However, moonlight has little effect on certain nocturnal mammals, primarily bats and woodland rodents (the latter of which

never spend time in the open) and on a few other species such as the white-tailed deer (*Odocoileus virginianus*).

Foraging Behavior

Most terrestrial nocturnal mammals would be expected to be negatively affected by artificial lighting (Beier 2006). This group includes those species that are negatively affected by bright moonlight because it inhibits their ability to forage, e.g., rodents and lagomorphs. In addition, those species that forage under low-light (not no-light) conditions, such as crepuscular periods, may have greater difficulty foraging near artificial lighting. The addition of illumination from artificial lights to illumination from a rising or setting sun and/or a Full Moon may raise light levels so much that available foraging periods become too short for the animal to maintain body mass. On the other hand, mammalian species that prey on nocturnal mammals might benefit from greater light availability as a result of the addition of artificial light.

Yurk and Trites (2000) reported on a pair of harbor seals that had learned to forage at night in the artificial lights under a bridge in Courtenay, BC, Canada. These seals fed extensively on out-migrating salmon smolts in the spring. The seals entered the river at dusk and waited in the shadowy part of the illuminated area under the bridges. The light–dark shadow boundary was well defined, especially under the upper of the two bridges, and this is the bridge where nearly all of the seals concentrated. The seals were observed with a red-filtered spotlight that apparently had no effect on numbers but did affect behavior—the seals often moved away from the red light and "seemed sensitive" near the light–shadow boundary of the spotlight. This response was in contrast to the research of Olesiuk et al. (1995), who earlier saw no evidence of a response to red light by harbor seals in the same river. They altered the availability of artificial lighting as an aid to nocturnal feeding by turning off lights on the bridge where seals concentrated. Turning off the lights initially caused a dramatic decline in the number of seals foraging near the bridge, but the seals eventually returned on subsequent nights (actually increasing to numbers higher than the original number seen), indicating that they became habituated to the lighting change. Apparently, the seals learned to use the residual lighting from the nearby city to help catch the salmon smolts.

Light may be used by other pinniped species. For example, Bonnot (1932) reported on a California sea lion that foraged at night on flying fishes that were concentrated around a light next to his vessel. The female swam on its back under the flying fish, then rapidly swam upward to grasp a fish—the same behavior observed in captive California sea lions (Hobson 1966).

Risk of Predation

Haulout behavior of Galápagos fur seals has been shown to be affected by lunar phases, suggesting an effect of natural light (Trillmich and Mohren 1981, Horning and Trillmich 1999). The authors speculated that these fur seals haul out in greater numbers near the Full Moon than at other times because doing so reduces the risk of predation by sharks because the greater ambient moonlight allows sharks to see more easily. Conversely, if the predators are terrestrial (e.g., brown bears near hauled-out seals), artificial lights would increase the possibility of predation at night because it would be easier for the predators to see the prey.

Biological Clock Disruption

Both short-term (circadian) and long-term (circannual) biological clocks may be disrupted by artificial light. Beier (2006) speculated about the many ways in which artificial lighting might affect circadian clocks. The greatest problems would result from the modification of circadian patterns that have evolved to maximize life-history attributes such as foraging efficiency or to reduce the risk of predation. Artificial lighting also could affect the production of melatonin and other hormones and could cause an individual to be out of circadian and physiological phase with conspecifics that were in an area that was not illuminated. In this context, even brief and fairly bright lights have been shown to shift biological clocks in mammals by 1–2 h (Halle and Stenseth 2000). In addition, the suppression of melatonin alters most biological rhythms in mammals and can reduce an individual's ability to suppress tumor growth. Beier emphasized that these effects had been shown in captive populations but had not been experimentally demonstrated in the wild.

Movement, Dispersal, and Activity

Artificial lighting may affect daily activity patterns in mammals. In San Francisco Bay, harbor seals that haul out on Castro Rocks have been shown to be disturbed at night by light from a nearby pier (Grigg et al. 2002). Facility lights also have been identified as potential attractants for polar bears because they illuminate a large area and are detectable at a great distance. These lights are used both for worker visibility and to help them detect polar bears (Perham 2005). A study in Canada, however, indicated that polar bears are not attracted to areas lit with high-intensity lights. In addition, there was some evidence that certain types of lights (e.g., strobe lights used to reduce bird strikes) may actually reduce the ability of workers to detect bears at a distance (Perham 2005).

In a study of responses of whales to human activity off of Cape Cod, Massachusetts, results indicated that a variety of species may respond negatively to light from brightly-reflective objects such as oceanographic cables and equipment housings (Watkins 1986). Initially, whales exhibited startle reactions and avoidance of these bright objects. However, they appeared to habituate quickly, sometimes moving close enough to touch the objects. These responses were visually driven because the same whales came very close to the objects at night but responded negatively to them during the day. Results also indicated that flat black paint consistently reduced the negative responses of whales to these objects.

Risk in Offshore Development

Information was limited regarding the potential effects of lighting from offshore development on marine mammals. Pidcock et al. (2003) conducted a risk analysis of the effects of a variety of factors, including artificial lighting, on Southern right whales, Australian sea lions, and other cetaceans from mining and oil and gas exploration in the Great Australian Bight Marine Park Marine Mammal Protection Zone, off of southcentral Australia. A variety of potential factors was scored from 1 (insignificant consequences) to 5 (catastrophic consequences) in terms of probable effects on these marine mammal taxa based on literature information. They concluded that the primary impacts of lighting during exploration would occur as a result of night work and flaring of natural gas, and during production as a result of light from rigs and ships. However, the overall risk of impact was expected to be low. The risk-assessment models for both exploration and production predicted that the impacts from artificial light would be insignificant and would occur with low to minor likelihood for all taxa.

In relation to the Stybarrow Development project off northwestern Australia, BHP Billiton (2005) concluded that there was no evidence that artificial lighting negatively affected migratory, feeding, or breeding behaviors of cetaceans. They reasoned that cetaceans generally used acoustic rather than visual senses to monitor their environment. Also, the presence of lights during development and production of the White Rose Oilfield offshore of Newfoundland, Canada, was expected to have a low effect on marine mammals (Husky Oil Operations Ltd. (2001).

1.3.1.2 Birds

Abundance & Use of Area

Several species-groups of birds inhabit and/or migrate through the Beaufort and Chukchi seas. These include waterfowl (Anseriformes, family Anatidae), loons (Gaviiformes, family Gaviidae), tubenoses (Procellariiformes, family Procellariidae), cormorants (Pelecaniformes, family Phalacrocoracidae), shorebirds (Charadriiformes, families Charadriidae and Scolopacidae), jaegers (Charadriiformes, family Stercorariidae), gulls and terns (Charadriiformes, family Laridae), alcids (Charadriiformes, family Alcidae), and corvids (Passeriformes, family Corvidae); Divoky 1984, Johnson and Herter 1989, Fischer and Larned 2004). Other groups, such as ptarmigan (Galliformes, family Phasianidae), nest along the coast but do not migrate through the area (they are resident), whereas others (e.g., raptors [Falconiformes] and passerines [Passeriformes, many families]) commonly nest in the area but do not commonly migrate over these arctic waters. Overall, birds are present in these waters from April or May to early November.

Waterfowl make up by far the largest group in the study area: at least four species of geese (brant *Branta bernicla*, Canada goose *Branta canadensis*, snow goose *Chen caerulescens*, greater white-fronted goose *Anser albifrons*), one species of swan (tundra swan *Cygnus columbianus*), at least one species of dabbling duck (northern pintail *Anus acuta*), and at least eight species of diving ducks (greater scaup *Aythya marila*, surf scoter *Melanitta perspicillata*, long-tailed duck *Clangula hyemalis*, common eider *Somateria mollissima*, king eider *Somateria spectabilis*, spectacled eider *Somateria fischeri*, Steller's eider *Polysticta steller*, red-breasted merganser *Mergus serrator*) regularly breed along and migrate through the coastal and offshore parts of these seas.

Three species of loons (red-throated *Gavia stellata*, Pacific *Gavia pacifica*, and yellow-billed *Gavia adamsii*) are common breeders on the Arctic Coastal Plain and migrate through Beaufort and Chukchi waters. The tubenoses in this area are visitors that breed elsewhere; they primarily are represented by northern fulmars (*Fulmarus glacialis*), which breed elsewhere in Alaska, and by short-tailed shearwaters (*Puffinus tenuirostris*), which breed in Australia and winter in Alaska during the boreal summer. The one cormorant occurring in the area of interest is the pelagic cormorant (*Phalacrocorax pelagicus*). Numerous species of shorebirds nest in this area and migrate along or over the ocean; these include three species of plovers (family Charadriidae) and

many species of other shorebirds (family Scolopacidae). Some actually migrate from Russia over high-arctic areas near the North Pole Russia (Flock 1973). There are three species of jaegers nesting along and migrating over the waters of the Beaufort and Chukchi seas: pomarine (*Stercorarius pomarinus*), parasitic (*Stercorarius parasiticus*), and long-tailed (*Stercorarius longicaudus*). A diverse suite of larids occur in this area, with at least six species of gulls (glaucous *Larus hyperboreus*, herring *Larus argentatus*, ivory *Pagophila eburnea*, Ross's *Rhodostethia rosea*, and Sabine's *Xema sabini* gulls and black-legged kittiwake *Rissa tridactyla*) and of the arctic tern (*Sterna paradisaea*) nesting and migrating in the area of interest. Only five species of alcids breed in the Chukchi and Beaufort seas in numbers: common (*Uria aalge*) and thick-billed (*Uria lomvia*) murres, black guillemot (*Cepphus grille*), and horned and tufted puffins (*Fratercula corniculata* and *F. cirrhata*). These species breed primarily in the Chukchi Sea because of a lack of suitable nesting habitat in the Alaska Beaufort Sea. In addition, some rarely breeding or non-breeding alcid species such as Kittlitz's murrelet (*Brachyramphus brevirostris*) and crested auklet (*Aethia cristatella*), respectively, occur in the Chukchi Sea (Divoky 1987, Divoky and Springer 1988, Day et al. 1999), moving north from areas where they are more common. The only corvid in this area is the common raven (*Corvus corax*), which has expanded its breeding range outward on the Arctic Coastal Plain by nesting on buildings and even occurs out onto the Beaufort Sea on artificial offshore drilling islands such as Northstar Island (Day, pers. observation).

Of the bird species observed in the area, two are protected under the Endangered Species Act (ESA): the Steller's eider (Alaska-nesting population) and the spectacled eider (Arctic Alaska population). Some other species are either Candidate Species for protection under the ESA (e.g., yellow-billed loon, Kittlitz's murrelet) or have declining populations (e.g., long-tailed duck, red-throated loon, ivory gull).

Life History

Anatomy and Physiology of Vision in Birds

Avian vision operates much the same way that mammalian vision does, although birds are far more dependent on vision because few have the sense of olfaction and essentially none have the ability to sense the environment by other senses such as echolocation (Walls 1942, Gill 1995, Beason 2003). In fact, vision is so important to birds that eyes occupy a significant proportion of the mass of a bird's head, and the eyes of some birds (which are much smaller than humans) are as large as those of humans—owls and eagles, for example (Walls 1942, Gill 1995). Indeed,

birds are the most visually oriented of all vertebrate classes in that most of their activities require precise visual discrimination (Hodos 1993). In contrast to mammals, however, most birds have eyes with limited powers of rotation within the sockets, and birds do not have a vascularized retina, instead supplying the retina with nutrition and oxygen through the pecten. Most nocturnally adapted birds also have a reflective layer, the *tapetum*, behind the retina, similar to that of mammals.

Also similar to mammals, birds have both rods (scotopic-adapted cells) and cones (photopic-adapted cells) in the retina. Most, if not all, birds have well-developed color vision, with the cones actually being colored, unlike those of mammals (Walls 1942, Nalbach et al. 1993, Varela et al. 1993, Gill 1995, Hart 2001, Beason 2003). At least some birds have up to six types of cones (four are colored and two are pale or colorless), with one type allowing them to see in the short-wavelength, ultraviolet (UV) part of the spectrum. Birds cannot see in the long-wavelength (infrared) spectra, however (Parrish et al. 1981, 1984; Varela et al. 1993, Blackwell 2002, Beason 2003). For example, there is evidence that hummingbird-adapted flowers have markers that are visible in UV light, and some species of birds have plumage that glows brightly in UV light. In addition, predatory species, such as Eurasian kestrels (*Falco tinnunculus*) apparently can see scent marks created by rodents only in UV light, suggesting a way in which raptors can detect patches of high densities of food when visiting an area for the first time (Viitala et al. 1995). In fact, it is possible that all birds can sense UV light, given the great taxonomic diversity of bird species possessing the ability to see it (Gill 1995, Beason 2003). In addition to these main types of single cones with colored photopigments, birds also have a double cone whose function is unknown but may be used to see polarized light or magnetic fields (Beason 2003) and/or for the detection of movement (Hart 2001). There also is recent evidence that interspecific differences in abundances of particular photoreceptors in various parts of the avian eye reflect differences in ecology more than they reflect phylogenetic relationships (Hart 2001). The fact that multiple carotenoids occur in mixtures in different cones suggests within-cell adaptations for seeing certain wavelengths of light (Varela et al. 1993). However, there is great speculation about the functions of oil droplets in avian eyes, with the various hypotheses not necessarily being mutually exclusive (Varela et al. 1993, Blackwell 2002).

Birds have a wide range of sensitivity to light of various wavelengths, ranging from the ultraviolet (~320–400 nm) to the red (>700 nm), exceeding the range that is visible to humans (400–700 nm; Nalbach et al. 1993, Blackwell 2002). In all birds that have been studied, the

photopigment that absorbs the longest wavelengths of light (~570 nm) is by far the most abundant (Varela et al. 1993). This pigment is iodopsin, and it appears to be the dominant photopigment in birds.

Nocturnally foraging species tend to have eyes that are structurally modified for seeing well at night. For example, birds that are adapted to visual foraging at night have more rods and a higher rod-to-cone ratio than do species using tactile foraging at night (Nalbach et al. 1993, Rojas de Azuaje et al. 1993). In addition, pigments of the rods of nocturnal bird species are highly concentrated and become saturated (i.e., become unresponsive) only with great difficulty (Walls 1942). Birds that are adapted to low light levels also often have large eyes (e.g., the large, tubular eyes of owls) and/or large pupils (Storer 1987, Martin 1993, Rojas de Azuaje et al. 1993, Day et al. 2003).

Optical Capabilities

Little research has been conducted on avian vision in marine-oriented birds. One aspect that has been investigated is corneal adaptations in tubenoses to minimize effects of refraction of water at the air–eye interface (Warham 1996). Apparently, most of the refraction in Manx shearwater (*Puffinus puffinus*) eyes occurs at the lens, rather than at the cornea, suggesting an adaptation for improving visual performance while diving.

Eye structure in diving bird species may be strongly modified. For example, king penguins (*Aptenodytes patagonicus*) which dive for foraging during the day to depths of 100–300 m and at night to depths <40 m, have large eyes that are long, large pupils, and a cornea with a low radius of curvature (Martin 1999, Blackwell 2002). The first two of these characteristics are similar to those of nocturnally foraging owls and are very different from those of diurnally foraging bird species. The flattened cornea is an adaptation to aquatic vision (Martin 1993, Blackwell 2002). In addition, these penguins have pupils that constrict to a pinhole in bright light (as do those of diving mammals), although the pupil becomes square, rather than the slit that is seen in mammals. This tendency for stopping down the pupil to pinhole size is not only an adaptation for minimizing damage to sensitive nocturnal photoreceptors (i.e., rods), it also is viewed as a way to preadapt the eyes to low light levels where the birds are going to be feeding. The pupils are stopped down so much in bright light that the amount of light hitting the retina is similar to that at depth. Hence, the small pupils seen at the water's surface allow the birds to accommodate rapidly to low light levels experienced underwater. Finally, these penguins also have extremely sensitive

eyes, which enable them to see at depth in light levels that are equivalent to minimal starlight and even can see in light levels that are below the visual threshold for humans.

The photopigments in the eyes of diving birds also may be adapted to particular wavelengths of light (Varela et al. 1993). For example, the iodopsin in the eyes of penguins is shifted in sensitivity of ~570 nm (green-yellow) to the shorter wavelength of ~543 nm (green), matching the shift in available light to the shorter-wavelength blue light found in their environment.

Other adaptations that have been studied include those of the eyes of tubenoses to night-vision (Brooke 1990). The density of rods in the eyes of the nocturnal Manx shearwater was not different from the density in the eyes of the diurnal northern fulmar; however, Brooke indicated that the fulmar may be more nocturnal at foraging than previously was thought. Another adaptation to nocturnality is the fact that the eyes of nocturnal tubenoses have a high proportion (~60%) of colorless cones, as is seen in other nocturnal birds, whereas the proportion in diurnal birds is low (~7% in the northern gannet, for example). The eyes of nocturnal shearwaters lacked the reflective *tapetum* seen behind the eyes of other nocturnal birds. However, the eyes of nocturnal tubenoses shine brightly, suggesting possible reflection from the retinal surface itself. Hence, Brooke concluded that the eyes of Manx shearwaters show some adaptations for nocturnal vision but that these adaptations are not as dramatic as might be expected from their nocturnal activities on colonies. However, perhaps improved olfaction aids in nocturnal navigation on the colony, so the eyes do not need to be as well adapted as might seem otherwise.

Little has been studied about optical adaptations to nocturnality in alcids (Gaston and Jones 1998). The conclusion of these authors, however, is that the eyes of alcids are extremely well adapted to vision in low light. Their evidence for this conclusion is that some alcids (e.g., common murres) forage in turbid waters near some colonies and that other species (e.g., black guillemots *Cepphus grylle*) winter at such high latitudes that they are foraging in darkness for much of the year. Another bit of evidence is the eyes of the Kittlitz's murrelet, which are proportionately larger than those of marbled murrelets (*Brachyramphus marmoratus*), probably as an adaptation for foraging in highly turbid glacial water (Day et al. 2003).

Behavior

Migration/Movements

Birds use a variety of cues to aid in migrating between breeding and wintering areas and *vice versa* (Alerstam 1990, Able 1995, Gill 1995, Kerlinger 1995, Weidensaul 1999). These cues are needed because wind, in particular, often moves birds in directions they do not want to go, thus displacing them geographically (called wind drift). These cues include sunlight and sunrise/sunset, starlight, topography, maps (landmarks), and internal compasses. In many cases, birds use a variety of cues in combination (especially magnetic compasses and celestial navigation; Wiltschko and Wiltschko 2003) or sequentially (Alerstam 1990), rather than relying on only one cue or another for an entire migration. Unfortunately, little is actually known about the exact ways in which birds use these various cues during migration. In addition, there is evidence that some birds are sensitive to gravitational changes caused by lunar cycles, but many details are poorly known at this point (Alerstam 1990).

Birds follow internal compasses in some cases, with up to three types of magnetic receptors involved (Wiltschko and Wiltschko 1995, Beason 2003). Some birds have been found to contain magnetic structures in the inner ear, elsewhere in the head, or even in the neck muscles, that function much as compasses do (Alerstam 1990, Beason 2003, Wiltschko and Wiltschko 2003, Mouritsen et al. 2005). For example, bobolinks (*Dolichonyx oryzivorus*) have both iron oxide and melanin on the upper beak in and near the ophthalmic nerve that is responsive to magnetic stimulation. Small crystals of magnetite also have been found in the heads of homing pigeons, sometimes in association with what is suspected to be ferritin, a protein that contains iron. Alternatively, the ferritin may be a protein that actually creates the magnetite (Alerstam 1990). Some birds have magnetite in the muscles of the neck, which are supplied with a large number of nerves, although some recent experiments question the importance of magnetite as an aid in navigation and instead suggest that some biochemical processes are used that are affected by magnetic fields (Alerstam 1990). However, continuing work by Wiltschko and associates indicate that magnetite clearly is involved in orientation of some species (e.g., Kirschvink et al. 1985, Wiltschko and Wiltschko 1995). For example, experiments have shown that magnetic fields can affect neural responses in birds' vision, but only if the eyes are illuminated, suggesting that the birds can somehow see magnetic fields through polarized light or other wavelengths (Alerstam 1990, Kerlinger 1995).

The avian magnetic compass is responsive to specific wavelengths of light, with disorientation occurring under red light (especially if the bird is not used to the red light) and yellow light, but no effect occurring under green light. Indeed, it appears that light of a particular wavelength is needed for magnetic-compass orientation to work (Beason 2003; Wiltschko et al. 1993, 2004; Wiltschko and Wiltschko 1999, 2001; Muheim et al. 2002). Photoreceptor molecules called cryptochromes recently have been discovered in mammalian eyes and are suggested to be similar to the structures involved in a photoreceptor-based magnetic-orientation system in birds (Ritz et al. 2000).

Sunlight and sunrise/sunset locations are cues that also aid in navigation during migration. Sunlight cues (i.e., the sun compass) involve the use of an internal circadian clock and the sun's position. Because the sun changes position by 15° of arc/h, the internal clock can be used to correct the sun's position in the sky to a bearing of True South (Hamilton 1962, Alerstam 1990, Weidensaul 1999). Sunrise and/or sunset also may be used to refine or reset migration compasses, such that some birds use sunset (or polarized light that occurs near sunset) as a way to reset their internal compasses in conjunction with magnetic compasses and/or stars (Kerlinger 1995). For example, savannah sparrows (*Passerculus sandwichensis*) have been shown to use the position of the setting sun to reset directional compasses every night. In fact, the accuracy of migratory orientation is much lower when sunset is obscured than when it is visible. Further, the birds' directional compass can be altered by as much as 90° if the location of sunset is altered through the use of mirrors.

Starlight is a celestial cue (i.e., stellar compass) that also may aid in navigation during migration (Alerstam 1990, Gill 1995, Weidensaul 1999, Wiltschko and Wiltschko 2003). Many birds are strictly nocturnal migrants, requiring a strong sense of stellar cues (Emlen 1967a, 1967b, cited in Wiltschko and Wiltschko 2003). The importance of such cues is reflected in the fact that many birds become disoriented and attracted to other sources of light when the sky becomes cloudy or foggy (Overing 1936, 1938; Alerstam 1990). Similar disorientation of nocturnally migrating waterfowl and shorebirds during overcast conditions has been seen in the Alaska Beaufort Sea, with migrating eiders showing greater confusion around a Full Moon when it was not visible than at other times (Day et al. 2005). In addition, several studies involving caged birds in planetariums have found that many species of nocturnal migrants change directional orientation with the locations of stars, with some species even using the North Star as an indication of True North (Alerstam 1990).

Topographic cues used by birds may be varied. For example, some cues such as mountain ranges or shorelines often form what are called leading lines, in that migrating birds approach them and then follow them for long distances. Mountain ridges, in particular, form leading lines for raptors, as indicated by the importance of raptor-counting and -banding sites such as Hawk Mountain, Pennsylvania, and the Front Range of Utah. Shorelines also tend to concentrate birds that do not want to be pushed offshore (e.g., terrestrial birds), requiring that they set down near the coast if wind drift is going to push them farther offshore, or concentrate water-oriented birds that do not want to be pushed ashore. If they are wide enough, water bodies also may be important barriers that concentrate some groups of birds. For example, soaring birds such as raptors and storks from Eurasia must cross open water to get between breeding areas in Eurasia and wintering areas in Africa. Because they cannot get uplift over the ocean from rising air, they must concentrate and cross at the narrowest water barriers including the Bosphorus in Turkey (~1 km wide; 1,000,000+ raptors and storks), and the Strait of Gibraltar (~14 km wide; ~750,000 raptors and storks; Finlayson 1992). Similar concentrations of hawks trying to avoid overwater flight occur in Veracruz, Mexico, and Panama City, Panama.

Internal maps and visual landmarks also are used in some cases as navigational aids (called piloting; Mouritsen 2003), although how these are used is one of the least-understood aspects of migration biology. For example, birds flying south in the fall adjust better for wind drift (i.e., they fly a better southerly bearing) if they are over the Hudson River Valley than if they are away from it (Kerlinger 1995). A variation of the map hypothesis is the vector-navigation hypothesis, in that birds have an innate time program coupled with an innate directional program; in other words, some birds are programmed to fly a certain direction in the fall for a certain length of time (Alerstam 1990, Mouritsen 2003). Unless birds in their first migration are able to follow other, experienced birds visually, they must have some sort of innate time/direction navigation system that gets them to the correct location. Indeed, there is strong evidence for such a system in a variety of European bird species (Kerlinger 1995, Mouritsen 2003, Wiltschko and Wiltschko 2003); presumably, such a system is important in many North American birds, although studies have not been conducted.

Circadian and Annual Clocks

Birds have circadian and circannual rhythms that are largely similar to those of mammals (Gill 1995). These circadian rhythms affect various aspects of daily life such as sleeping, feeding,

metabolic activity, alertness, and body temperature, whereas the circannual rhythms affect various aspects of natural history such as reproduction, molt, and migration.

Many aspects of circadian rhythms in birds are similar to those of mammals. Birds possess an innate circadian clock that is near, but not exactly, 24 h long (Gill 1995). Hence, daily light/dark cycles actually are important cues needed for resetting the internal clocks of birds to an appropriate 24-h period. These circadian rhythms also are important in the proper functioning of the sun compass, which is needed for proper orientation during migration. Importantly, circadian rhythms include a brief daily period of photosensitivity during which the circadian clock is reset. Although not able to determine with certainty, Gill (1995) believed that this daily period of photosensitivity is similar to that seen in mammals.

Circannual rhythms in birds also function much as they do in mammals. Again, circannual rhythms are nearly, but not exactly, 1 year long, resulting in drift of phenology in some aspects of life history if the birds do not have sufficient external cues from natural light (Gill 1995). Seasonal daylength probably is the most important cue entraining circannual rhythms, similar to the importance of natural light/dark cycles to circadian rhythms. In spring, increasing daylength causes hormonal changes that result in the prenuptial molt, building of pre-migratory fat, migration to breeding areas (especially in high-latitude species), and reproduction once the bird arrives at the breeding grounds. Changes in daylength are believed to be measured by the birds' internal clocks. Short days of mid-winter are needed to reset birds' annual clocks through the development of a photorefractory (insensitive) period, especially in migratory higher-latitude birds.

Birds do not measure daylength visually, as mammals do, but instead do so with special receptors in the hypothalamus of the midbrain (Gill 1995). These receptors do not need to have visual information sent to them via the eyes, for even eyeless birds will develop gonads if these cells are stimulated. Instead, these cells are stimulated simply by light that penetrates the skull and brain. These cells are stimulated by light ~500 nm (blue-green) in wavelength. After stimulation, the hypothalamus secretes luteinizing hormones (LH) and the pituitary gland secretes follicle-stimulating hormones (FSH), both of which affect the reproductive condition of birds.

Feeding

Birds, especially marine and coastal birds, feed by a variety of methods that can be grouped into the two general categories of surface-feeders and diving-feeders (Ashmole 1971, Schneider and Shuntov 1993). In the Beaufort and Chukchi seas, the primary surface-feeders include a tubenose (northern fulmar *Fulmarus glacialis*), shorebirds (especially phalaropes), jaegers, and gulls and terns, all of which consume food floating at or near the water's surface or on beaches. In the Beaufort and Chukchi seas, the primary diving-feeders include the diving ducks, loons, a tubenose (the short-tailed shearwater), the pelagic cormorant, and the alcids. The other taxa forage either benthically in shallow water (swans, dabbling ducks) or on or near beaches or in coastal marshes and wetlands (geese, some ducks, raven).

These coastal birds forage on a variety of prey in the Chukchi and Beaufort seas (Ashmole 1971, Hunt et al. 1981, Sanger 1987, Vermeer et al. 1987, Sanger and Ainley 1988, Schneider and Shuntov 1993). The waterfowl forage primarily on vegetation and seeds, although the seaducks forage benthically on invertebrate taxa such as mysids, euphausiids, and mollusks and the mergansers forage on fishes. The loons forage primarily on fishes and secondarily on large, mobile invertebrates such as shrimp, both in the water column and near the bottom. The fulmar is an omnivore that feeds on mobile prey such as fishes and invertebrates, but also scavenges and feeds on planktonic jellyfishes; in contrast, the shearwater is a euphausiid specialist. The cormorant feeds demersally, primarily on fishes and large crustaceans such as shrimp. Shorebirds form a diverse group that forages during the breeding season primarily on insects but switches to invertebrates on beaches during the nonbreeding season. Phalaropes, the one aquatic group of shorebirds, forage primarily on small planktonic crustaceans while at sea. The jaegers forage on small mammals and birds during the breeding season but switch to primarily fish while at sea in the nonbreeding season. The gulls eat a variety of prey, from small mammals, birds, insects, fishes, and invertebrates, depending on the species and location, during the breeding season. During the nonbreeding season, they become omnivorous, feeding on invertebrates, fishes, other birds, and carrion. In contrast, terns are primarily fish-feeders that occasionally eat invertebrates if they are large enough and concentrated sufficiently. Finally, the alcids are a diverse group that comprises primarily fish-feeders (murres, guillemots, puffins) and plankton-feeders (auklets, Kittlitz's murrelet).

During the boreal summer, marine-oriented birds generally are diurnal-feeders, although some, such as the red-legged kittiwake (*Rissa brevirostris*), forage at night. During the boreal winter,

however, daylight becomes much more limited, and birds may forage under low light levels or at night (Systad and Bustnes 2001). In addition, during the boreal summer, some species exhibit gender differences in activity patterns that occur at different times of the day and night. For example, during the night, breeding thick-billed murres in Labrador show a clear gender difference in foraging and chick-brooding times, with 54% of females foraging at night (near sunrise and sunset) but <1% of males doing so at that time; consequently, day-brooding birds primarily are females whereas night-brooding ones primarily are males (Jones et al. 2002). Nonbreeding shorebirds also show effects of light, with greater nocturnal foraging occurring in some species when a moon is visible (Dodd and Cowell 1996).

Attraction to Light

A variety of avian taxa have been documented to be attracted to artificially lighted structures. Those seabird taxa that are attracted most strongly to lights are members of the Procellariiformes (especially the nocturnal shearwaters, petrels, diving-petrels, and storm-petrels) and, to a smaller extent, the Alcidae (especially the nocturnal ancient murrelet *Synthliboramphus antiques*) and the auklets, many of which are crepuscular (Mailliard 1898, Murphy 1936, Swales 1965, Imber 1975, Harrow 1976, Dick and Donaldson 1978, Reed et al. 1985, Telfer et al. 1987, Rojek 2001, Le Corre et al. 2002, Livingston 2002, Black 2005, Montevecchi 2006). In Alaska, the dominant seabird species attracted to lights at night include northern fulmar, sooty shearwater (*Puffinus griseus*), storm-petrels, and crested auklet (Mailliard 1898, Dick and Donaldson 1978, Livingston 2002). For waterfowl in Alaska, those taxa having the greatest attraction to lights include some of the seaducks, especially the eiders and, to a lesser extent, long-tailed ducks (USFWS 2006; Day et al. 2005). In contrast, cormorants rarely are recorded as being attracted to lights (Hope Jones 1980).

Gauthreaux and Belser (2006) reviewed sources of light that may attract birds and cause collision mortality. These sources include lighthouses and lightships, flood lights and ceilometers, city lights and horizontal glow, fires and gas flares on oil platforms, and broadcast and communication towers. They noted that very little is known regarding how birds are attracted to lighting during the night. Spatial disorientation may be the result of a bird using lights as a visual reference after losing its visual cues to the horizon, as suggested by Herbert (1970), and may be reluctant to leave the sphere of light influence once encountered. In addition, light intensity may blind the individual by bleaching of optic pigments, causing an inability to detect visual cues that could be observed when adapted to darkness (i.e., the loss of night vision). This author also noted

several studies showing that immature migratory songbirds were more attracted than adults to artificial night lighting.

Birds appear to be attracted to lighted offshore platforms to a greater degree during cloudy or inclement weather than during clear weather. Migrating passerines in the North Sea often are attracted to and land on offshore oil platforms during migration when the sky is obscured by clouds, leaving the next morning when the sun rises and the birds can reorient their internal compasses (Alerstam 1990). Attraction of seabirds to offshore oil and gas platforms also has been recorded in the Gulf of Mexico (Ortego 1977, Russell 2005), and in the Bering Sea (Baird 1990) and Beaufort Sea (Day et al. 2005) of Alaska. In the Gulf of Mexico, the dominant species being attracted are passerines migrating over the Gulf, with seabirds being a minor component, whereas the dominant species in the Bering Sea were seabirds. In the Northern Gulf of Mexico, the interactions between migrating birds and offshore oil and gas platforms were investigated (Russell 2005). Results showed that weather had an important effect on the number of birds circulating around the platforms. Large numbers of birds were attracted during overcast nights, especially with rain, whereas clear nights attracted birds infrequently. During haze or extensive cloud cover and on moonless nights, birds tended to circle the platforms. Wind direction did not affect the development of this circling behavior. Birds appeared to be attracted to platform lights and were unwilling or unable to leave the cone of broadcasted light. The authors concluded that, during overcast nights, birds may become spatially disoriented by bright light due to the loss of navigational reference points such as stars and the moon.

Light Type and Color Spectrum

Birds have been shown to be differentially attracted to both light type and color spectrum. With regard to FAA obstruction lighting on wind farms and communication towers, continuous (non-flashing) lights at night were more attractive than flashing lights. Red incandescent lighting may be more attractive than white strobes are, but this hypothesis has not been tested in a controlled experiment (Kerlinger and Hatch 2001, Kerlinger 2004). In addition, lights with shorter off-cycles (time between blinks) may be more attractive to night migrants than are lights with longer off-cycles (Kerlinger and Hatch 2001).

Beason (1999) stated that birds can be attracted to communication towers based on lighting color and the duration (i.e., flashing, strobe, or continuous). He believed that red lights may be more attractive than white lights, and that strobe lights may be less attractive than continuous lighting,

but these conclusions have not been proven experimentally. Disorientation is another potential impact of artificial lighting. For five species of birds, he showed that disorientation or a change in direction of orientation may be produced by longer wavelengths such as red or orange. He suggested that these wavelengths may interfere with the magnetic compass. However, neither the mechanism of magnetic orientation or flight behavior, if other information sources (e.g., stars) were available, has been validated. Wiltschko et al. (1993) and Gauthreaux and Belser (2006) also concluded that red lights may cause disorientation in birds.

Recent research in the North Sea region has focused on the attraction of birds to various colored artificial lights. Poot et al. (2008) showed that bird orientation was influenced more by white and red light than by green and blue light. To reduce the risk of attraction to human built structures, they recommended minimizing the use of red and white lighting containing visible long wavelength radiation. The natural gas producer NAM (Nederlandse Aardolie Maatschappij; owned by Shell and ExxonMobil) has been involved in twelve years of research on the attraction of migratory birds to lights on offshore oil and gas platforms in the North Sea. In particular, the research addressed whether the response of birds to light was dependent upon its color. Joop Marquenie (pers. com.) of NAM has initiated and directed a research team, including research scientist Hanneke Poot, which has experimented with the attraction of birds to artificial light in the Netherlands, with eventual potential application to lighting of offshore oil platforms. On an island beach in the North Sea, they evaluated bird response at night to lights covered with red, green, blue, and white filters. The study demonstrated that birds reacted most strongly to white and red light and the most weakly to green and blue light. For all artificial light colors, responses were strongest on overcast nights. The team's work continues with assessing bird reaction to various types (metal halide, light-emitting diode, and QL) and spectrums of lighting. This research, also involving Royal Philips Electronics lighting, includes designing light sources low in the red spectrum and appear blue-green to green. In a 2007 pilot project off the Dutch coast, most of the external lights on an offshore gas production platform were replaced with these specially designed "bird friendly" lights (van de Laar 2007). During the fall 2007 bird migration, the species observed and abundances in the vicinity of the platform were compared with platform surveys from previous years under comparable seasonal and weather conditions. Results showed 2-10 times fewer birds circling the platform with the new light source in comparison with the former standard white and orange (sodium high pressure) lighting. Likewise, the number of birds landing on the platform decreased in comparison to former lighting conditions. The observed

reduction in bird attraction actually may have been underestimated because a number of white and orange lights had not yet been replaced for technical reasons by the time of the study.

In contrast to the above observations that red light may cause attraction and/or disorientation in birds, other recent studies have concluded that red lights may be "safer" to birds with regard to aviation obstruction lighting. Evans et al. (2007) evaluated the responses (i.e. accumulation or aggregation) of birds in cloud cover to alternating periods of man-made light characteristics. The study was conducted near Ithaca, New York, in October by using commercial work-light luminaries with red, blue, and green filters. Induced bird aggregation was determined by visual observations and calling rates. They concluded that, for birds migrating in cloud cover, bird aggregation occurred in blue, green, and white light, but not in red light. In addition, flashing white and red light did not induce aggregation. They suggested that with equal light intensity, flash on-time, and flash rate, migrating birds would be more responsive to flashing white light than to flashing red light.

Effects of Artificial Night Lighting

Direct Influence through Mortality

Attraction of birds to artificial lighting on structures may result in direct mortality through collision. Mortality may result from contact with the lighted structures themselves or through disorientation that results in collision with the ground (Herbert 1970, Mallory et al. 2001, Montevecchi 2006). Mortality also may result from hypothermia of stunned or exhausted birds that have become immersed in cold water or oily residue on the decks of boats, predation on incapacitated birds, or from incineration in flares during the release and combustion of natural gas.

For example, newly fledged Xantus's murrelet (*Synthliboramphus hypoleucus*) chicks have been shown to be attracted to lights on boats and can become separated from their parents as a result (Rojek 2001, Montevecchi 2006); such separation probably would result in death of the chick. Further, the concurrent attraction of gulls to lighted boats will cause increased predation on these small nocturnal seabirds, which fledge at night to minimize gull predation. A similar attraction of ancient murrelet chicks to lights has been recorded (Gaston 1992). Further, bright lights near some seabird colonies can potentially cause disruption of breeding activities, increased predation by gulls and owls, and/or a reluctance of nocturnal birds to visit the colony because of high predation rates (Watanuki 1986, Rojek 2001, Montevecchi 2006).

Environmental conditions may cause or exacerbate rates of attraction and collision, in that the loss of view of the night sky tends to result in greater attraction of birds. This loss of migratory orientation is most common in nocturnally migrating passerines flying over large stretches of open ocean (e.g., Russell 2005). A second facet is attraction to intense sources of light, causing collisions during stormy periods, especially those with poor visibility. This phenomenon has been seen in Alaska with fishing boats and industrial structures (USFWS database; Dick and Donaldson 1978, Day et al. 2005), in the Antarctic with fishing boats (Rojek 2001 and references therein; Black 2005), in California with nocturnal seabirds and fishing boats (Rojek 2001), around offshore oil and gas platforms in the North Sea (Bourne 1979, Sage 1979, Hope Jones 1980, Wallis 1981, Alerstam 1990), and near offshore oil and gas platforms in the northwestern Atlantic (Wiese et al. 2001, Montevecchi 2006). Hundreds to tens of thousands of seabirds may be killed under such stormy conditions (e.g., Dick and Donaldson 1978, Black 2005, Montevecchi 2006). In addition, seabirds and marine waterfowl tend to fly closer to land during foggy conditions than during clear weather (Chaffey 2003, cited in Montevecchi 2006), increasing their chances of becoming attracted to lighting on coastal buildings.

Day (pers. obs.) has often seen birds, especially nocturnal seabirds, being attracted to lights on ships at sea in Alaska, including landings of fork-tailed storm-petrels (*Oceanodroma furcata*), ancient murrelets, Cassin's auklets (*Ptychoramphus aleuticus*), and whiskered auklets (*Aethia cristatella*). At night near a large nesting colony in the western Aleutian Islands of Alaska, he observed large numbers of birds coming aboard a ship, even with the outside lights turned off. These birds were also colliding with a deckhand who had accidentally turned on a flashlight in his back pocket, with tens of birds hitting him every minute or landing nearby. He also has seen a few birds coming aboard boats at night in the North Pacific Ocean, recording one Cook's petrel (*Pterodroma cookii*) and many red-necked (*Phalaropus lobatus*) and red (*Phalaropus fulicarius*) phalaropes. The phalaropes, which probably were migrating, landed during a foggy night, and 10-20 dead birds were noted on deck the next morning.

A lunar effect may also be associated with light attraction and associated mortality. In the Hawaiian Islands, fledgling Newell's shearwaters (*Puffinus newelli*) are attracted to streetlights and other external illumination around the New Moon (Telfer et al. 1987). At an oil-production platform in Alaska, migrating birds, including eiders, showed a greater rate of circling or erratic flight behavior than of straight-line flight behavior around a Full Moon when the moon was not

visible than when it was visible, suggesting that these birds were using the Full Moon as an aid in orientation (Day et al. 2005). Similarly, many migrating birds show a lunar periodicity in attraction to, and mortality at, lighthouses around both a New Moon and a Full Moon (Crawford 1981, *contra* Verheijen 1980, 1981a, 1981b). Finally, some birds show avoidance of bright natural light when feeding young (Klomp and Furness 1992), suggesting avoidance of bright moonlight. Reed et al. (1985) also demonstrated lunar effects on bird attraction on the island of Kauai, Hawaii. He observed that fledgling threatened and endangered Procellariiform birds (Newell's shearwater, dark-rumped petrel *Pterodroma phaeopygia*, and band-rumped storm-petrel *Oceanodroma castro*) were attracted to bright coastal floodlights. After circling the lights, many collided with man-made structures, causing significant mortality. This attraction was decreased during a Full Moon.

Collision mortality was evaluated in the North Sea at the FINO 1 unmanned offshore research platform (Huppop et al. 2006) that was brightly lit at night. From October 2003 to December 2004, bird carcasses found on the platform were documented during 44 visits by helicopter. A total of 442 bird carcasses of 21 species were recovered, and nearly all were in good physical condition. Approximately 76 percent had outwardly apparent injuries, and the remaining possibly died from exhaustion after circling the platform. More than 50 percent of the collisions occurred during two nights (i.e., 1 October 2003 and 29 October 2004) described as having very poor visibility and mist or drizzle. They suggested that these weather conditions increased attraction to the illuminated platform. In addition, disoriented birds circled around the platform repeatedly, so both their risk of collision and their energy consumption increased. These authors assumed that the total number of collisions was underestimated because most of the birds probably fell into the sea or were consumed by gulls.

Bright lights such as those from fires (e.g., Mailliard 1898) or from gas flares may also cause the mortality of birds at coastal or offshore sites. Sage (1979) first reported the attraction of seabirds and migrating passerines to flares on offshore oil platforms in the North Sea and the subsequent incineration of large numbers of birds on some nights (but see Bourne 1979, Hope Jones 1980, and Wallis 1981 for a different view of the phenomenon). Similarly, shearwaters, storm-petrels, and dovekies (*Alle alle*) are attracted to lights and flares on offshore oil platforms in the northwestern Atlantic (Wiese et al. 2001). As noted by Montevecchi (2006), mortality associated with artificial lighting, including flaring of hydrocarbon gas at offshore platforms, appears to be episodic, with impacts ranging from no or minimal (Hope Jones 1980) to tens of thousands of

birds killed by flaring (Sage 1979). This phenomenon has also been observed in the Arctic, in that a large gas flare in the Alaskan Beaufort Sea during fall migration caused the attraction and near-collision of a large number of long-tailed ducks and glaucous gulls at an offshore oil-production island (Day et al. 2005).

In contrast to these studies, others have concluded that impacts of artificial light from offshore platforms on birds most likely would be limited. Department of Trade and Industry, UK (2004) contended that little or no mortality of birds has been attributed to exploration and production activities in the United Kingdom continental shelf. In its review of seabird vulnerability to offshore hydrocarbon development, the Department concluded that mortality associated with flaring or lighting would not affect either regional or global breeding populations of seabirds based on colony performance of seabirds in the North Sea. The Canada–Nova Scotia Offshore Petroleum Board (2002) also suggested that seabird impacts from attraction to lighting and flaring on drill rigs and supply boats would be minor, short-term, and sublocal to local in extent. Russell (2005) in a study of migrating birds and offshore oil and gas platforms in the northern Gulf of Mexico noted that whereas birds may be attracted to gas flares, virtually no birds were burned. He stated that this absence of impact was consistent with observations at terrestrial fields along the Gulf Coast.

Indirect Influence through Energetic Costs

The attraction of migrating birds to lights or alteration of migratory orientation as a result of attraction may have energetic implications and, potentially, negative effects on survival. Migration is one of the most energetically expensive activities in the life cycle of birds (Gill 1995, Weidensaul 1999). Recent research indicates that certain wavelengths of light can alter the migratory orientation of birds, such that their navigation system no longer properly functions (Wiltschko et al. 1993, Beason 2003). For example, long-wavelength (orange to red) light has been shown to cause disorientation or a change in migratory direction in the five species of birds in which it has been studied. Apparently, these wavelengths interfere with the birds' magnetic compasses. If the disruption is sufficiently strong, the birds could incur significant energetic costs if it caused them to fly off course. Consequently, deviations from normal migratory pathways might have physiological effects that result in decreased chances of survival. For example, the amount of energy consumed by birds that circled Northstar Island for several hours (see Day et al. 2005, above) was not insignificant. In addition, other authors (e.g., Bourne 1979, Hope Jones 1980, Wallis 1981, Wiese et al. 2001) have reported records of large numbers of

migrating passerines occasionally circling offshore oil and gas platforms for hours or days, eventually resulting in exhaustion and subsequent drowning at sea or mortality from starvation. The long-term effects of excessive energy loss from light attraction on subsequent winter survival or breeding are not known. However, given the extreme sensitivity of migrating seabirds and seaducks to the effects of winds that may dramatically increase energetic costs (Day et al. 2004, 2005), it could be assumed that the energetic costs of light attraction would have negative effects on survival and/or reproduction.

For the Stybarrow Development project off northwestern Australia, BHP Billiton (2005) suggested that the lighting of the Floating Production, Storage, and Offloading (FPSO) vessel connected to sub-sea oil wells could cause the disorientation of seabirds. They considered that the attraction of migrating birds to light from offshore platforms could have a significant impact on seabird survival in some circumstances. Marquenie and van de Laar (2004) showed that large flocks of migrating seabirds can be attracted to the lights and flares of offshore oil platforms in the North Sea, especially between midnight and dawn and on cloudy nights. They stated that this attraction could be significant when offshore platforms are located on long-distance migration routes. Such attraction can drain fat reserves, and any delay such as resting on the platform or circling around it potentially could reduce an individual's survival. BHP Billiton (2005) concluded that the likelihood of such light impacts from the Stybarrow Development Project would be extremely low because migrating birds in the area are at or close to the end of their migration. These birds would not soon be undergoing subsequent long-distance flights, even if some were attracted to the FSPO. The presence of lights during development and production of the White Rose Oilfield offshore of Newfoundland also was predicted to have a small effect on marine birds and be similar to the effects of light from marine transportation and fishing vessels (Husky Oil Operations Ltd. 2001).

A second energetic cost of artificial light could be increased energy expenditure as a result of increased defense of breeding territories. However, little information is known on this topic. A recent study by Miller (2006) did find that American robins (*Turdus migratorius*) sing earlier and, hence, longer in areas with light pollution than they do in areas with natural background light. The implication is that these birds may be expending greater energy in defense of territories in areas that are illuminated by artificial light and that this effect may occur at a population level.

Measurement of Bird Migration, Attraction, and Collision Potential

There are several ways to study nocturnal migration, light attraction, and collision potential in birds. These methods are discussed here briefly.

Moonwatching Surveys of Avian Migration

Lowery (1951) pioneered the systematic use of moonwatching to study the nocturnal migration of birds; earlier attempts at moonwatching are discussed in his monograph. In effect, teams of observers count with a telescope the number of birds crossing the lunar disk on the night of a Full Moon. These counts are converted to hourly or nightly "densities' of migration. In addition, observers can determine frequencies of flight directions by classifying directions as a clock scale (e.g., birds going to due east would have a direction of 3:00). These data can compare migration "densities" by hour of the night, by night, by location, and by flight direction. Unfortunately, moonwatching surveys are limited in use to the period around the Full Moon and, specifically, to clear nights around the Full Moon. They also can provide no information on the altitude at which birds fly and, thus, provide no insights into collision potential.

Ceilometers

The use of airport ceilometers (which are bright lights usually ~25–30,000,000 cp pointed straight up in the night sky) to study bird migration was conducted over a fairly brief time period. This use was of short duration because of two problems: ceilometers caused massive attraction of birds to the lights (e.g., Coffey 1964), resulting in inflated estimates of migration volume, and, when operated continuously at airports, they caused massive mortality of birds as they became exhausted or disoriented and hit the ground or the light (e.g., Arbib 1950, Bartlett 1952, Howell et al. 1954, Chamberlain 1955, Ferren 1959). The latter problem is the reason why airport ceilometers no longer are left turned on to determine ceiling height, but instead are turned on and off in short bursts.

Acoustic Surveys of Avian Migration

Some studies use acoustic surveys to measure nocturnal migration (Berthold 2001, Farnsworth et al. 2004). In some species, migratory calls stimulate conspecifics to start migrating. These calls also may be made during migration, a behavior that is thought to improve migratory orientation (Berthold 2001) in the large, loose flocks of migrating passerines. Some scientists have developed automatic systems that record bird calls over a specific location, and then they analyze the tapes for species identification. Recently, William Evans of Cornell University developed a

system that records bird calls and compares them with a database of calls on a computer in the field; that way, the call files and the analyzed data are downloadable on a regular basis (Evans and O'Brien 2002). This method has both strengths and weaknesses. The strength is that it can be used to determine the species that are migrating and their relative numbers; on the other hand, many species of birds do not call at all while migrating. In addition, calling rates vary within and among even passerine species (Berthold 2001, Farnsworth et al. 2004) and among nights (Farnsworth et al. 2004), so determining actual numbers of individuals based on recorded bird calls is difficult, if not impossible. The ability to detect calling birds also depends to some extent on background noise, so some weather conditions (e.g., high winds) make estimating the numbers and accurate flight altitudes of migrating birds difficult.

Radar Surveys of Avian Migration

Radar has been used to study bird migration since shortly after World War II, when the newly developed technology in Britain discovered that what appeared to be squads of enemy planes passing by every spring and fall actually were flocks of birds (Eastwood 1967, Gauthreaux and Belser 2003, Larkin 2005). Radar, the acronym for "Radio Detection and Ranging", employs radio waves that are transmitted at the speed of light, and their back-echoes are used to interpret what is in the environment; objects that are moving may be birds, bats, and/or insects. Radars come in a variety of sizes and wavelengths, with the two most common types for bird studies being X-band and S-band (Skolnik 1980). X-band radars operate in the microwave frequency, between 8 and 12 GHz (wavelength 2.4–3.75 cm), and tend to be of low power (10–12 kW). S-band radars also operate in the microwave frequency, between 2 and 4 GHz (wavelength 7.5–15.0 cm), but tend to be of higher power (25 kW). The distance of detection of an object depends on many factors, including the area of the radar cross-section of the object and the wavelength and power output of the radar.

Each radar type has its strengths and weaknesses. In general, X-band radars are useful for providing high-resolution images of bird movements within a few kilometers of the sampling site, whereas S-band radars tend to be more powerful and provide information over a larger area. X-band radars have often been used to study bird movements in mobile laboratories (e.g., Gauthreaux 1985a, 1985b; Cooper et al. 1991), primarily because of low cost, ease of moving, and ease of operation. S-band radars are larger and require larger antennas, making mobility difficult; high cost also is an issue. X-band radars cannot sample in even moderate precipitation (rain or snow), however, because the wavelengths are similar enough in size to those of raindrops,

causing so many echoes on the display screen that bird-associated echoes cannot be differentiated. In contrast, S-band radars have longer wavelengths and, hence, have fewer problems with precipitation. Finally, X-band radars tend to be high-resolution and can provide highly detailed information on bird movements (e.g., location, speed, flight direction, and trackline; Gauthreaux and Belser 2003).

Radars have other weaknesses. First, the identity of targets seen on radar display screens is unknown, requiring additional techniques (e.g., night-vision goggles) to determine identity. In addition, all radars have shadow zones behind hills, heavy vegetation, and similar solid objects behind which flying objects cannot be detected. This problem can be overcome in most cases with careful placement of sampling sites with respect to the direction of bird migration. However, this placement is not possible in some cases, making radar sampling in some areas impossible. Other weaknesses are that, in coastal locations, radar samples poorly during periods of rough seas (sea clutter obscures the screen) and that they cannot detect the altitude at which birds fly in the way tracking radars (which are much more expensive) can. This problem with flight altitude can be resolved, however, by tilting the radar on its side with a specially modified mount (Harmata et al. 1999).

NEXRAD Radar Analysis

Other important types of radar used in studies of bird movement are weather radars (i.e., the WSR-88D or "NEXRAD" and its predecessor, the WSR-57). These are highly powerful (750 kW for the WSR-88D) S-band doppler radars that operate with a wavelength of 10.3–11.1 cm (Gauthreaux 1992, Gauthreaux and Belser 2003) and can sample the intensity of bird migration within ~200 km of the radar's location. The network of NEXRAD radars across the US allows the study of bird migration at a very large scale (Gauthreaux and Belser 1998, 2003; Gauthreaux et al. 2003). Unfortunately, the number of NEXRAD radars in Alaska is small, limiting the actual spatial coverage of the state.

These radars can detect migration intensity, flight speed, and flight direction at large scales. NEXRAD can be used to determine general migratory pathways, migratory stopover habitat, and effects of weather on migration (Eastwood 1967, Gauthreaux 1975, Gauthreaux and Belser 2003). However, they generally are not useful for collecting high-resolution passage-rate or flight-altitude data over small areas because the minimal resolution for NEXRAD is 1 km × 1 km. The resolution issue also makes it difficult to filter insect noise from the data because NEXRAD does

not provide information on individual targets. Further, NEXRADs are stationary and often do not provide low-altitude coverage over some areas because of the curvature of the earth, shadow zones behind mountains and other factors.

Thermal Animal Detection System (TADS)

Infrared sensors from Denmark are new-generation remote-sensing equipment that can be used to study bird movements at night (Desholm et al. 2006). The most sophisticated of these is Forward-Looking Infrared (FLIR), which provides images of temperature on a TV-type display screen. Because birds are much warmer than the background environment against which they are flying, their images are readily interpretable. In fact, differences in external temperature may be seen through feathers of different color (Day, pers. obs.). As sharp as FLIR images are, however, their utility is limited by the high cost of this recently declassified military hardware and by engineering-related aspects of the technology itself (e.g., liquid nitrogen used, requiring a substantial power source).

A newer infrared system that has been developed is the Thermal Animal Detection System (TADS). This system uses cameras that effectively detect in the infrared spectrum. TADS have been mounted on towers in offshore windfarms to estimate the number of birds colliding with turbines in remote locations where it is impossible to measure collision rates any other way (Desholm et al. 2006).

1.3.1.3 Fishes

Abundance and Use of Area

The fish communities of the Beaufort and Chukchi seas are comprised of 98 species representing 23 families (USDOI 2008). Forty-nine species are considered common to both seas. Environmental factors considered important to arctic fishes include reduced light, seasonal darkness, extended periods of low temperatures and ice cover, low diversity of flora and fauna, and low seasonal productivity.

Anadromous fishes, which are those migrating from saltwater to spawn in freshwater (mainly salmonids), have been the focus of most research in the region. Jarvela and Thorsteinson (1999) found that the most abundant salmonid species in the region were arctic cisco (*Coregonus autumnalis*), least cisco (*Coregonus sardinella*), broad whitefish (*Coregonus nasus*), and Dolly Varden (*Salvelinus malma*). Whitefish, also in the salmon family, are amphidromous in that they

overwinter in fresh water and spawn and mature at sea (National Research Council 1994). Overall, arctic cod (*Boreogadus saida*), fourhorn sculpin (*Myoxocephalus quadricornis*), and arctic flounder (*Pleuronectes glacialis*) are the most abundant marine fish in the area. The Arctic cod is an important food source for marine mammals and birds and may influence their distribution and abundance. The saffron cod (*Eleginus gracilis*) also is abundant locally and is important in nearshore food webs in the Arctic (National Research Council 1994).

The movement of many marine fish species in the study area has been shown to be correlated with salinity levels and ice melt. As the salinity levels decrease and the ice thaws in summer, arctic cod, fourhorn sculpin, and arctic flounder move into nearshore waters (Craig et al. 1984). During the summer months, a band of warm, brackish-water develops just off the shoreline and provides an important food supply for these fishes (Craig et al. 1984). This zone of brackish-water also is vital to anadromous fish for feeding and migrating. As winter approaches, the warm, brackish water band recedes and fish remain near shore, under the ice. Most marine fishes spawn during the winter. From November through February, arctic cod may spawn under the ice in both shallow coastal areas and offshore waters. Most anadromous species return to fresh water and spawn by mid-September (AKDNR 1999).

In the winter, the warm-water band is absent, and anadromous fish species return to unfrozen pockets of fresh or brackish water in their natal streams or rivers to spawn or to overwinter (Craig et al. 1984, Wilson 2006). For example, the arctic cisco begins life in the Mackenzie River, Canada, winters in the Colville River of Alaska for several years, and then returns to the Mackenzie River to spawn (Thorsteinson and Wilson 1995). The Colville and Sagavanirktok rivers provide wintering habitat for many anadromous fish species, including the arctic cisco, least cisco, and broad whitefish (Thorsteinson and Wilson 1995).

In the Beaufort Sea, a small inshore commercial gillnet fishery targeting arctic cisco, least cisco, and broad whitefish takes place annually between October and November (Wilson 2006). No other commercial fisheries occur in this area (Wilson 2006). In the southeastern Chukchi Sea, a summer and fall chum salmon fishery occurs annually in Kotzebue Sound (Wilson 2006).

Basic Anatomy and Physiology of Vision

Although relatively small in comparison with other organs, the eye plays an integral role in feeding, schooling, and migration patterns in fishes. Morphologically, the eye of bony fish is

similar to that of all other vertebrates. The tough outer layer is the sclera, which helps maintain the shape of the eye. Within the sclera is a transparent layer called the cornea, which makes contact with the water. Light passes through the cornea and then through the lens, which focuses the light onto the retina, which is the light-sensing part of the eye. Lastly, the iris helps to regulate the amount of light coming into the eye. Fish have liquid in the eye that has similar properties to that of water allowing light to travel unbent through the eye and to generate a clear image (Helfman et al. 1997). There is evidence that some fishes have interference filters located on the cornea that may help to regulate the perception of color (Lythgoe 1975)

The lens in fishes usually is large and spherical in shape and is positioned in such a way that it nearly touches the cornea. The placement of the lens close to the cornea, along with the positioning of the eyes on either side of the head, gives most fishes a wide lateral field of view (Bond 1996).

The retina houses the visual-cell layer, which is responsible for detecting a wide array of light intensities by means of two types of photoreceptors: rods and cones. As the light is captured by the photoreceptors, the retina converts the light rays into electrical impulses and transfers these impulses along the optic nerve to the brain, where they are interpreted as images.

Each photoreceptor can detect light at different thresholds by changing position within the visual cell layer. The rods are more sensitive at low light levels, whereas the cones are more sensitive at high light levels. Under low light levels, the rods contract and the cones elongate, giving way to "dark adapted" (scotopic) vision. Under high light levels, the opposite occurs, so that the cones contract and the rods elongate, creating "light adapted" (photopic) vision. Note that this physical modification of the photoreceptor cells during the Purkinje shift does not occur in birds or mammals.

The movement of the rods and cones relative to the light is generated through photosensitive pigments in the retina called rhodopsins and porphyropsins; however, most marine fishes do not have porphyropsins (Bond 1996). The stimulation of the rhodopsins and/or porphyropsins within the cell generates the electrical impulses and results in the sensation of vision (Bond 1996).

Influence of Light

Nightingale et al. (2006) provided a comprehensive summary of the potential effects of artificial ambient lighting on fish. The following discusses their review along with additional applicable information.

Age and Species

Responses to artificial light may vary by developmental state and species (Nightingale et al. 2006). Studies have shown a correlation between foraging strategies of fish species and their responses to light. For example, sockeye (*Oncorhynchus nerka*), pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), and chinook (*Oncorhynchus tshawytscha*) salmon, which usually are found in estuaries and lakes, exhibit schooling behavior, are active at night, and move away from lights (Hoar 1951, Godin 1982). In contrast, species that are found in streams (e.g. Atlantic salmon *Salmo salar*, coho salmon, and steelhead *Oncorhynchus mykiss*) exhibited no nocturnal activity when exposed to light (Hoar 1951, Godin 1982).

Research by Hoar (1951) indicated that salmonids exhibit different responses to light depending on their life stage. In laboratory studies, young sockeye fry showed negative phototaxis (i.e., movement away from the light) and would remain under the cover of stones, whereas older fry ventured more out into the light. Younger pink salmon fry were found to swim near the surface under low light conditions, but moved to deeper water in higher light. Older pink salmon fry demonstrated no changes in activity in response to elevated light.

Influence of Light Duration and Spectrum

Fishes have been shown to respond to varying light duration and spectrum (Nightingale et al. 2006). The response to changes in light duration depends on the length of time fishes are pre-exposed or acclimated to light. Fishes are more likely to adjust to light of constant duration (e.g., lights at the end of a dock), than to light of shorter duration (e.g., strobe lights).

Constant light levels (dark or light) allow fishes to become fully adapted and adjust their behavioral responses to fit the conditions, whereas short durations of light or dark periods do not allow enough time for fishes to adjust. For example, strobe lights produce abrupt bursts of intense light over a duration that are too short for retinal adaptation to occur (Dera and Gordon 1968, Loew and McFarland 1990, Nightingale et al. 2006) and may induce avoidance behaviors in fishes. Many studies have been conducted on the effectiveness of using strobe lights to

generate avoidance behaviors in salmonids (Maiolie et al. 2001, Ploskey and Johnson 2001; Johnson et al. 2003, 2005). According to Nemeth and Anderson (1992), bright mercury-vapor lights and strobe lights caused avoidance in juvenile coho and chinook salmon, whereas dim mercury-vapor lights attracted juvenile chinook salmon. Lights have been placed on fish ladders to direct the fish away from dams (Larinier and Boyer-Bernard 1991a, 1991b), and power plants have used lights to prevent fish from being drawn into the intake pipes (Haymes et al. 1984). However, there appears to be no single combination of spectrum, intensity, and duration that attracts or repels all species: the response is dependent on the light spectrum sensed by the fish, and this varies by species (Nightingale et al. 2006).

Light spectrum may also affect a fish's response to light, and changing the color spectrum can induce or suppress certain behaviors. Fishes that live in shallow waters, streams, and lakes are most likely to be sensitive to red and yellow wavelengths, whereas fishes in deeper-water environments (e.g., the ocean) are more sensitive to blue wavelengths (Beatty 1969, Folmar and Dickhoff 1981). For example, mercury-vapor lights, which emit substantial energy in the blue and ultraviolet spectrums, have been found to attract marine fishes (Wickham 1973, and Puckett and Anderson 1987). Other studies on juvenile chinook and coho salmon and steelhead also have demonstrated their affinity for mercury-vapor lights (Nemeth and Anderson 1992).

Migration

Artificial light can have potential adverse effects on the migration behavior of fishes. Most species undergo migration, usually to feed or breed, and the presence or absence of light can trigger this behavior. Hoar (1958) reported that peak migration is a result of synchronization to lighting conditions among individuals to allow for minimal contact with predators. Consequently, any changes in ambient light conditions along migration routes may interrupt movements, cause increased predation, and reduce the number of successful migrants (Nightingale et al. 2006). A field study on sockeye, chum, pink, and coho salmon by McDonald (1960) in the Skeena River Drainage System, British Columbia, found that all species exhibited the same nocturnal pattern of movement during migration. However, changes in light intensity appeared to regulate downstream movement, and light from artificial sources was shown to delay migration. Other studies (Prinslow et al. 1980, Tabor et al. 2001) have also reported delays in the migration of sockeye and chum salmon caused by artificial light. For example, sockeye fry in streams almost completely stopped migration when exposed to even low levels of artificial light (Nightingale et al. 2006).

Foraging

The daily activity patterns of most fishes are related to ambient light; however, they are not strictly bound to these patterns, and most display some plasticity in their behaviors (Hobson 1965, Reebs 2002). Many species have a particular range of illumination that triggers or stops foraging behavior. This range may vary among individuals, developmental stages, and with environmental conditions (Nightingale et al. 2006).

Negative relationships between illumination and foraging behavior have been documented by Contor and Griffith (1995) in juvenile rainbow trout, in that fewer fish were found to forage during a full moon or when an artificial light was present. For other fishes that forage by sight, increases in illumination can produce foraging opportunities not normally available at lower light levels. However, the enhanced foraging success might cause competition between formerly less efficient nocturnal foragers and fishes that normally feed at the higher illuminations, possibly causing a shift in local food webs.

Predation Risk

Small changes in light intensities can alter interactions between predator and prey (Nightingale et al. 2006). Increased lighting has been demonstrated to increase the risk of predation among fishes. Juvenile salmonids reduce detection by predators through vertical migration, which allows them to maintain a constant ambient light environment (Scheuerell and Schindler 2003). However, artificial illumination could eliminate the effectiveness of vertical migration as an anti-predator behavior. For example, Hobson (1966) found that elevated light conditions increase the visibility of prey from below against the illuminated background, thus increasing predation rates. Nightingale and Simenstad (2001) suggested that artificial lighting on overwater structures at night can increase risks of fish mortality due to changes in fish distribution and predator/prey relationships.

Light-altered predator/ prey interactions have been documented in the field. Security lighting on a wharf in Puget Sound illuminated schools of prey fishes and attracted spiny dogfish (*Squalus acanthias*; Prinslow et al. 1980). As salmon fry traversed their migratory route, they experienced high predation rates by sculpins, especially in the areas of the brightest lighting (Tabor et el. 1998, 2001). Yurk and Trites (2000) demonstrated predation of migrating salmon smolts by harbor seals under artificial lights in the Puntledege River, British Columbia. To avoid

predation, some salmonids have also been shown to forage in extremely dark conditions, even though doing so would offer less efficient feeding opportunities (Fraser and Metcalfe 1997).

Reproduction

Little is known about the effects of artificial light on courtship and spawning in fishes. Although some evidence does show that courtship can be affected by artificial light, these relationships have yet to be fully investigated (Endler 1987, Long and Rosenqvist 1998). Some research on pelagic fishes, however, has indicated that artificial light may disrupt spawning (Nightingale et al. 2006). For example, Woodhead (1966) demonstrated that cods that usually spawn at night stopped spawning when exposed to a bright light.

1.3.1.4 Invertebrates

Abundance and Use of Area

Plankton and other marine invertebrates make up the basis of the food web in the Chukchi and Beaufort seas and are an important food source for fishes, birds, and marine mammals. In the Beaufort Sea, phytoplankton are suspended in the water, within the benthos, and under the sea ice. They include diatoms, dinoflagellates, and flagellates, and their abundance is greatest in waters less than 5 m. In this area, phytoplankton populations peak in late July and early August due to the increased photoperiod and receded ice cover (USACE 1999) and decline in September as photosynthesis is limited by lower light levels (AKDNR 1999).

Zooplankton include macroscopic crustaceans such as copepods and many larval forms of other invertebrates and fishes. This group also includes the jellyfish, krill (euphausiids), and amphipods. Zooplankton are found throughout the water column and in the epibenthos, especially in coastal waters (USACE 1999). Copepods are a major food source for bowhead whales and arctic cod, whereas euphausiids and pelagic amphipods are important sources of food for ringed seals, arctic cod, seabirds, and bowhead whales. Birds and fishes also feed on the abundant mysids in nearshore waters (National Research Council 1994). The species-diversity and abundance of zooplankton probably increase with increasing distance from shore (AKDNR 1999)

Benthic invertebrates, especially isopods, compose a large percentage of the biomass within the Beaufort and Chukchi seas. They are affected by sea ice, which prohibits the overwintering of most species in waters less ~7 ft. Within the benthos exist crustaceans, polychaetes, and bivalves

(USACE 1999). The benthic community of the eastern Chukchi Sea is very diverse, with gray whales feeding on benthic amphipods, and walruses and bearded seals consuming clams and gastropods. The Beaufort Sea is less important to marine mammal populations such as gray whales, bearded seals, and walruses because the benthic community is restricted to a narrower continental shelf (National Research Council 1994).

There is also a hard-bottom invertebrate community in the Chukchi and Beaufort seas. This type of benthic community contains large kelps, microalgae, and benthic invertebrates that associate themselves with rock and other hard substrate. These communities support sponges, soft corals, hydroids, sea anemones, bryozoans, chitons, nudibranchs, sea squirts, sea stars, fishes, and crabs (USACE 1999).

The nearshore invertebrate community includes those living within the bottom (infauna such as polychaete worms and bivalves), those living on or near the bottom (epibenthic fauna such as amphipods, mysids, and isopods), and those living in the water column (pelagic fauna such as copepods and chaetognaths that are important foods for anadromous fishes).

Numerous pagophilic (ice-associated) invertebrates are associated with the ice of the Chukchi and Beaufort seas. Sea ice in polar marine ecosystems serves two major functions, in that (1) it supplies habitat for photosynthetic algae and nursery grounds for invertebrates during a period of the year when the water column does not sustain the growth of phytoplankton, and (2) it releases organisms to surface water as the ice melts, fostering blooms that are significant to overall marine productivity (Krembs and Deming 2007). This large biomass of unicellular photosynthetic algae develops as light becomes available in the spring through the summer. The ice algae will contribute over half to the total arctic marine primary production; thus, they are an important part of the marine food web.

Basic Anatomy of Vision

Invertebrates display a wide variety of photoreceptors, ranging from simple multicelluar light-detecting organs called ocelli in cnidarians (corals and jellyfish) to complex color vision systems. However, most invertebrates possess compound eyes. This type of eye differs from the vertebrate eye in that, during development, it differentiates from the epidermis rather than from the Central Nervous System as in chordates (Stierwald et al. 2004). The advantage of this eye form is that it uses less brain for vision processing; consequently it is found in small organisms. Although there

are a number of different types of compound eyes, which can differ with developmental state, they all possess the same basic structural features (Ball et al. 1986). Squid, a cephalopod occurring in the northeastern Chukchi Sea (USDOI 2006), differs from other invertebrates in that its eye includes a single lens much like the vertebrate eye.

The hexagonal lattice of the compound eye is formed by the clustering of many ommatidia. Ommatidia contain all the necessary structures for sight, and are capable of creating an independent image. In addition, they house the receptor elements where the absorption of light is initiated. Constant light or dark conditions can affect the structure and function of the invertebrate eye (Hariyama et al. 1986), and some invertebrate eyes may change on a diurnal rhythm.

Orientation

Many species of larval invertebrates orient their swimming to light. By swimming either toward or away from light, they affect their vertical position in the water, and hence their dispersal by ambient currents. Although few studies have examined the mechanisms of invertebrate orientation at the individual level, it has generally been found that larvae switch from swimming towards light in their early larval stages to away from light as they develop (McCarthy et al. 2002). For some invertebrates, it also has been suggested that if a larva were to exhibit negative phototaxis later in its development, then it would have a greater probability of encountering shallow habitats in which to settle. Thus, it is important to consider not only the adult organisms' reaction to light but also other developmental stages because their behaviors may differ drastically.

Migration Patterns

Diel vertical migration (i.e., downward migration during the day and upward at night) is common in marine invertebrates. A changing light level usually is considered to be the most likely cue in stimulating the vertical migration of zooplankton. As the zooplankton rise with decreasing light levels to feed on phytoplankton, their vertebrate and invertebrate predators follow. Diel migration generally is considered a behavior to avoid the damaging effects of UV light that enters the water. This behavior is most often seen in invertebrates that inhabit coastal environments due to the high levels of UV radiation that penetrates these waters, yet can vary depending on predator-prey interactions and other variables (Kehas et al. 2005). In the Barents Sea, Blachowiak-Samolyk et al. (2006) found that arctic zooplankton do not perform diel vertical

migration during the spring and summer with continuous lighting. In the Barrow Strait of the Canadian Arctic, Fortier et al. (1971) found that copepods displayed diel vertical migration under the sea ice during the spring that may be related to the vertical distribution of food and to the vulnerability to visual predators.

Although light does play a major role in invertebrate migration, other conditions such as wave height, also have been shown to have an effect (Martin 2002). The vertical distribution of invertebrates also may be affected by environmental conditions such as ice cover and hydrographic factors.

Predation

Many marine organisms maximize their foraging success by using illumination. Whether by stalking from below, exploiting bioluminescence, or by hiding in light/dark areas and attacking, invertebrates' responses to light can affect their foraging success and risk of predation (Viherluoto and Viitasalo 2001, Newcomb et al. 2004).

The literature search located no studies evaluating the influence of light on risk of predation for marine invertebrates in the Beaufort and Chukchi seas. However, relationships between light and foraging success were addressed in a study of zooplankton and fishes associated with petroleum platforms in the Gulf of Mexico (Keenan and Benfield 2003). The study showed that the waters around these petroleum platforms generally contained high densities of a wide variety of fish species, with the blue runner (*Caranx crysos*) being one of the most abundant. The diet of the blue runner contains a high proportion of zooplankton that is abundant around petroleum platforms, particularly at night. Results suggested that these platforms may act as plankton accumulators through a combination of hydrodynamic entrainment and attraction to lights at night. Moreover, the blue runner was able to forage on zooplankton throughout the night under artificial illumination from the platform.

Artificial Light Impacts

Artificial lighting has been used by fisherman for centuries because it has proven to be a successful tool for attracting, concentrating, and facilitating the capture of a number of commercially-desirable marine organisms, including invertebrates. For example, a majority of the world catch of squid is caught by the use of lights to attract them. Major light-induced

fisheries for squid, octopus, and cuttlefish are found off Japan, Thailand, New Zealand, and California, and in the southwestern Atlantic (Montevecchi 2006).

No information was located regarding impacts of artificial light in polar regions on marine invertebrates. We can only speculate regarding the effects of ambient artificial light on the invertebrate community and on energy transfer to higher trophic levels such as fishes, birds, and marine mammals in the Beaufort and Chukchi seas.

2.0 LIGHT CHARACTERISTICS

2.1 Light Spectrum

Light normally refers to a small part of the electromagnetic spectrum that interacts with the eye and initiates visual sensation. The photoreceptors of the eye are sensitive to electromagnetic radiation between about 380 and 780 nm. Visible light is positioned between ultraviolet radiation (100–400 nm) on the low wavelength side and infrared radiation (780–10^6 nm) on the high wavelength side. Electromagnetic radiation also includes radio waves as well as X-rays and gamma rays. Within the visible portion of the spectrum, the spectral sensitivity can be further divided into colors with blues associated with the lower portion of the visible spectral range (400–450 nm), greens with the middle of the range (500-550 nm) and reds with the upper portion (600–700 nm). There is no sharp cutoff on color sensations, but rather, a blending of one into the other (IESNA 2000).

2.2 Reflectance and Transmission

Upon encountering a surface, light can be reflected away or refracted through the surface to an underlying substance. Light can then be transmitted, absorbed, and/or diffused within the substance. The three types of reflection are specular, spread, and diffuse. A specular reflection occurs when light is reflected away from a surface at the same angle as the angle of the incident light, as with a mirror. A spread reflection occurs when light is reflected from an irregular surface at multiple, yet similar angles as the incident light. A diffuse reflection occurs when a rough surface reflects the light at multiple angles.

Light is refracted when it bends and changes velocity as it passes from one material to another. Refraction varies with incident angle and the refractive index of the material. The refractive index of a material is the ratio of the speed of light in a vacuum to that in the material, and varies with the wavelength of the incident light. The index of refraction is higher for shorter wavelengths of light. Thus, blue light is refracted more than red light, called dispersion, as shown when a prism displays the spectral components of white light.

Transmission occurs when light travels through a material and is affected by absorption, reflection, and refraction. A material can absorb all or a portion of incident light rather than fully transmitting light, generally converting it to heat. Diffusion or scattering occurs when light is reflected or transmitted at multiple angles after contacted an irregular surface (e.g., fog). The

degree of diffuse transmission or reflection as light passes from one substance to another is dependent on the refractive index of each substance and the size and shape of the constituents in the substance diffusing the light.

2.3 Offshore Platform Lighting

Offshore platforms generally are fitted with lights for navigational support, helicopter safety, and worker safety and efficiency. In addition, an obstacle-lighting system was recently constructed to minimize collisions of eiders with structures on Northstar Island in the Beaufort Sea. The following discusses the design of these four lighting systems.

2.3.1 Aids to Navigation

As aids to navigation, obstruction lighting systems on oil and gas drilling and production platforms erected in OCS waters are under authority of the U.S. Coast Guard (USCG 2005) and Minerals Management Service (USDOI 2005). Specifically, obstruction lights on these platforms must be white, have 360° lenses, display a quick-flash characteristic of approximately 60 flashes/min, be of sufficient candlepower to be visible for at least 5 miles, and be displayed at a height not less than 20 ft above the water. When more than one light is displayed, all lights must be operated to flash in unison. Obstruction lights must be displayed at all times between the hours of sunset and sunrise and during periods of reduced visibility.

In addition, structures having a maximum horizontal dimension of 30 ft or less on any one side or diameter must have one obstruction light with 360° visibility. Structures having a maximum horizontal dimension of over 30 ft but not more than 50 ft must have two obstruction lights installed on diagonally opposite corners, or 180° apart on circular structures. Structures having horizontal dimensions of over 50 ft must have an obstruction light on each corner or 90° apart on circular structures.

2.3.2 Helicopter Flight Deck Lights

For night use, perimeter lights should delineate the heliport flight deck on offshore petroleum facilities. API recommends installation in accordance with API RP 2L (API 2005) by using alternating yellow and blue omnidirectional lights of approximately 30–60 watts (W) to outline the flight deck. Flood lights that could dazzle the pilot should be adequately shielded. Flight-deck obstructions also should be fitted with omnidirectional red lights.

The FAA does not have jurisdiction for helidecks on offshore platforms but would for onshore helidecks. Since 1996, the FAA standard for onshore helicopter deck lighting has been green (Don Gallagher, FAA, pers. comm.). The former standard for onshore helideck lighting was yellow, so some historical facilities may be exempt from the new standard and continue to use yellow.

2.3.3 Safety and Performance Lighting

Lighting for offshore platform installations also is used to provide for safety and facilitate job performance for operating personnel (API 2005). Safety lighting generally involves low levels of light, whereas job-performance lighting requires higher light levels. It is recommended that lighting systems be designed to provide for slightly greater than initially desired light levels to permit for deterioration of the lamp and dirt accumulation on the lens. According to API Recommended Practice 14F (API 2005), the minimum recommended level of illumination for safety in open deck areas is 0.5 ft-candles. The minimum recommended level of illumination for efficiently conducting visual tasks in open deck areas is 5 ft-candles. In addition, when installed in Division 1 locations (based on ignition potential), lighting fixtures (including ballasts) should be explosion-proof.

2.3.4 Anti-Collision Lighting

An anti-collision lighting system was constructed on Northstar Island in the Beaufort Sea to minimize the potential for collision of eiders with the infrastructure (Day et al. 2005). This system consisted of a series of 14 white strobe lights mounted on masts along the perimeter of the sheetpile wall, with 4 on the eastern side, 3 on the northern side, 5 on the western side, and 2 on the southern side of the island. These lights were mounted 45 ft above the surface of the ocean and fired at a rate of 40 flashes/minute. Lights fired asynchronously within and between each side of the island. The type of light was Honeywell Flashguard 2000B strobe lights which emitted white light (i.e., all wavelengths) from a daytime strobe light (20,000 candela) and a nighttime flashing light (2,000 candela) with the switching controlled by a photocell. This type of light is considered a medium-intensity obstacle light for marking tall structures for aviation safety (i.e., FAA type L-865 or L-866).

2.4 Light Sources

Light sources used on the Arctic coast, including off-shore platforms and various support facilities, probably are similar to those used in other commercial and industrial lighting applications. We did not find any information on the specific lighting sources used in the West Dock buildings and storage areas, Endicott Spur drilling island, and Northstar Island platform or communities such as Kaktovik, Barrow, Icy Cape, or Point Hope. General light source characteristics and use under typical conditions are discussed in the following (IESNA 2000, API 2005).

2.4.1 Incandescent

Although incandescent lights are not very energy efficient, they are inexpensive and the fixtures (luminaries) needed to house them also are inexpensive and easy to install. These lights usually are found in the interiors of buildings, often in reflector lamps mounted in down-light fixtures in the ceiling, and frequently are used in combination with fluorescent lamps. Incandescent lamps produce light by heating a tungsten wire filament to such a high temperature that light is emitted. Incandescent lighting is not recommended for general areas in offshore applications because of the short life of the lamp, its low efficiency, and its susceptibility to vibration (API 2005).

2.4.2 Fluorescent

Fluorescent lamps are low-pressure discharge sources, with light produced predominantly by fluorescent powders activated by UV photons in the gas discharge. Within the gas discharge, mercury atoms are stimulated by collisions with electrons, and then UV energy is emitted at 253.7 nm. This UV radiant energy excites phosphor powder that, in turn, gives off light in the visible region of the spectrum. Fluorescent lamps operate at about 30 W and produce about 2500 lumens. Because the light efficiency of the lamp depends on maintaining the mercury vapor pressure at a particular level, the lamps must stay cool, with surface temperatures on the order of 40–60°C.

To operate from normal AC line sources (100–240 V, 50–60 Hz), fluorescent lamps require ballasts between the line and the lamp for it to operate properly. Most ballasts made for fluorescent lamps are electronic devices that take the incoming line voltage and convert it to a high-frequency, controlled current source between 40 and 100 kHz that then flows through the gas of the tube. For integral Compact Florescent Bulb (CFL) products made to operate on the AC

line, the electronic ballast is built into the lamp structure. For linear lamps and some compact products, the ballast usually is a separate component.

Because fluorescent lamps are sensitive to cold temperature, they usually are not suitable for outdoor use in cold environments such as the study area. Such lamps usually are used in offices and other interior work areas requiring lighting levels of 10-70 ft-candles and in areas with low headroom because they have high lamp efficiency, long lamp life, and low profile.

2.4.3 High-Intensity Discharge

There are three types of High-Intensity Discharge (HID) lamps: High-Pressure Mercury, High Pressure Sodium, and Metal Halide. All of these lamps depend on a discharge in a mercury atmosphere whose pressure is on the order of a few atmospheres. They also have a partial atmosphere of argon or other rare gas fill to ignite the cold lamp. In the case of High-Pressure Mercury, the light is produced by the mercury arc itself. The arctube, usually made of quartz, is contained within a larger glass jacket to allow it to become hot enough to vaporize the mercury dose fully and to protect the environment from the UV radiation emitted by the arctube during lamp operation. The discharge is maintained between two metal electrodes, usually tungsten, that provide the current feed between the ballast and discharge tube.

High-Pressure Sodium lamps (HPS) are normally used in outdoor applications where accurate color rendering is not critical, such as roadway lighting. HPS has the highest light efficacy and longest life of any commercial light source (e.g., 140 lumens per W at 24,000 hours for a 400-W light source). The light comes from the pressure-broadened emission of the sodium D-line, which is dosed in the arc tube with mercury. Very little light is emitted in the blue end of the spectrum, making this lamp inferior in terms of color rendition. Because sodium ionizes much easier than mercury, no evidence of the mercury is seen in the light output; however, mercury is needed for the lamp operation. Because sodium reacts with quartz, the arctube is made from polycrystalline translucent alumina. Because alumina cannot be shaped once it has been formed, the sealing techniques are more complex than those for mercury or metal halide lamps.

In Metal Halide lamps (MH), their quartz arctube contains small amounts of metal halides mixed with mercury. The metal halides commonly found in these lamps are scandium and sodium iodide. As the arctube reaches thermal equilibrium through the discharge in the mercury atmosphere, the metal halides partially vaporize and then dissociate in the hotter parts of the arc.

The metal atoms then are electronically excited by the hot arc and emit light characteristic of that metal. By combining the metals and controlling the amounts of the halides, MH lamps can be designed that have good color rendering and lamp efficacies between 80 and 120 lumens per W, depending on wattage and type.

We could not find information on the specific light sources that are used to light the work areas of offshore platforms or onshore facilities, but such lighting probably would be produced primarily by metal halide sources. Further, the 400-W scandium-sodium lamp probably would be the most frequently used light source. Because HID sources, particularly MH sources, are rather compact, optical reflecting fixtures are easily constructed for increasing the intensity of light in a given direction. Such optical-fixture designs are commercially available from a variety of manufacturers, some specializing in providing such fixtures for offshore platforms. Those lights intended for use for offshore platforms would have to be explosion-proof and corrosion-resistant. Otherwise, their characteristics would be identical to those used in other large industrial facilities.

2.5 Spatial Measurement Characteristics of Lamps

The light output characteristics of lamps are described by four spatial parameters. First, the total light output of the lamp in all directions is called the **lumen output** or lumen flux. The lumen output is approximately proportional to the power input to the lamp for a given type of lamp. The normal relationship between power input and lumen output is given by the lamp efficacy. For Metal Halide and fluorescent-lamp sources, the efficacy of the lamp is on the order of 100 lumens per watt (lpw). In this case a 100-W lamp would produce 10,000 lumens. For comparison purposes, a 100-W incandescent household lamp produces about 1700 lumens; the efficacy of this lamp therefore is 17 lpw.

The most important parameter for lighting design is the **illuminance** that is provided at a given location. It is measured in lumens/ft^2, called ft-candles (fc) or lumens/m^2 (lux). Because a square meter contains almost 10 ft^2, the illuminance in lux is about ten times the illuminance as measured in ft-candles. The IESNA Handbook (2005) provides recommended values for the illuminance needed for various functions. These recommendations normally range between 1 and 100 fc. These illuminance recommendations by IES are often used in other standards or recommended practices, for example API Recommended Practice 14, Section 9 Lighting (API 2005). The issues involved in designing a space with a specific level of illuminance on a surface are the selection of lamp types, spacing, and wall/ceiling/floor reflectances.

Another term used for light output, particularly for reflector lamps, is the **luminous intensity**. The luminous intensity is the amount of light contained within a cone surrounding a given direction from the source. The luminous intensity of a source is constant with distance from the source. Reflector lamp properties describe the center-beam candlepower of the lamp and the beam size, usually assumed to be circular, in degrees from the center line of the beam. That center line usually is a line normal (perpendicular) to the surface lens of the lamp. The unit for luminous intensity, candlepower (cp), is lumens/steradian. A steradian is the solid angle that creates a surface area on a sphere equal to the radius of the sphere squared. Thus, the surface of a sphere has 4 steradians. For a source that emits light uniformly in all directions (e.g., the sun), the lumen output is 4π times the luminous intensity. The goal of reflector optics, either built in as an integral part of the lamp or as a separate fixture, is to collect most of the light generated by a source and concentrate it in a given direction. The smaller the beam angle, the larger the luminous intensity at the center of the beam becomes.

Because the amount of luminous flux within a cone is conserved, the amount of light/ unit area within that cone decreases as the square of the distance from the source. Thus, the illuminance of a source at a given distance from the source (d) is always given as the luminous intensity divided by the distance from the source squared (d^2). If the lamp candlepower value at the center of the beam is known, the illuminance at a given distance from the lamp can be calculated by dividing by the distance squared. Conversely, if the illuminance can be measured, the luminous intensity of the source can be calculated. These equations assume that a single source is responsible for the illuminance measured.

Another term used in lighting measurements is **luminance**. Luminance is defined as the luminous intensity in a given direction divided by the projected area of the source. Thus, the luminance of a fluorescent lamp is the luminous intensity divided by the projected area of the lamp. If one views a 4-ft, 1-in diameter fluorescent lamp normal to the lamp axis, then the luminance is the luminous intensity divided by the projected area of the lamp (i.e., 0.33 ft^2). For a fluorescent lamp with a 3000-lumen output, the luminous intensity normal to the lamp is about 300 cp, so the luminance is about 900 cp/ft^2. In contrast, a 400-W Metal Halide lamp produces about 40,000 lumens with a luminous intensity normal to the arc tube of about 4000 cp. The arctube is about 5 cm long, and its diameter is about 2 cm. Thus, the luminance is about 400,000 cp/ft^2, or over 400 times that of the fluorescent lamp. The Metal Halide candlepower value is 16

times that of the fluorescent, so at a distance 4 times farther from the Metal Halide source than from the fluorescent source, the illuminance created by both sources would be equal. However, the luminance does not change with distance, so that ratio remains constant. The luminance of a bare-filament incandescent lamp is about the same as that of a high-intensity discharge source because the filament is so small in area.

Luminance values cannot be increased with the aid of reflector optics. When a reflector is used to redirect the light from a high-intensity discharge lamp on a given object or surface within a given angle, the luminance is calculated as above using the larger candlepower values in the beam, but now dividing by the area of the reflector opening. The increase in size of the apparent source by the use of optics is as large as or larger than the increase in candlepower. Thus, the use of optical devices to focus the light in a given direction almost always will reduce the luminance of the source.

3.0 LIGHT MONITORING PROGRAM

3.1 Lighting on a Structure

Light monitoring can be conducted to assess the performance of a lighting system in comparison to specific design criteria (API 2005). Such criteria would include the lighting requirements of Stipulation No. 8 (USDOI 2003), whereby structures associated with offshore drilling in the Beaufort Sea must be lighted enough to avoid avian mortality but that light radiating outward from structures also must be minimized. To determine whether lighting levels are being minimized, a photometric survey with a light meter can be conducted, as described in Recommended Practice for Marine Lighting (IESNA 1997). Lighting levels in specific exterior areas would be compared with the minimum recommended levels of illumination for safety and efficiency on offshore petroleum facilities as shown in Tables 1 through 7 (API 2005). After initially adjusting lighting levels to produce slightly-more-than-desired light levels to allow for lamp deterioration and dirt accumulation on the fixture lens (API 2005), a determination would be made whether the outward radiation of light was being minimized.

Table 1. Minimum recommended levels of illumination for safety

Hazard Requiring Visual Detection	Slight	Slight	High	High
Normal Activity Level	Low	High	Low	High
Ft-candles	0.5	1.0	2.0	5.0

Table 2. Minimum recommended levels of illumination for efficient visual tasks

Area	Minimum Lighting Level (ft-candles)
Walkways, Stairways, Exterior	2.0
Entrance Door Stoops	5.0
Open Deck Areas	5.0
Wellhead Areas	5.0

Table 3. Minimum recommended levels of illumination for safety

Area	Minimum Lighting Level (ft-candles)
Stairways	2.0
Exterior Entrance	1.0
Open Deck Areas	0.5
Lower Catwalks	2.0

CIE (2003), in its Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations, described lighting limitations for a variety of lighting zones, from national parks to urban areas, as shown in Table 4. Offshore platforms and coastal infrastructures in the Beaufort Sea probably would be considered either Zone E2 (Rural, Low district brightness) or Zone E3 (Suburban, Medium district brightness) if outward lighting was to be minimized.

Table 4. Environmental lighting zone

Zone	Surrounding	Lighting Environment	Examples
E1	Natural	Intrinsically dark	National parks or protected sites
E2	Rural	Low district brightness	Industrial or residential rural areas
E3	Suburban	Medium district brightness	Industrial or residential suburbs
E4	Urban	High district brightness	Town centers and commercial areas

CIE (2005) has provided recommended maximum values of light parameters (in lux) for the control of obtrusive light. Values are provided for pre- and post-curfew conditions, with curfew meaning the time after which stricter requirements will apply for control of obtrusive light. The following are maximum values of vertical illuminance on surrounding properties (i.e., light trespass), with values the summation of all lighting installations.

Table 5 Maximal values of vertical illuminance

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Illuminance in Vertical Plane (E_v)	Pre-curfew	2 lux	5 lux	10 lux	25 lux
	Post-curfew	0 lux	1 lux	2 lux	5 lux

CIE (2003) provided maximum values for intensity of luminaries in designated directions (Table 6), where lighting is likely to be maintained, not momentary or short-term.

Table 6. Maximum values for intensity of luminaires in designated directions.

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Luminous Intensity Emitted by Luminaries (I)	Pre-curfew	2500 cd	7500 cd	10000 cd	25000 cd
	Post-curfew	0 cd*	500 cd	1000 cd	2500 cd

*Note: If luminaire is for public road lighting, this value may be up to 500 cd.

CIE (2005) and CIE (1997) also provided maximum values of Upward Light Ratio and/or area-lighting luminaire criteria with regard to limitation of sky glow, as shown in Table 7. Sky glow is defined as the brightening of the night sky caused by reflection of radiation scattered from atmospheric constituents (e.g., gas molecules, aerosols, particulates).

Table 7. Maximum values of Upward Light Ratio and/or area-lighting luminaire criteria.

Light Technical Parameter	Application Conditions	Environmental Zones			
		E1	E2	E3	E4
Upward Light Ratio (ULR)	Ratio of luminous flux incident on horizontal plane just above luminaire in its installed position, to total luminaire flux	0	0-5	0-15	0-25

If it is determined that outward light radiation is not being minimized on these structures, nonconformities would be recorded with respect to recommended practices, and recommended improvements in lighting for a given facility would be provided. Lighting design parameters could then be modified to reduce upward lighting, as described in CIE (2003). These modifications include greater mounting height, greater lamp setback, smaller luminous output, the use of controlled-beam or sharp-cutoff luminaires (e.g., use of louvers, baffles, or shields), or low vertical-aiming angle.

In addition, the Illuminating Engineering Society of North America (IESNA), jointly with the International Dark-Sky Association (IDA), is developing a Model Lighting Ordinance (MLO) for municipalities interested in regulating outdoor lighting. The MLO addresses four areas of concern: excessive lighting, light that trespasses onto neighboring properties, glare, and sky glow. The MLO will describe the Environmental Zones in more detail than CIE (2003) and will create zones for the candlepower distribution of fixtures.

3.2 Lighting at a Distance

The light emanating from an offshore drilling platform or land installation also can be quantified at a distance with a newly-developed instrument called the "NightMeter™ Light Trespass System", developed by Lighting Sciences, Inc., Scottsdale, AZ (http://www.lightingsciences.com/testingequipment.php). This instrument consists of a telephotometer (i.e., a combination of a telescope and a digital photometer) that is aimed at the

luminaire to be measured. The variable iris can be set to measure the luminance of a single luminary or a selected group of luminaries. A laser-based rangefinder is used to measure the distance to the light source. Once the horizontal distance and illuminance are known, the luminous intensity is calculated and displayed on the incorporated microprocessor and digital display. The display results then can be compared with the lighting-intensity limits agreed upon for the installation. The instrument can measure illuminance from 0.001 to 1500 lux (0.01–150 ft-candles) for a distance up to 3,280 ft. The instrument also can be used to measure lux in the vertical plane.

3.3 Modeling

Lighting levels on offshore platforms and associated structures also may be modeled with computer-software programs to achieve desired light parameters for a particular application. These commercially-available programs perform point-by-point calculations of either incident, direct, or reflected light on a real surface or an imaginary plane. Many of these programs allow the building of complex facility geometries with architectural shapes. A three-dimensional CAD model of the surface information of the facility also can be imported, and surface properties can be assigned during the import process.

Lighting-design programs can determine light parameters relative to "real" locations in XYZ space by using repetitive three-dimensional trigonometry and can display the results graphically for evaluation. Thus, the programs are used to predict or quantify the intensity and distribution of artificial or natural light in the environment. For this application, waste light, including upwards and sideways luminous flux to surfaces, sky, ground, and water from an individual luminary or the whole installation, may be calculated.

These computer programs also can graphically generate color images of the behavior and intensity of light within the environment and can indicate values relative to user-set limits. They also can be used to visualize and share different lighting scenarios before they are specified, purchased, and installed. Application design may be evaluated over a facility or an area, with average, minimum, and maximum values being used to assess compliance with design objectives.

Luminaires may be placed, oriented, and edited individually or in groups in a graphics mode for many of these programs. Navigation tools may allow real-time movement through the space and viewing of the facility from any angle to analyze light levels. The display of results may use

color to indicate the compliance of parameters as values at grid points in a 3-D layout view of the installation. The parameter profile may also be viewed as isolines or shaded diagrams to evaluate lighting intensity and patterns. Individual calculation points that exceed the limit can be highlighted, thus allowing design adjustments.

Many of these programs can calculate combinations of the following lighting parameters:

1) Horizontal and vertical illuminance;
2) Intensity from each luminaire;
3) Surface illuminance;
4) Waste light from the total installation;
5) Waste light determined for application surfaces, 'other' surfaces, sky, ground, or water;
6) Upward waste light ratio for each luminaire;
7) Total emitted flux and upward waste light ratio; and
8) Maximum upward intensity.

4.0 MITIGATION/MANAGEMENT CONSIDERATIONS

4.1 Offshore Platforms

According to Stipulation No. 8: Lighting of Lease Structures to Minimize Effects to Spectacled and Steller's eiders, lessees in the Beaufort Sea must minimize the radiation of light outward for all exploration or delineation structures so as to minimize the likelihood that migrating spectacled or Steller's eiders will strike these structures (USDOI 2003). Stipulation measures (*in italics*) follow, along with comments on their effectiveness based on this review:

- *Shading and/or light fixture placement to direct light inward and downward to living and work structures while minimizing light radiating upward and outward:* Field studies have quantitatively demonstrated that shielding lighting fixtures can reduce the attraction of birds to lighted structures, and significantly reduce associated mortality.

- *Types of lights:* The Dutch natural gas producer, NAM, continues to evaluate the differential attraction of birds to the type and spectrum of artificial light. Their studies have shown that birds may respond to shorter wavelength light (i.e., green) with less disorientation and/or attraction than longer wavelength light (i.e., white and red). The floodlights on an offshore platform in the North Sea have been exchanged for specifically designed green lights with the red spectrum deleted. Bird response studies for this platform showed a 2-10 times reduction in the number of circling birds, and a decrease in the number of birds landing on the platform.

- *Adjustment of the number and intensity of lights as needed during specific activities:* The review demonstrated strong evidence that decreasing both the number and intensity of lighting will reduce the attraction of birds to artificial lighting.

- *Dark paint colors for selected surfaces:* Painting structures a bright color has been proposed to reduce risk of bird collision. However, this has not been demonstrated in a controlled field experiment. Flat black paint was shown to consistently reduce the responses of whales to brightly reflective objects such as oceanographic cables and equipment housings.

- *Low reflecting finishes or coverings for selected surfaces:* No information was located regarding the use of low reflecting finishes or coverings for structure surfaces. The review found no studies that evaluated whether birds can better detect UV-reflective than non-reflective surfaces. In addition, strong evidence was not shown that bird use, mortality, or risk differed between wind turbine blades painted with a UV-light reflective paint and those painted with conventional paint.

- *Facility or equipment configuration*: Lighting design parameters may be modified to reduce upward lighting. These include greater mounting height, greater set back of lamp, smaller luminous output, using controlled beam or sharp-cutoff luminaires (e.g., use of louvers, baffles, or shields), and low vertical aiming angle.

USDOI requirements are to apply to all new and existing Outer Continental Shelf oil and gas leases issued between 156°W longitude and 146° W longitude for activities conducted between May 1 and October 31 (USDOI 2003). USDOI also encouraged operators to consider such measures in areas east of 146° W longitude because of occasional sightings of listed eiders and because such measures could reduce the potential for collisions of other, non-ESA listed migratory birds that are protected under the Migratory Bird Treaty Act. USDOI (2004) proposed similar lighting requirements to minimize the likelihood that migrating spectacled or Steller's eiders would strike a drill rig or tower structure associated with development of the Northwest National Petroleum Reserve in Alaska.

In its Biological Assessment of Steller's Eider and Spectacled Eider for the proposed DeLong Mountain Terminal facility on the eastern Chukchi Sea, USACE (2003) reviewed the attraction of these species to artificial light. They noted that the literature and testimony of vessel crews have documented that high-intensity lights of fishing boats and other vessels may attract sea birds, including eiders, and may result in collision. The risk of collision with the trestle facility was believed to be greater during darkness or inclement weather, and attraction to diffuse light tended to increase during rainy or foggy weather. They noted an unpublished USFWS report that hundreds of unidentified eiders had collided with Bering Sea crab vessels, probably after being attracted to the bright lights on board.

The lighting protocol for this facility included the minimization of light radiating outward by the use of shading and/or light fixture placement to direct light inward and downward to living and work surfaces, with the exception of strobe lights on the trestle and on the platform. Structures should be lighted and/or marked to make them more obvious to migrating eiders. These lighting requirements would apply only between May 1 and November 31, when listed eiders may be migrating through the area. The USACE (2003) also recommended that a casualty-collection system extending over the water be designed, installed, and monitored daily to catch birds that had collided with the infrastructure of the facility. Because birds are able to see color, brightly colored paint also may mitigate the potential for collisions with the trestle during fog. However, the authors suggested that seals would not be affected by painting the trestle a bright color because seals are essentially colorblind due to their eyes having only green cones.

In order to minimize attraction of birds to offshore platforms, an experimental program was designed by Day et al. (2005), which evaluated the effects of anti-collision lighting at Northstar

Island, Alaska on the movements and responses of eiders and other species. Results showed that the lights caused avoidance of the island by eiders but that response was inconsistent and not dramatic in most cases. At times, the lights actually appeared to cause attraction to the island. Based on their methodology, data would be collected on the movements, behavior, and flight altitudes of migrating eiders and other birds during the late summer and fall with ornithological radar and visual and night-vision equipment. Data would be collected in 25-minute sessions, and weather data would be collected during the 5-minute break. Data collected at beginning of each session would include wind direction, light condition, precipitation, visibility, moon phase, and lighting phase (on or off). Ornithological radar would be used to monitor movements of migrating birds. For each target echo seen, the following data would be collected: time of day, observation number, target species type, cardinal transect crossed, flight direction, flight velocity, flight behavior, island-passing success, and island passing distance. For each bird or flock seen, the following data were collected: species, flock size, flight direction, minimal flight altitude, island-passing behavior, change in flight altitude, distance from island at which behavior changed, and closest distance from island the flock approached. As with radar data, the time of day, general flight behavior, and island-passing success also would be collected. For the data summaries and analyses, the data would be examined in terms of environmental factors that have been shown to affect movements and/or collision rates of migrating birds.

Day et al. (2005) also recommended continued use of the lighting system at night during the fall migration of eiders. They suggested modifications to the existing system to improve the avoidance response of eiders, including changes in flashing rate, flashing synchrony, light intensity, and/or wavelength. The lighting system could be set up on offshore floats and the lighting parameters could be modified remotely. Also, research on captive animals could be undertaken to maximize the deterrent system's effectiveness.

Reed et al. (1985) demonstrated that light-shielding decreased attraction of Newell's shearwaters, dark-rumped petrels, and band-rumped storm-petrels to coastal flood lights by nearly 40% in Hawaii. Montevecchi (2006) also recommended shielding of lights to reduce impacts to seabirds, especially during peak fledgling periods. He also cautioned against the projection of light into the sea by extinguishing unnecessary inside and outside lights and by covering windows at night.

As described above, although painting structures a bright color has been proposed to reduce bird collisions, the use of UV-reflective paint has not been demonstrated to influence bird responses to

painted surfaces. This finding is based on a literature and field study of avian responses to UV-light reflective paint for the National Renewable Energy Laboratory (Young et al. 2003). The review found no studies that evaluated whether birds can detect UV-reflective surfaces better than non-reflective ones. In addition, in their field study at a wind farm in Wyoming, there was no strong evidence that bird (i.e., mostly passerines and raptors) use, mortality, or risk differed between turbine blades painted with a UV-light reflective paint and those painted with conventional paint.

Black (2005) indicated that researchers working under the Convention on the Conservation of Antarctic Marine Living resources have started modifying their activities to reduce light attraction of seabirds. First, shipping operations at some of the subantarctic islands with large populations of nesting seabirds that are known to become attracted to lights have been changed, such that major deck operations no longer are allowed during nocturnal hours. In addition, cabin windows now are sealed to prevent the escape of light, in that black-out blinds are used on all portholes and windows with external lighting are minimized to that required for safe navigation and vessel operation. In addition, the number of exterior lights that are lit has been minimized, and the ship's captain is to be notified if birds start colliding with the ship. In areas with the potential for icebergs, large ice lights (essentially bright deck lights) can still be used at night. However, newer technology that is available now as off-the-shelf products, such as infrared imagery, can be used at night to see icebergs at night while emitting no visible light (Day, personal observation). These ships currently are investigating this technology's utility in the Antarctic.

Following the change in light beam characteristics for a lighthouse on Lake Erie to a narrower and less powerful beam, a drastic reduction in songbird mortality was observed (Jones and Francis 2003). This result demonstrated the effectiveness of even simple changes in light signatures to decrease avian attraction to light. The authors suggested two techniques to minimize collisions of nocturnal migrants with tall, lighted structures. First, they recommended the downgrading of lighthouse lamp intensities was recommended because of advances in navigation technology. They also recommended changing to a flashing or intermittent light system, because fixed and rotating-beam systems appeared to be more attractive to birds. The interruption of a fixed light source may permit dispersion of birds "trapped" in the beam of light. Russell (2005) had similar conclusions for oil platforms in the Gulf of Mexico by suggesting that continuous lighting around a platform may cause birds to begin circling. He also suggested that

circling may be eliminated by designing lighting baffles or providing more directional lighting that interrupts the light source.

Deterrence equipment has also been suggested to lower the incidences of bird collision with structures. Breco Buoys, which emit a variety of loud digital noises from a floating unit, have been used as auditory deterrents for seaducks at oil platforms off the northern coast of Alaska (Kerlinger and Hatch 2001). Deterrence devices suggested for reducing bird collisions at wind farms include wire marking, flappers, bird flight-diverters, swan flight-diverters, and spiral vibration dampers (Avatar Environmental et al. 2004). Their effectiveness in hazing Arctic species from artificial light sources is not known.

4.2 Industrial Support Facilities

Manville (2005) recommended a series of procedures to reduce the risk of bird collision with buildings, bridges, and towers. Among the practices that could have application to the artificial lighting of industrial-support facilities are:

Buildings

- At night, turn off lights both inside (specifically the outside periphery offices where lighting can shine outside) and outside of buildings, especially during periods of migration.
- Avoid spotlights with powerful, continuous beams, ceilometers, and intense bright lights, especially during spring and fall migration and during inclement weather at night.
- Use minimal-intensity strobe (e.g., neon) or downward-shielded incandescent lights and reduce lumen intensity.
- Avoid continuous-red or pulsating-red incandescent lights on or near tall buildings or other structures. Evidence indicates that white and probably red strobe lights are less attractive to birds than is solid light of either color.
- Where lighting must be used (FAA 2000 Advisory Circular), minimum-intensity and maximum off-phased (3-second between flashes) white strobes are preferred.
- Where antennas are installed on buildings, avoid guy wire supports, especially in conjunction with incandescent lighting. Use lattice or monopole antenna-tower construction.

Bridges

- Where pilot warning/obstruction lighting is not an issue, use low-intensity/lower-wavelength blue, turquoise, or green lights. These wavelengths tend not to disrupt the magnetic orientation of several families of birds. In addition, avoid red and yellow lights.

- Use blue jelly-jar LED (Light Emitting Diode) lights on suspension cables and rectangular blue LED lights on bridge decks. These lights have low energy consumption, produce bright but directional light (25% as bright as a 100-W bulb), and provide for long-distance viewing while minimizing light pollution that could lead to bird attraction.

- Install lights during birds' non-nesting periods. Advice from the nearest USFWS Field Office should be sought, especially on when birds may be breeding.

- Turn off lights during spring and fall migration periods, especially during overcast, cloudy, and/or hazy conditions.

Antennas and Communication Towers

- Avoid lighted, guyed towers whenever possible.

5.0 DATA LIMITATIONS/GAPS

This review has demonstrated that numerous species of birds may be attracted to ambient artificial light, especially during inclement weather. In the study area, seabirds such as eiders and long-tailed ducks may be at risk of collision with lighted offshore platforms and industrial-support facilities. The literature review demonstrated that, at least for birds, the likelihood and severity of biological effects are likely to vary with local conditions of the environment (e.g., weather, season, time of day, lunar phase) and condition of the individual (e.g., age, migration phase). Mortality events that have been documented appear to be episodic and generally occur during inclement weather.

The mechanisms that could result in biological impacts, however, are sufficiently varied that no single explanation may be sufficient to describe the risk of impact from a particular type or source of artificial light. For example, the literature rarely described adequately the characteristics of such light to allow associated biological responses to be interpreted with confidence. Results often did not demonstrate potential ecological significance or were shown to support only limited quantitative conclusions. The data available on collisions of birds with lighted platforms remains very limited and often is collected non-systematically. Thus drawing general conclusions from such observations made under specific environmental circumstances may prove to be difficult.

This review demonstrated the paucity of research on the response of marine-oriented birds to artificial light. Some passerine species have been shown to differentially respond to both light duration and color spectrum. However, these conclusions generally have not been supported by controlled field studies. In addition, recent research in New York concluding that night-migrating birds respond less to red light than to shorter wavelengths appears to contradict many earlier studies that have found disorientation to be common in red lighting. It is also not known whether seabirds' responses to lighting are similar to those of passerines, and whether green lighting, as demonstrated for the North Sea offshore platform, would be as "bird-friendly" to distantly-related birds such as eiders.

For marine mammals, fishes, and invertebrates, significant gaps and uncertainties exist in the extent of knowledge about potential impacts of artificial light, including those species found in the Beaufort and Chukchi seas. For these taxa, strong evidence was not provided to show that the impacts of artificial light from offshore platforms or associated structures would be biologically

consistent and significant. Few studies have evaluated the responses of marine mammals, fishes, and invertebrates to artificial light, however, and their results generally are descriptive and qualitative. In addition, for those studies that have been conducted (e.g., disruption of circadian and/or circannual biological clocks in mammals) lighting effects were shown in captive populations but have not been experimentally demonstrated in the wild. We can only speculate regarding the effects of ambient artificial light on the trophic transfer of energy in the Beaufort and Chukchi seas and conclude that the state-of-science addressing the potential consequences of ambient artificial lighting from offshore platforms and support facilities on marine organisms remains limited in almost all cases.

6.0 ALTERNATIVE APPROACHES AND SAMPLING STRATEGIES

The following research needs could be addressed to better understand the impacts of artificial light on marine organisms in the study area.

1. Determine those light characteristics (i.e., color, type, duration, intensity, flashing synchronicity) and environmental conditions (e.g., weather) under which the effects of light on behavior might occur. Design experiments similar to those conducted by NAM in North Sea but target seabirds rather than passerines. Use offshore floats as lighting platforms and remotely modify lighting parameters. Also, monitor light impacts on marine mammals such as seals and polar bears in coastal areas. Station biologists on platforms and monitor bird responses as described in USDOI studies in the Gulf of Mexico.

2. Experiment with "bird-friendly" green lighting on a platform in Cook Inlet and compare results with other conventionally lit platforms.

3. Assess the influence of lighting on habitat choice by birds, marine mammals (e.g., seals, polar bears), and fishes. Studies should consider the extent of available habitat and usage, habituation, and behavioral interactions with artificially-lighted facilities. For fishes, could study the effects of artificial lighting on migratory behavior in coastal areas.

4. Develop a standardized protocol for data collection and a systematic analysis of bird collision casualties. Monitor direct impacts and assess factors that influence the ability to estimate mortality accurately. Potential has been shown for recording collisions acoustically or with radar or infrared monitoring.

5. Develop a model to forecast bird migration and collision potential in the Beaufort and Chukchi seas with the aid of weather forecasts to establish a basis for mitigation measures.

6. Evaluate operational practices to minimize lighting effects. For example, evaluate the effectiveness of daily (e.g., foggy evenings) or seasonal (e.g., during migration) lighting shutdowns.

7. Assess the utility of audiovisual, infrared, and radar technologies to detect bird species presence, abundance, location, height, and movement in the study area.

8. Monitor ongoing studies of light attraction to provide additional information on the potential responses of eiders and other sea ducks to lighted structures. These include the NAM lighting studies on the platform in the North Sea and evaluations of bird responses to offshore windfarm lighting in the North Sea.

9. Compare lighting assessments with deterrence-based lighting systems on existing structures that appear to be working effectively (e.g., Northstar Island).

10. Evaluate if artificially lighted structures may act as plankton accumulators through hydrodynamic entrainment and/or attraction to lights during dark periods.

7.0 CONCLUSIONS

Studies of ambient artificial light impacts on marine species have demonstrated that responses to light can vary widely by taxon and environmental conditions. These responses may be dependent on many factors, including the type of lighting, its spectral characteristics, and its intensity. Individual responses within a given species also may vary due to a combination of factors, including season, developmental stage, and previous exposure.

The volume of information regarding potential effects of lighting was much greater for arctic marine mammals and birds than for fishes and invertebrates. A moderate amount of literature on the potential responses of marine mammals to artificial lighting was reviewed, but little information pertained to the study area. Marine mammals are adapted for foraging under low light conditions, and those species found in the study area would forage for a large part of the year in dark habitats. Some information was located regarding the effects of moonlight on activity patterns, but literature on the impacts of artificial light was scarce. In general, marine mammals do not appear to be attracted by artificial lighting, but they may be locally disturbed. Some species such as seals have used artificial lighting in urban areas to increase foraging success on fish. Many of the potential physiological effects would be considered speculative, as many of the conclusions were based on laboratory studies, and little of that work has been tested in the field. In general, the potential impacts of artificial lighting on marine mammals in the study area are not well understood.

Many species of birds have been shown to be attracted to artificial light, especially during cloudy or inclement weather. The attraction of seabirds to offshore oil and gas platforms has been demonstrated in most of the world's marine regions where oil & gas development occurs, including the Beaufort Sea. This attraction of birds to artificially-lit structures may result in direct mortality through collision, which may occur with the lighted structures themselves or through disorientation that results in collision with the ground or other, unlighted structures. Birds also may suffer mortality from contacting flaring at offshore oil/gas platforms. This type of mortality appears to be episodic, with impacts ranging from no or minimal mortality to many thousands of birds killed by flaring. Birds also may be impacted by the increased energetic costs of migrating toward or circling of a lighted structure such as an offshore platform. Birds have been shown to be disoriented by longer-wavelength (i.e., red) light that may interfere with the bird's magnetic compass. Studies in the North Sea indicate that shorter wavelength (i.e., green)

lighting may be less attractive to birds, and an experimental program with green lighting on an offshore platform in the North Sea demonstrated a 2-10 times reduction in birds circling the platform. The seasonal presence and behavior of spectacled and Steller's eiders in the project area suggests a potential for collision risk in the Beaufort and Chukchi seas.

Studies on the impact of artificial light on fishes are limited, with few direct data available for assessing lighting effects on fish species in the Beaufort and Chukchi seas. Light is an important factor contributing to fish behavior. Studies focused in temperate regions have shown that fish migration, feeding, schooling, and other activities may be affected by changes in light frequency, duration, and/or intensity. Artificial lighting has been shown to modify the spatial distribution, daily movements, predation rates, and community structure of fish species in more temperate areas. Lights have been used to direct fish away from dams and intake pipes of power plants. However, there appears to be no single combination of spectrum, intensity, and duration that attracts or repels all species. The sensitivity of fish species in the Beaufort and Chukchi seas to artificial light remains to be evaluated, and any potential population-level impacts would be considered unknown at this time.

As with fishes, few direct data are available for assessing the effects of light on invertebrate species in the Beaufort and Chukchi seas. Changing light levels is considered the most likely stimulus for the diel vertical migration in many planktonic invertebrate taxa, but other environmental conditions such as ice cover and hydrographic factors also may contribute. Research on the effects of artificial lighting on marine invertebrates worldwide is limited, and there was essentially no information in the literature on this topic for invertebrates that inhabit the study area.

The literature review showed that offshore platforms generally are fitted with lights for navigational support, helicopter safety, and worker safety and efficiency. Navigational lighting is under the authority of the US Coast Guard and Minerals Management Service, whereas helicopter flight-deck lighting must adhere to FAA standards when onshore or API recommendations when offshore. Safety and performance lighting may follow API recommendations. An obstacle-lighting system designed to minimize the potential for collisions of eiders with structures on Northstar Island in the Beaufort Sea also was described.

Light sources on offshore platforms and on support facilities along the Arctic coast probably are the same as those used in other commercial and industrial lighting applications, with the exception that fluorescent lights would not be used outside because of their ineffectiveness at low temperatures.

A light monitoring program for lease structures was proposed in Section 3.0 to ensure that upward and outward lighting levels are minimized to reduce the collision risk of migrating eiders. For this program, lighting levels in specific exterior areas would be compared with those recommended for safety, efficiency, and/or control of obtrusive light, based on API and CIE criteria. A determination then would be made whether these light-minimization requirements were being followed; if not, the lighting system on the structure could be re-designed accordingly. Lighting levels also could be modeled using commercially-available computer software programs, and the lighting system could be modified to achieve desired light parameters.

Mitigation and management procedures were presented, and their potential effectiveness was evaluated individually in terms of reducing potential for bird collision with structures. Measures holding the most promise included reducing the number and intensity of lights, shading lights, shielding unnecessary light, possibly using shorter wavelength (i.e., toward green) luminaires, and using intermittent lighting systems. Proposed measures for which effectiveness may be weak included the color of paint and the use of low-reflecting or UV-reflecting finishes. Very little information was located on mitigation for the attraction of marine mammals, fishes, and invertebrates to artificial ambient light.

In summary, for the Beaufort and Chukchi sea region, which is dark for a significant portion of the year, the current state of knowledge on the effects of artificial light on marine fauna is extremely limited. Potential impacts of lighting on offshore platforms or support facilities could include the attraction or repulsion of some species of birds, seals, fishes, and invertebrates. The result could be the localized, short-term abundance or dispersal of some species. The risk of bird collision with these structures most likely would be decreased if lighting levels on the platforms and industrial support facilities were minimized. The potential for ecologically significant or long-term impacts from ambient artificial lighting on regional populations of marine fauna can only be speculated on at this time.

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The Department of the Interior Mission

As the nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the Offshore Minerals Management Program administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil, and other mineral resources. The MMS Royalty Management Program meets its responsibilities by ensuring the efficient, timely, and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States, and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: 1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties; and 2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.