Marine Pollution Bulletin 60 (2010) 1383–1385

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Editorial

Light pollution in the sea

Chemical pollutants, coastal zone destruction, habitat loss, nutrient discharges, hypoxic zones, algal blooms and catastrophic overfishing have all heavily impacted life in our oceans (Bowen and Depledge, 2006). Major efforts are being made worldwide to manage and minimise these threats. However, one particular pollutant, light, is still permitted to flood into our seas almost unchecked. It is alarming that as the intentional and unintentional illumination of the coastal zone and nearshore environment increases unabated, we still have little idea of the extent to which intertidal and sublittoral ecosystems are being affected. There is also growing concern regarding the introduction of light into the deep sea (Widder et al., 2005).

1. Sensitivity to light

Almost all living organisms are sensitive to changes in the quality and intensity of natural light in the environment (Longcore and Rich, 2004). This is such a widely distributed characteristic that it seems likely to have arisen very early in evolutionary history, possibly on several occasions. It might even suggest that the evolution of life in the oceans proceeded largely in the photic zone. Obviously, for algae and seaweeds, photosynthetic activity is critically dependent on available light, while in marine animals, tidal, daily, monthly and seasonal cycles in natural light intensity and quality are reflected in rhythmical fluctuations in behaviour and physiology that are appropriately tuned to the prevailing ecological circumstances (Depledge, 1984).

Humans use the influence of light on several kinds of organisms to great advantage. For example, for centuries fishermen have deployed lanterns to attract fish to their nets, while modern day natural resource managers set out lights to attract larval fish to coral reefs to boost fish stocks and enhance biodiversity (Munday et al., 1998). There are numerous vivid accounts in the literature of people using their knowledge of light-entrained rhythms to reap rewards. South Pacific islanders for example, exploit moon phase spawning of polychaete worms to ensure bountiful harvests of eggs and sperm that are considered a culinary delicacy (Thorson, 1971).

2. Light pollution

Light pollution of the sea has only become a really significant issue over the last ca. 50–80 years. It has been defined as the “degradation of the photic habitat by artificial light” (Verheijhen, 1985). Simply put, light pollution occurs when organisms are exposed to light in the wrong place, at the wrong time or at the wrong intensity. Following the mounting, well-publicised evidence of disturbance of the behaviour of birds, bats and insects, there is now growing concern that light pollution might exert damaging effects on aquatic species in lakes, rivers and our seas, especially in coastal areas. All organisms equipped with an optic orientation system are potentially susceptible. In the sea, the behaviour, reproduction and survival of marine invertebrates, amphibians, fish and birds have been shown to be influenced by artificial lights (Verheijhen, 1985). These effects arise from changes in orientation, disorientation, or misorientation and attraction or repulsion from altered light environments (Longcore and Rich, 2004; Salmon et al., 1995). In animals exhibiting compulsive stimulus behaviour, the strength and number of artificial lights may override any feedback control mechanisms. This is exemplified by sea turtles hatchlings that rely on visual cues to orient themselves seaward, which consequently renders them vulnerable to light pollution. In one anecdotal report, 500 green sea turtle hatchlings crawled to their deaths in an unattended bonfire on a beach of Ascension Island (Mortimer, 1979). On a Turkish beach, light pollution arising from a paper mill, a tourist resort and a coastal village led to less than 40% of loggerhead turtle hatchlings reaching the surf (Peters and Verhoeven, 1994). The construction of buildings in close proximity to critically important nesting beaches, as seen in the recent urban development in Gabon’s capital, Libreville, places human populations and their attendant light sources close to critical nesting sites for the endangered leatherback sea turtle (Bourgeois et al., 2009). Disorientation and misorientation due to light pollution often divert hatchlings along their paths to the sea leading to unnecessary energy expenditure and increased risks of dehydration and terrestrial predation (Bourgeois et al., 2009; Verheijhen, 1985). Urban skylines can present irregular silhouettes and as a result, unreliable cues to female turtles. The confusing horizon field presented to new hatchlings which rely heavily on horizon elevation cues results in increased mortality (Salmon, 2006). Indirect adverse effects of artificial lighting include a higher risk of human interference via greater likelihood of approach towards more visible animals and of abandonment of nesting attempts if turtles become aware of humans prior to oviposition.

Other ecological effects of light pollution include disruption of predator–prey relationships. For example, Harbor seals (*Phoca vitulina*) congregate to feed in illuminated areas on juvenile salmon as they migrated downstream. Predation falls off when the lights are turned off (Yurk and Trites, 2000). In zooplankton, vertical migrations in the water column with the day–night cycle help to reduce predation by fish and other marine organisms, when light is available (Gliwicz, 1986). Artificial light disturbs this activity. Community changes arising from light pollution may have knock on effects for ecosystem functions (Gliwicz, 1986, 1999). Even remote areas can still be exposed to sky glow. Along the expanding front of suburbanization, light may spill into wetlands and estuaries that

0025-326X/$ - see front matter
doi:10.1016/j.marpolbul.2010.08.002

are often the last open spaces in, or close to, cities (Longcore and Rich, 2004).

Perhaps surprisingly, light pollution penetrates into deep ocean environments (Kochevar, 1998). Here, only very dim, homochromatic, down light is available, supplemented by bioluminescence from marine organisms. Most inhabitants possess highly specialized visual systems, which are incredibly sensitive to even minute amounts of light. This renders these organisms extremely vulnerable to damage associated with bright artificial lights of manned and unmanned submersible vehicles (Kochevar, 1998). The current efforts to deal with the oil well disaster in the Gulf of Mexico has revealed the extent to which light pollution can occur in the deep sea, albeit that the effects are secondary to the effects of oil pollution in this case.

There is a widely held, but incorrect belief that organisms living in caves (whether under the sea or under land masses) do not come into contact with light and are therefore insensitive to it. However, as with deep sea creatures, many cave dwelling organisms are bioluminescent and are exquisitely sensitive to any ambient light and light pollution. Most if not all, cave dwelling organisms and others living remotely from daylight, evolved from organisms that at one time dwelt in the light and hence retain vestiges of light sensing systems.

3. Growing concerns regarding light pollution

Over the last ca. 150 years there has been an exponential increase in the use of artificial light to illuminate the night. This trend continues to this day. On land, street lights, lighting in office buildings and homes, and floodlit sports facilities, industrial complexes, etc., are the sources which inadvertently introduce light into nature (RCEP, 2009). In coastal areas, where many of our major cities such as Mumbai, Shanghai, Alexandria, Miami, New York City and London are located, long stretches of the shoreline are strongly illuminated. Indeed, light pollution of shallow seas has become a global phenomenon (Elvidge et al., 1997). There are at least 3351 cities in the coastal zones around the world shedding light onto beaches and into sublittoral areas. In Asia, 18 of the region's 20 largest cities are located on the coast, on river banks or in deltas. Even in Africa where the availability of electric lighting is sometimes limited, coastal light pollution is emitted from major cities such as Abidjan, Accra, Algiers, Cape Town, Casablanca, Dakar, Dar es Salaam, Djibouti, Durban, Freetown, Lagos, Luanda, Maputo, Mombasa, Port Louis and Tunis (UN-HABITAT, 2009).

Our understanding of the polluting nature of artificial light is emerging concurrently with an understanding of how patterns of human development and economic globalization are intensifying its impact. The UN estimates that the global population will increase to a point where there are two and one half billion more human inhabitants than today (UNPOPIN). Inevitably, this growth will be associated with further light pollution. The nature and scale of growth provides an even louder clarion call for focus on the environmental consequences of artificial light as well the need to mitigate those consequences. The main conclusion to be drawn from looking at the changing population dynamics over the next generation is that virtually all of the two and half billion new citizens of our World will live in small and medium sized cities within emerging economies (Balk et al., 2008). Thus, while mega-cities continue in their dominant position, more modest sized cities will serve as the true future centres of growth. This means that artificial light will not only continue to intensify with population growth, but that the number of locations of high intensity light pollution will also increase dramatically. Even in areas where total population growth is low, such as in the OECD countries, analysis suggests that the environmental influences of night light will continue to spread. Consideration of data provided by the US National Geophysical Data Center (NOAA), reveals that total population growth and the spatial patterns of human growth can be, and often are, unrelated (Bowen et al., 2006; FAO, 2005). Migration to the coast, so common in many parts of the world, and the "sprawl" of development, present a challenge regardless of total population growth rates.

While most of the future increase in artificial light will reside with permanent resident populations, economic globalization will also play a role. In 2009, the UN World Tourism Organization (UNWTO) estimated that there were nearly 900 million international tourist arrivals worldwide. The economic growth and development pressure (very often coastal) of new supporting infrastructure, driven by international tourism, cannot be ignored. Indeed, touristic development may be a disproportionately important driver of artificial light use simply because it tends to occur in areas of enhanced natural beauty – and environmental vulnerability. In other words, wherever tourism increases, so too does light pollution.

Holiday visits to beaches vividly reveal the extent to which artificial lighting systems have been deployed along coastlines. More systematic studies demonstrate the extent of the change that has occurred. Innovative research using satellite imagery has tracked the movement of populations over time. This is based on the principle that wherever human population density increases it is almost always associated with increased use of artificial light at night. From a comparison of images taken at various times over the past 50 years with present day images, it is clear that not only has population density increased in many coastal areas around the World, but this is associated with dramatic increases in light intensity in the coastal zone.

4. What can be done?

From a mitigatory/regulatory perspective the above mentioned patterns of human population change may provide vehicles to more efficiently limit future environmental damage associated with artificial light. If intensifying urbanization is effectively anticipated and understood, it might be easier to coordinate regulatory responses and technological efficiencies of scale. Thus, if most of the future growth is geographically concentrated, the ability to coordinate light pollution control measures could be enhanced. The same might be said of touristic development. It provides a commonality of activity that can be dealt with by a more concerted and directed response.

In all other spheres of activity that result in artificial light impacting marine life, there are clearly possibilities to regulate light spillage into the sea. Whether from coastal developments or fishing, or from oil and mining exploration or from cruise liners and other merchant shipping activities, there are a wide range of opportunities to regulate and thereby minimise potential adverse effects of light pollution. Simply embedding the idea that in everything we do, consideration needs to be given to minimising the amount of light we release into the environment, would be a helpful step forward.

5. Summary

Whatever is done, it is first and foremost essential to recognize the scale and scope of the potential problem in hand. It is almost unimaginable that if we discovered a new pollutant today that had pronounced effects on fundamental cellular processes, that affected biological rhythms of cells, and that potentially affect photosynthesis, that we would not control or regulate its release into natural ecosystems! Yet this is precisely what we do when we allow light to spill into our seas, estuaries, rivers and lakes, as well as into terrestrial ecosystems. The evidence is clear that the feeding, reproductive and migratory behaviour of some species is already affected. It seems timely therefore to reconsider our profligate use of light and to pay more attention to its biological effects. If nothing else, more prudent use of artificial light would also reduced energy consumption and related greenhouse gas emissions, surely a worthy goal in itself?

Acknowledgements

We gratefully acknowledge the support of the UK Government Foreign and Commonwealth Office and of the Peninsula Foundation, UK, for providing financial support to facilitate collaboration among the authors.

References

Balk, D., McGranahan, G., Anderson, B., 2008. Urbanization and ecosystems: recent patterns and future implications. In: Martine, G., McGranahan, G., Montgomery, M. (Eds.), The New Global Frontier: Cities, Poverty and Environment in the 21st Century. Earthscan Publishers, London, pp. 183–201.

Bourgeois, S., Gilot-Fromont, E., Viallefont, A., Boussamba, F., Deem, S.L., 2009. Influence of artificial lights, logs and erosion on leatherback sea turtle hatchling orientation at Pongara National Park, Gabon. Biol. Conserv. 142, 85–93.

Bowen, R.E., Depledge, M.H., 2006. Rapid assessment of marine pollution. Mar. Pollut. Bull. 53, 541–544.

Bowen, R.E., Davis, M., Frankic, A., 2006. Human development and resource use in the coastal zone: influences on public health. Oceanography 19 (2), 62–71.

Depledge, M.H., 1984. Disruption of endogenous rhythms in *Carcinus maenas* following exposure to heavy metal pollution. Comp. Biochem. Physiol. 78A (2), 375–379.

Elvidge, C., Baugh, K.E., Kihn, E.A., Davis, E.R., 1997. Mapping city lights with nighttime data from DMSP Operational Linescan System. Photogramm. Eng. Rem. Sens. 63, 727–734.

FAO, 2005. Coastal GTOS draft strategic design and phase I implementation plan. In: Christian, Robert, Baird, D., Bowen, Robert E., Clark, David, DiGiacomo, Paul, de Mora, S., Jimenez, J., Kineman, John, Mazzilli, S., Servin, G., Talaue-McManus, L., Viaroli, P., Yap, Helen (Eds.). GTOS Report No. 36. FAO, Rome, 93pp.

Gliwicz, Z.M., 1986. A lunar cycle in zooplankton. Ecology 67, 883–897.

Gliwicz, Z.M., 1999. Predictability of seasonal and diel events in tropical and temperate lakes and reservoirs. In: Tundisi, J.G., Straskaba, M. (Eds.), Theoretical Reservoir Ecology and Its Applications. International Institute of Ecology, Sao Carlos.

Kochevar, R.E., 1998. Effects of Artificial Light on Deep Sea Organisms: Recommendations for Ongoing Use of Artificial Lights on Deep Sea Submersibles. Technical Report to the Monterey Bay National Marine Sanctuary Research Activity Panel.

Longcore, T., Rich, C., 2004. Ecological light pollution. Front. Ecol. Environ. 2 (4), 191–198.

Mortimer, J.A., 1979. Ascension Island: British Jeopardize 45 years of conservation. Mar. Turtle Newslett. 10, 7–8.

Munday, P.L., Jones, G.P., Öhman, M.C., Kaly, U.L., 1998. Enhancement of recruitment to coral reefs using light-attractors. Bull. Mar. Sci. 63, 581–588.

National Oceanic and Atmospheric Administration (NOAA), US National Geophysical Data Center, Version 4 DMSP-OLS Nighttime Lights Time Series. <http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html>.

Peters, A., Verhoeven, K.J.F., 1994. Impact of artificial light on the seaward orientation of hatchling loggerhead turtles. J. Herpetol. 28, 112–114.

Royal Commission on Environmental Pollution, 2009. Artificial Light in the Environment. TSO, London, 43pp.

Salmon, M., 2006. Protecting sea turtles from artificial night lighting at Floridás oceanic beaches. In: Rich, C., Longcore, T. (Eds.). Ecological Consequences of Artificial Night Lighting. pp. 141–168.

Salmon, M., Tolbert, M.G., Painter, D.P., Goff, M., Reiners, R., 1995. Behavior of Loggerhead turtles on an urban beach: hatchling orientation. J. Herpetol. 29, 568–576.

Thorson, G., 1971. Life in the Sea. World University Library, London. 256pp.

UN-HABITAT (2009). ‘‘State of the World's Cities 2008/9: Harmonious Cities" launched by the United Nations Human Settlements Program (UN-HABITAT).

United Nations, Department of Economic and Social Affairs, Population Division (UNPOPIN). <http://www.un.org/esa/population>.

Verheijhen, F.J., 1985. Photopollution: artificial light optic spatial control systems fail to cope with incidents, causations, remedies. Exp. Biol. 44, 1–18.

Widder, E.A., Robinson, B.H., Reisenbichler, K.R., Haddock, S.H.D., 2005. Using red light for in situ observations of deep-sea fishes. Deep Sea Res. Part I: Oceanogr. Res. Papers 52 (11), 2077–2085.

Yurk, H., Trites, A.W., 2000. Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. Trans. Am. Fish Soc. 129, 1360–1366.

Michael H. Depledge
European Centre for Environment and Human Health,
Peninsula Medical School,
Universities of Exeter and Plymouth,
Truro, TR1 3HD, UK
E-mail address: michael.depledge@pms.ac.uk

Céline A.J. Godard-Codding
Department of Environmental Toxicology,
The Institute of Environmental and Human Health,
Texas Tech University,
Lubbock, TX 79409, USA

Robert E. Bowen
Environmental, Coastal and Ocean Sciences,
University of Massachussetts,
Boston, MA, USA