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review

Fishing in the dark: the science and management of recreational fisheries at night

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ABSTRACT.—Recreational fishing is a popular activity around the globe, generating billions of dollars in economic benefit based on fisheries in marine and inland waters. In most developed countries, recreational fisheries are managed to achieve diverse objectives and ensure that such fisheries are sustainable. While many anglers fish during daylight hours, some target fish species during the night. Indeed, sensory physiology of some species makes them vulnerable to capture at night, while being more difficult to capture during the day. However, night creates a number of challenges for recreational fisheries assessment and management. In some jurisdictions, fishing is prohibited at night (through both effort and harvest controls) or there are specific restrictions placed on night fisheries (e.g., no use of artificial lights). Here, we summarize the science and management of recreational fisheries at night covering both inland and marine realms. In doing so, we also provide a review of different angling regulations specific to night fisheries across the globe, as well as the basis for those regulations. We discuss the extent to which there is both need and opportunity to actively manage anglers who are targeting fish at night and how this differs from fisheries that occur during lighted periods. We provide two case studies, one for white sturgeon (*Acipenser transmontanus* Richardson, 1836) and one for walleye [*Sander vitreus* (Mitchill, 1818)], for which nighttime closures have been used as a fisheries management tool to control effort and harvest (illegal harvest in the case of the sturgeon case study). Based on the synthesis, we conclude that natural resource management agencies should decide if and how they need to manage recreational fisheries at night, recognizing the practical challenges (e.g., compliance monitoring, stock assessment) with doing so in the dark.

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Recreational fishing is defined as fishing of aquatic animals (mainly fish) that do not constitute the individual's primary resource to meet basic nutritional needs and are generally not sold or otherwise traded on export, domestic, or black markets (UN FAO 2012). It is a popular activity around the globe, estimated to be practiced by approximately 10% of the global population (Arlinghaus and Cooke 2009, Arlinghaus et al. 2015b). On an annual basis, as many as 40 billion fishes may be captured by recreational fishers, of which more than half are released (Cooke and Cowx 2004). Recreational fishing yields numerous benefits around the globe, not the least of which is generation of tens of billions of dollars of direct and indirect economic activity (Arlinghaus and Cooke 2009, Tufts et al. 2015). A variety of gear types can be used in recreational fisheries, but the dominant one is rod and reel (i.e., angling). Although relative to commercial fisheries, the effects of recreational fishing on global fish decline and the environment are regarded as more benign (Cooke and Cowx 2006, Lewin et al. 2006), there are certainly examples of fish population declines and even collapse attributed to recreational fishing (see Post et al. 2002). Increasingly, recreational fishing targets species or populations that are declining, which is creating a number of management challenges (Coleman et al. 2004, Cooke et al. 2016).

Given the importance of recreational fishing, it is not surprising that in many jurisdictions, particularly in developed countries, governance structures exist to support the sustainable management of recreational fisheries. Typically underpinning such management efforts are science-based fishery assessments. In developing countries and emerging economies, science capacity is often lacking and governance structures (in terms of policy instruments) fail to provide natural resource agencies with the tools and support needed to actively manage fisheries. At the core of recreational fisheries management are traditional harvest control regulations such as bag limits and size limits (Johnson and Martinez 1995). However, effort controls are gaining in popularity (e.g., protected areas, seasonal closures, Cox et al. 2003). Recreational fisheries management is often regarded as a partnership between government and various stakeholder groups through formal or informal co-management agreements (UN FAO 2012). With adequate regulations related to harvest and effort control, along with requisite habitat protection (see Lapointe et al. 2014), most recreational fisheries can be managed to achieve multiple benefits.

Nighttime (and its associated darkness) is omnipresent around the globe and many fishes can certainly be captured during nocturnal periods, reflecting species-specific differences in sensory physiology and feeding activity. Quantifying the number of anglers who fish at night has a number of practical challenges (e.g., safety and logistics of working on or near water at night). From an enforcement perspective, night and its associated darkness can provide "cover" for those that intend to not comply with regulations. From a science and management perspective, the vast majority of staff effort is focused on daytime periods. Here, we provide the first synthesis on the science and management of recreational fisheries at night. First, we describe fishing at night from the perspective of a fish, exploring how species-specific sensory physiology and biology contributes to vulnerability to capture. Next, we characterize the state of night fishing, identifying examples of specific tactics used to target fish at night. Then, we summarize the science and assessment of fishing at night needed to support fisheries management. Finally, we explore strategies used to manage fishing at night with a particular focus on policy compliance challenges using several case studies where night-specific management regulations have been implemented.

With increasing recreational fishing effort on a global basis, it is our hope that our synthesis will provide managers with information to achieve recreational fisheries sustainability by managing fisheries around the clock, not just during daylight. We are global in our approach, covering marine and inland recreational fisheries, but limit our review to recreational angling (i.e., fishing via hook and line). We recognize that depending on latitude (e.g., polar regions) and season, night and darkness are not always aligned, but for the purpose of our synthesis, we take night to imply darkness at least in a relative sense compared to daytime periods.

Fishing at Night from a Fish's Perspective

Predatory gamefishes exhibit species-specific diurnal rhythms in both sensory physiology and feeding activity (Reebs 2002). Physiological adaptations of gamefishes to low light levels, including overcast conditions, crepuscular periods, and night, may explain why catches of many species peak at these times. Midday clouds can drop aquatic light intensities by one to two orders of magnitude; during crepuscular periods, intensity can change roughly tenfold every 10 min (Fig. 1A). Natural nocturnal light levels are a million to a billion times dimmer than those at high noon, depending on moon phase (Warrant 1999, Johnsen 2012). Many predatory fishes forage visually, using rod photoreceptors during scotopic (dim/dark) conditions to increase sensitivity and form monochromatic images, and cone photoreceptors under photopic (bright) conditions to form high-resolution, contrasting images of prey. Nocturnal foragers have large eyes, a high rod:cone ratio, slow vision, poor acuity, prevalent tapeta lucida, high luminous sensitivity (Warrant 1999, Horodysky et al. 2008), and/or may have enhancements in chemosensory and mechanosensory systems for food search (Pohlmann et al. 2004). Examples of such fishes include walleye [*Sander vitreus* (Mitchill, 1818)], adult brown trout (*Salmo trutta* Linnaeus, 1758) and bull trout [*Salvelinus confluentus* (Suckley, 1859)], channel catfish [*Ictalurus punctatus* (Rafinesque, 1818)], weakfish [*Cynoscion regalis* (Bloch and Schneider, 1801)], and swordfish (*Xiphias gladius* Linnaeus, 1758). By contrast, predators of daylight hours have smaller eyes, higher cone:rod ratios, faster vision, better acuity, wider chromatic sensitivity, and moderate luminous sensitivity (Horodysky et al. 2008). Examples of these fishes include bonefish (*Albula* spp.), striped bass (*Morone saxatilis* (Walbaum, 1792)], yellow perch [*Perca flavescens* (Mitchill, 1814)], and northern pike (*Esox lucius* Linnaeus, 1758). Of course, the latter species can still be captured under low light levels.

Within a species, luminous sensitivity can be extended under falling light levels as permitted by physical and physiological bounds by widening pupils, increasing temporal and spatial summation of ganglion cells, and/or via circadian retinomotor movements that withdraw the pigment epithelium protecting rod photoreceptors from daylight (Fig. 1B, Warrant 1999). However, because of unavoidable tradeoffs, physiological responses that increase sensitivity come at the cost of slower temporal resolution, reductions in acuity due to reduced spatial summation, and constrained chromatic sensitivity (Horodysky et al. 2010). Under natural low-light conditions, diurnal predatory fishes may be forced to cease visual foraging when image formation is impaired, and turn increasingly to encounter-based chemosensory, acoustic, and/or mechanoreceptive cues to locate and track prey as per species-specific adaptations and abilities (Hara and Zielinski 2006). Some dim-light and nocturnal

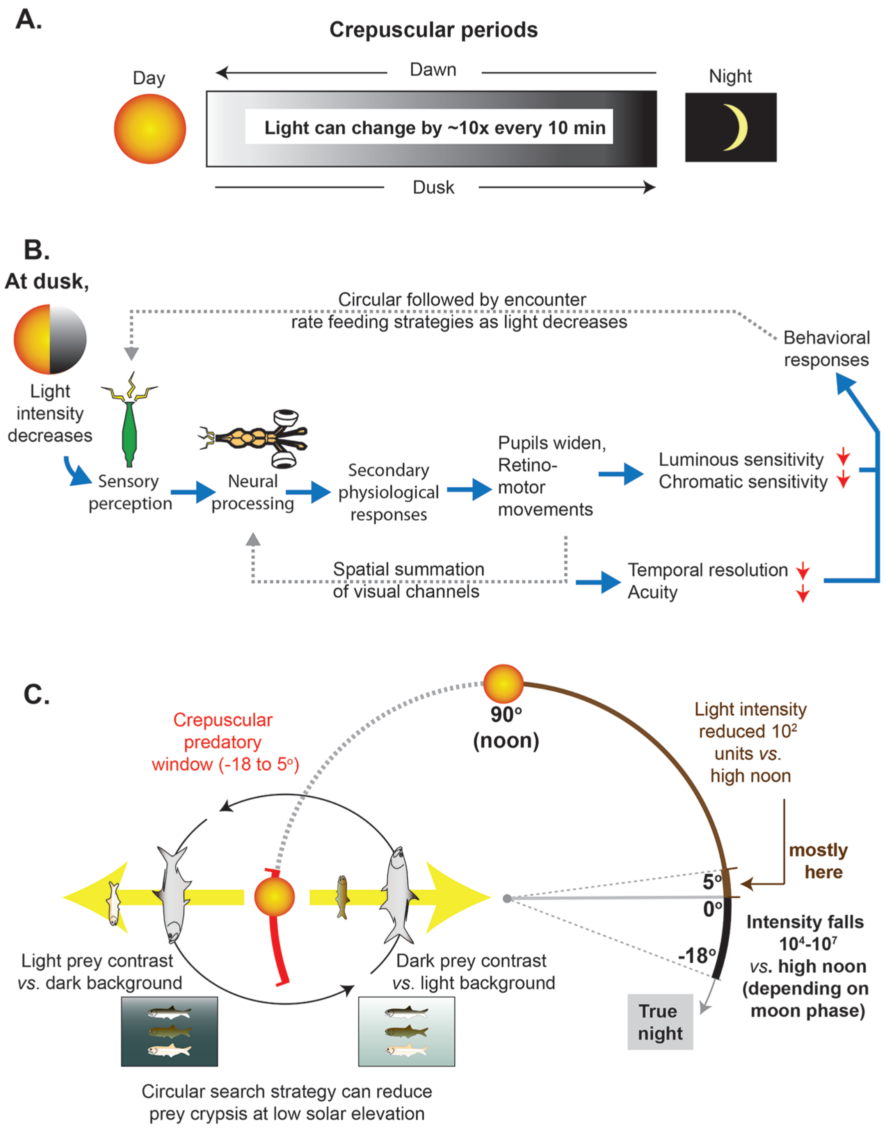

Figure 1. Mechanistic examination of light conditions, ecophysiological processes, and behavioral strategies during crepuscular periods. (A) Changes in light intensity during dawn and dusk. (B) Mechanistic pathways (blue arrows) of changes in light intensity at dusk on physiology and behavior, with feedbacks (dashed gray arrows). (C) Effects of low solar elevation and changing light intensities characteristic of crepuscular periods on prey visual contrast and behavioral foraging strategies of a predator (following Johnsen 2003, Johnsen and Sosik 2003).

foragers such as burbot [*Lota lota* (Linnaeus, 1758)] and flathead catfish [*Pylodictis olivaris* (Rafinesque, 1818)] may cue predominantly on chemosensory cues (Døving and Gemne 1965, Hinkens and Cochran 1988, Daugherty and Sutton 2005), which are dependent on water flow, and may be less affected by aquatic photodynamism.

Crepuscular periods are brief photodynamic windows enveloping the night in which the solar elevation is low, light intensity and spectra change rapidly, and many prey countershading and camouflage strategies can be counteracted by predators and exploited by anglers (Fig. 1C) (Johnsen 2003, 2012). It is thus not surprising that much fishing effort is exerted, and angling success experienced, at these times. Light intensity changes by roughly 2 log units between 0° and 5° of solar elevation, as the sun is near the horizon (Johnsen 2003, 2012). Below the horizon, light changes by 10^4–10^7 units from the time of first/last light (–18°) to sunrise/sunset (i.e., 0°), and is intensely dominated by shorter (UV and blue) wavelengths (Warrant and Johnsen 2013). Once the sun is >18° below the horizon (i.e., true night), the blue twilight is replaced by dimmer and redder starlight, airglow, and zodiacal light (new moon), by a dim spectrum that resembles slightly red-shifted daylight in spectral composition (full moon), or a combination (intermediate moon phases) (Warrant and Johnsen 2013). At low solar elevation, the rising or setting sun can illuminate the lateral flanks of animals to a much higher degree than the overhead noon sun. Viewing backgrounds away from the low-elevation sun are dark/shaded, whereas those into the sun are bright (Johnsen and Sosik 2003). When viewed away from the sun, dark-flanked prey become slightly less cryptic than at noon, but the flanks of mirrored, light-colored, countershaded prey contrast strongly against the dark background (Fig. 1C; Johnsen 2003, Johnsen and Sosik 2003). Conversely, when viewed into the plane of the low-elevation sun, dark-flanked and countershaded prey contrast strongly against the bright background, and mirrored and light-colored prey experience better crypsis (Fig. 1C; Johnsen 2003). Mirrored organisms can never be completely cryptic when backlit by the sun because this requires the physical impossibility of a reflectance >1 (Johnsen and Sosik 2003). In fact, both mirrored and light-flanked prey block sunlight, leaving silhouettes that are darker than the veiling spacelight.

During crepuscular periods, predators can increase the visibility of prey by searching in circular patterns relative to the low solar elevation, creating background optical mismatches (Fig. 1C). Predators can then drive prey toward the surface, where the asymmetry of the aquatic light field will be most pronounced (Johnsen 2003). Interestingly, countershading coloration patterns that are effective at noon can leave prey highly conspicuous at dawn and dusk, as either their dorsum or ventrum will contrast strongly against the optical background into or away from the sun. Finally, predators transition between circling and encounter-rate strategies when light becomes a factor limiting image formation (early in dawn or late into dusk). Once all sunlight is extirpated, the natural conditions of true night can impede schooling and visual foraging in many fishes, depending on moon phase (Helfman 1993, Fréon et al. 1996). Diurnal game fishes such as largemouth bass [*Micropterus salmoides* (Lacépède, 1802)] may be able to visually forage under a full moon's light intensity, but not under starlight typical of a new moon (McMahon and Holanov 1995).

Objects viewed from below block downwelling light from the night sky and may be silhouetted against the surface (Johnsen 2003), thus anglers fishing under waxing, waning, and new moons often opt for large, dark, water-displacing lures to attract fish to the silhouette, sound, and vibration. Others select odoriferous baits that generate a chemical plume to stimulate olfactory and gustatory systems. Chemical light sticks, where legal, may also be added to bait in an attempt to enhance catchability. In commercial fisheries, Hazin et al. (2005) compared the catch-per-unit effort (CPUE) of squid-baited hook baskets illuminated by light sticks to those without light sticks for catching swordfish with an artisanal longline vessel fishing at 30–150 m depth. Hazin et al. (2005) found that using a light stick on alternating hooks (i.e., on three out of six hooks) significantly increased CPUE relative to using no light stick or a light stick on every hook. Similar evaluations of light sticks in recreational fisheries are lacking.

Night Fishing

For a variety of sensory and environmental reasons, some species of fishes become active at night (Emery 1973, Munz and McFarland 1977; Fig. 2). There is diel variation in catchability with sampling gears (e.g., electrofishing, netting; Pope and Willis 1996); however, diel variation in CPUE with recreational fishing gear has not been well studied. Yet, some anglers like to go fishing in the evenings or early in the morning before daybreak, suggesting that fishing during crepuscular periods and at night is productive. In some specialized fisheries, anglers will specifically wait for nightfall to go fishing. Although the fishing can be rewarding, fishing at night is logistically challenging depending on the target species, particularly due to visibility and navigational issues. However, urbanization has led to the installation of artificial lights along coasts and embayments, which shine into the water (Nightingale et al. 2006; Fig. 3). Such lighting attracts baitfish (Ben-Yami 1976, 1988) and insects, which in turn draws predatory fishes close to shore (Browder 2012). At night, anglers can target these artificially lit areas. For example, anglers often target common snook [*Centropomus undecimalis* (Bloch, 1792)] that follow baitfish into the shallow, illuminated areas. Some fishing guides explicitly mention "fishing under lighted docks" in their advertising materials emphasizing how artificial lighting (in this case, light pollution) can be exploited by anglers.

Sometimes fishing is best without light, especially when target species have evolved to feed in darkness and/or are photophobic. Nightingale et al. (2006) described how weakfish forage only below 0.5 lux and anglers avoid fishing during the full moon because their targets are inactive. For other species, feeding/vulnerability can be enhanced during full moon phases when visual predators have more light with which to perceive potential food items (Fig 2). However, fish feed using many different senses (see above, Pavlov and Kasumyan 1990) meaning that visual cues are not entirely necessary for catching fish. New et al. (2001) ablated the eyes of muskellunge (*Esox masquinongy* Mitchill, 1824) and found that they used somatosensory cues to inform their angles of prey attack. Benthic feeding species such as catfishes (Siluriformes) feed at night using olfactory and gustatory cues, sweeping the benthos with external tastebuds (such as on barbels) to inform feeding (Atema 1971). Anglers can fish at night for these benthivores with passively fished set lines by sinking baited hooks to the benthos and waiting for fish to ingest the bait, generally hooking themselves (often in the throat or stomach because the hook is ingested with the bait). Fishing with set lines is illegal in some jurisdictions, particularly because set lines can increase the probability of deep hooking and mortality of fish that are captured. To indicate when a fish strikes, tools such as bells or alarms can be fixed to the rod. Electronic bite alarms are marketed to carp (*Cyprinus carpio* Linnaeus, 1758) anglers that fish from shore at night so that when they fall asleep with their bait set, the battery-powered alarm will sound to indicate a strike. Setting baits under floats or bobbers that are reflective or glow-in-the dark can also increase strike detection in the dark (Johnson 2013). Some manufacturers produce fishing rods that have tips intended to glow at night (often in the presence of black light) to facilitate strike detection. The angling

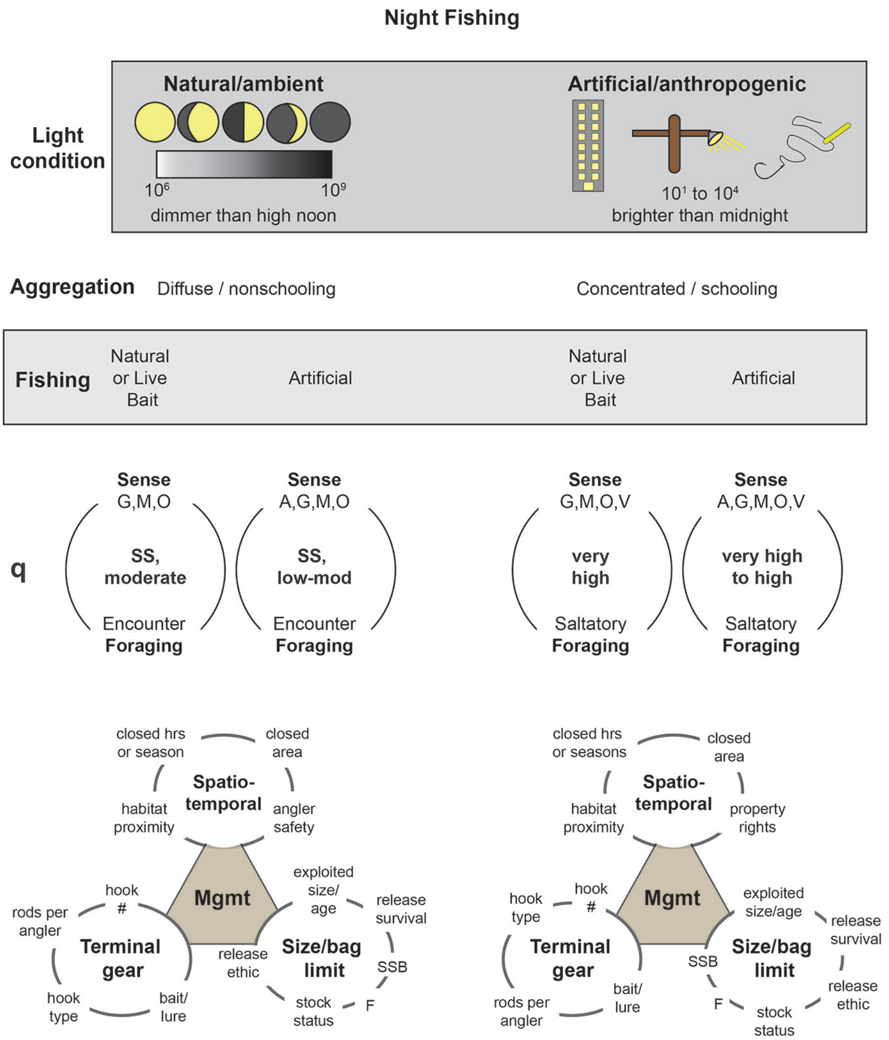

Figure 2. Night fishing under natural and anthropogenically-influenced conditions. Human artificial lighting can increase nocturnal light intensities to within 10^4 units of high noon, leading to changes in fish aggregation, available sensory modalities, foraging strategies, and catchability (q). Management strategies for natural and anthropogenically-influenced nocturnal fisheries should consider spatiotemporal properties, terminal gears, and size and bag limits. SS = species specific. Senses are: audition (A), gustation (G), mechanoreception (M), olfaction (O), and vision (V).

industry (including the outdoor media) are acutely aware of the market for night fishing with many books, videos, television segments and magazine articles on the topic. There are also a number of charters advertised as being specific to fishing at night (e.g., fishing off head-boats off the shores of North Carolina and South Carolina for deepwater reef fish; fishing for swordfish off the Atlantic coast of Florida).

One of the oddest night-specific fisheries issues that emerges is for specialized carp angling where it is common to place fish captured at night in “carp sacks” to hold the fish until the daylight when photographic opportunities are better. However, during

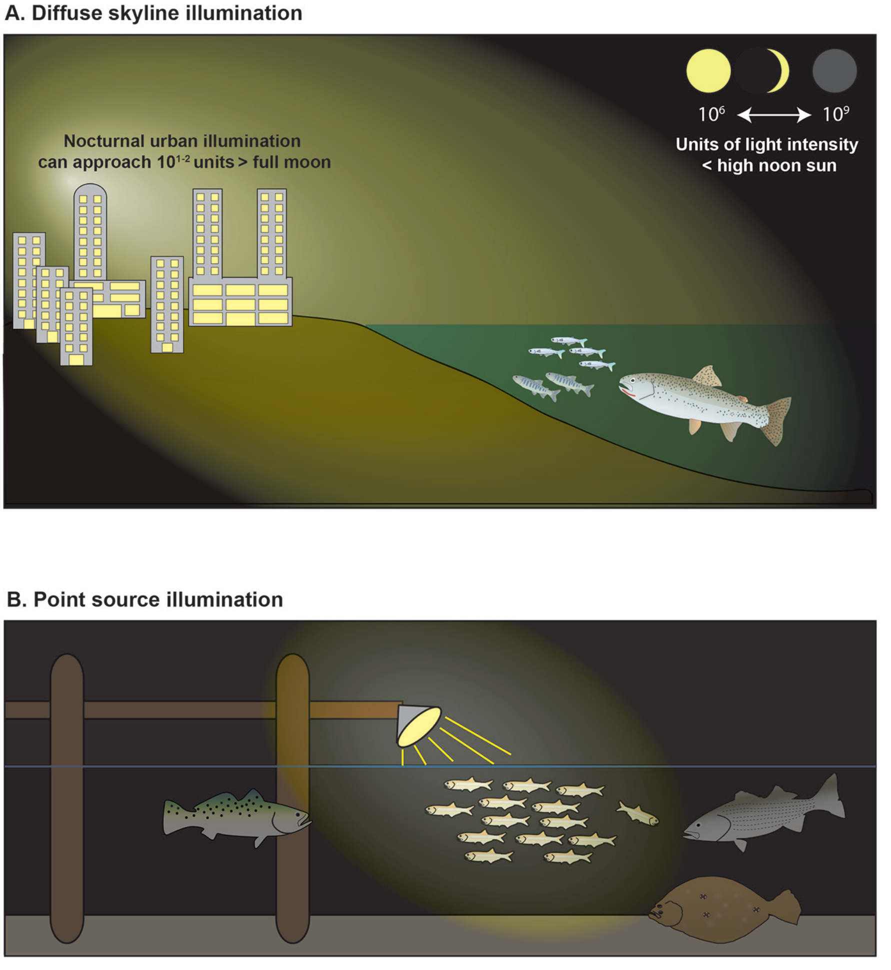

Figure 3. Two categories of anthropogenic artificial light, with influences on aquatic habitats. (A) general illumination of the urban night sky can increase aquatic light up to 10,000 times brighter than the new moon, enabling visual foraging by piscivores such as cutthroat trout (Mazur and Beauchamp 2006). (B) Point source illumination typical of docks, piers, bridges, marinas, and waterfront restaurants. Light is far more limited and concentrated by point sources, increasing asymmetries of prey contrast under the light and predator crypsis in the shadow lines. Both artificial light conditions increase nocturnal foraging and catchability of predators that would not be able to forage visually under natural conditions.

retention in the carp sack, the fish become quite vigorous so it is necessary to intentionally air expose the carp (often by hanging them from a tree in the carp sack) to induce some level of physiological exhaustion so that the fish can be held for photos. Although this practice may seem to be one that would be deleterious to fish, research on the topic suggests that carp are extremely robust to both carp sack retention and prolonged air exposure such that there is negligible mortality and rapid recovery from the associated stress (Rapp et al. 2012).

Night Science and Assessment

Where fisheries management exists globally, the general governing principle is that the management strategies follow a science-based approach. Differences among target species and the behaviors anglers employ to catch fish vary widely among fisheries, such that research to identify species-specific impacts due to recreational fishing have been recommended, particularly for catch-and-release (C&R) fishing (e.g., Cooke and Suski 2005). Similarly, it cannot be assumed that conditions that affect daylight fishing apply broadly to night fishing. Yet, night fishing is often explicitly excluded from fisheries assessment surveys (e.g., Brouwer et al. 1997, Smallwood et al. 2006, Zeller et al. 2007), including the Marine Recreational Information Program (MRIP) of the US National Marine Fisheries Service that did not include night sampling in their surveys until 2013. This lack of inclusion may reflect the position that night fishing is not widely popular. In a study of the Majorca Island recreational fisheries, nighttime anglers represented only 2.4% of fishing activity (Morales-Nin et al. 2005), yet in a survey of angling behaviors in the South African shore fishery, 54% of anglers interviewed indicated that they participated in night fishing, and 34% of their fishing activity took place at night (Brouwer et al. 1997), indicating that popularity of the practice is globally variable. Therefore, the dearth of available literature on night angling survey results speaks to the presence of a knowledge gap, and likely speaks to the challenges in conducting such surveys, rather than to a lack of interest or need. Researchers may look to studies documenting impacts of devices and behaviors commonly used to target fish at night to inform research priorities, but it must be determined whether these results apply to fishing at night.

As discussed in the earlier sections, fish biology and behavior is influenced by diel patterns. Diel migrations, whether from benthic to littoral zones, from offshore to inshore regions, or vertical migrations in the water column, can result in differences in species composition between day and night (Bassett and Montgomery 2011). This suggests that there potentially may be significant differences in expected outcomes of recreational fishing behaviors. For example, the increased presence of predators in a nocturnal community may result in an increase in post-release predation after a C&R event because predation rates can increase at night (Danilowicz and Sale 1999). In a study of recreational bycatch affecting the critically endangered gray nurse shark (*Carcharias taurus* Rafinesque, 1810) in Australia, no diel patterns in hooking were found, though authors noted that *C. taurus* was the only predator in the area taking bait at night (Robbins et al. 2013), a finding that also raises the potential implication of diel patterns in recreational bycatch. Tropical mangrove estuaries are predominantly comprised of nocturnal fish (Ley and Halliday 2007), and a third of fish fauna in any ecosystem may be nocturnal (Helfman 1978, cited in Bassett and Montgomery 2011), supporting the idea that conditions for night fishing may be different, and species assemblages at night may differ. Further, diel variations in catchability have been noted for some species (Benoít and Swain 2003), which could potentially impact recommendations for catch limits.

Night fishing may result in different species-specific impacts due to changes in key angling variables, such as extended handling times and air exposure as a result of reduced visibility in darkness. Rates of deep hooking, injury, and post-release mortality may also be tied to reduced visibility as anglers may be slower to register bites, particularly if using “passive” techniques such as bobbers (Lennox et al. 2015) or set lines. Moreover, handling and unhooking times can increase at night as a result of poor visibility. Differences in angling methods between day and night could result in different hooking mortality rates for released fish that are independent of difference in handling time due to poor visibility. Anecdotally, night fishing involves more use of artificial lights and scent-based attractants than day fishing. There is much variability among species in response to light (i.e., differences among and within species according to life stage) and there is a high degree of plasticity in these responses (Nightingale et al. 2006), which could influence the extent to which anglers using light can directly or indirectly impact populations. Further study of recreational fishing at night can inform regulations for night fishing; for example, the use of circle hooks may be warranted to reduce deep hooking associated with using passive fishing techniques at night (Cooke and Suski 2004).

Differences in angling communities and angler behavior at night should be another integral component of night surveys, including attempts to understand motivation and external relationships with other users. For example, Arlinghaus (2005) noted that there might be conflict among nighttime recreational fishers in areas where these activities overlap with some types of commercial fishing (e.g., those that use fyke nets). Differences may also exist within the angling community; in the Maldives, recreational fishing is not popular among locals, focusing mainly on tourists, yet locals do participate in recreational night fishing (FAO Fisheries and Aquaculture Department 2009), which suggests that angling communities may exhibit diel variation in composition in some areas. This conclusion is supported by the suggestion to relax the ban on night fishing in urban Berlin, Germany, as a way to promote urban fishing experiences, because night fishing is more popular with urban than rural anglers (Arlinghaus et al. 2008). To some extent, this pattern may be driven by the prevalence of anthropogenic illumination.

There are challenges inherent in conducting surveys of night fisheries, including considerations of safety and unintended contributions of safety and research gear to study outcomes. Safety considerations, both perceived and actual, have been suggested as one of the driving factors in a lack of night studies (Smallwood et al. 2011). In addition to reduced visibility constraining safe operation of equipment, increased activity of land- or water-based predators (e.g., crocodiles) at night is also a concern in some areas. The use of surveys and interviews conducted during the day can be used to gather information regarding angler behaviors and perspectives, and for some fisheries, creel surveys can safely be performed at night. Roving creel surveys were used at night in a study of a prawn fishery in New South Wales, Australia, where researchers were able to identify prawn fishers because of artificial light bobbers affixed to the scoop nets they used (Reid and Montgomery 2005).

New technologies, such as the use of remote and infrared cameras, may be helpful in alleviating some of the safety concerns associated with night surveys. Remote cameras using infrared to observe shore-based angling activities at night found that camera placement was integral to ensuring that the number of people in a party could be identified, and to identifying which activity types were taking place (Smallwood et al. 2011). Conversely, a study conducted to identify night assemblages found that use of infrared light (as opposed to white light) resulted in improved surveys because infrared light allowed researchers to distinguish among individuals more effectively (Harvey et al. 2012). In a study comparing underwater assessment techniques using bait and infrared video to conduct underwater surveys, the authors found that olfactory-driven species arrived at video sites sooner, whereas non-olfactory driven species were captured more readily in traditional underwater survey techniques (using scuba and/or snorkel; Bassett and Montgomery 2011). The authors concluded that the type of survey will yield different species-specific encounter and catchability rates depending upon the sensory capabilities of the organisms (Bassett and Montgomery 2011).

In addition to new technologies, more traditional methods may prove suitable for night surveys, though diel differences in efficiency should be tested. When electrofishing for smallmouth bass (*Micropterus dolomieu* Lacépède, 1802), Paragamian (1989) suggested fishing at night would improve gear efficiency and catch numbers, because CPUE was higher. Questions regarding night fishing activities might also represent an opportunity to invest more fully in sources of local knowledge for assessment (Hamilton et al. 2012). Concerns about using local knowledge include potential for recollection bias, that such information has been devalued as being purely anecdotal, and that integration into formal assessment methodologies is challenging (Johannes and Neis 2007), but these concerns can be addressed by approaching the collection of local knowledge in a scientific and verifiable way (e.g., see Arlinghaus and Krause 2013). With such concerns accounted for, local fisher knowledge can help to close gaps in scientific understanding (Johannes and Neis 2007), and can be useful in identifying likely research priorities and safety concerns.

Management at Night

Fisheries management activities can often be categorized as managing habitat, managing people, and managing fish(es) (Krueger and Decker 1999, Arlinghaus et al. 2015a). Here we briefly discuss the relevance of night to those three elements of recreational fisheries management. We also provide two recent high-profile case studies that involved regulating recreational angling activities for white sturgeon (*Acipenser transmontanus* Richardson, 1836) and walleye [*Sander vitreus* (Mitchill, 1818)].

Managing people is one of the more common recreational fisheries management strategies as it relates to elements of angler access, effort, and harvest. Questions regarding diel differences in angler behavior can inform management decisions related not only to outcomes for fishes, but issues of compliance, enforcement, and even promoting the practice of angling. For example, differences in compliance with fishing regulations among night anglers could be a factor in informing the need for more enforcement at different times of day. Enforcement and compliance monitoring is inherently more difficult (and dangerous) at night. Of course there are developments in night vision goggles and aircraft or drone-based night imaging [e.g., forward looking infra-red (FLIR) thermal imaging] that do provide enforcement staff with some tools for peering into the dark. Motivations for angling may also differ at night, impacting which management or enforcement strategies are likely to be successful. Anglers who prefer to fish at night have expressed a desire to avoid increasing boat traffic, warm temperatures, and to increase catch rates that may decrease in times when fish are subjected to higher amounts of angling pressure (Quinn 2014). Some anglers have even indicated preferences related to the phases of the moon, believing catchability of their target species to be influenced by moonlight (Quinn 2014).

Regulations surrounding night fishing are also variable; for example, the activity is permitted in some areas of Portugal but prohibited in others such as the Parque

Natural do Sudoeste Alentejano e Costa Vicentina (Veiga et al. 2010). Night fishing is banned entirely in Greece, but is widely permitted in Cyprus, where licenses are only required if fishers intend to spearfish at night (Pawson et al. 2008). In the Back Bay National Wildlife Refuge (and indeed in all such refuges) in the Virginia, USA, night fishing activities were banned (see USFWS 2009). However, local angling groups lobbied successfully for opening limited night fishing opportunities for striped bass (*M. saxatilis*). A special lisence was required to fund the additional staff time (for assessment, management, and enforcement) to ensure that the fishery was properly regulated and monitored. A practical aspect of any efforts to limit nighttime fishing involves defining "nighttime" in a manner that is enforceable. Typically, nighttime periods are identified relative to "published" sunrise and sunset periods (e.g., a closure from dusk until dawn starting 1 hr after sunset until 1 hr before sunrise). Other common regulations relevant to night involve placing restrictions on specific gears. For example, use of artificial lights (for fish attraction) are prohibited in many jurisdictions. Also typically restricted are lures/baits that contain a light source, but lures that "glow" (e.g., using glowing paint) tend to be allowed.

Management Case Study: Lower Fraser River Sturgeon Night Fishing Closure.—The Fraser River is a large river system in British Columbia (BC), Canada, that originates near the Alberta border and drains a significant portion of the province. The lower Fraser River comprises the >180 km section from its mouth upstream to Hells Gate in the Fraser Canyon, and supports large populations of all five species of Pacific salmon (*Oncorhynchus* spp.), steelhead [*Oncorhynchus* mykiss (Walbaum, 1792)], coastal cutthroat trout [*Oncorhynchus clarki* (Richardson, 1836)], bull trout, and white sturgeon. The Lower Mainland, which includes the lower Fraser and BCs largest metropolitan city (Vancouver), also supports BC's largest human population. The number of federal and provincial fishery enforcement staff is small relative to the size of the human population, the extent of the fisheries, and area to enforce. The lower Fraser currently supports important cultural and multi-million dollar First Nations (FN), commercial and recreational salmon fisheries, and a multi-million dollar recreational C&R white sturgeon fishery.

The lower Fraser River is split into two jurisdictions: the river is designated as tidal downstream of the CPR rail Bridge at Mission BC, and non-tidal upstream of the bridge. Fisheries and Oceans Canada (DFO) manages and regulates all fisheries in tidal waters. FN, recreational and commercial Pacific salmon fisheries, in both tidal and non-tidal waters, are also managed by DFO. Tidal and non-tidal nighttime angling closures on the lower Fraser, and some tributaries, were implemented by DFO to better manage the recreational salmon fisheries, including the sockeye salmon [*Oncorhynchus nerka* (Walbaum, 1792)] fishery. The nighttime closure includes 1 hr after sunset until 1 hr before sunrise, and was implemented in 2002.

The white sturgeon fishery on the lower Fraser has been a C&R only fishery since the early 1990s, and has grown significantly since the late-1990s. However, recent studies (Nelson et al. 2014) indicated that the population was not growing as expected. The province has had concerns with respect to sturgeon night fishing for more than a decade because white sturgeon typically feed in the dark, making them vulnerable to capture by angling at night. However, darkness is also the primary time when poachers operate on the lower Fraser. Due to its high value for its flesh and its eggs, white sturgeon can bring large sums in the illegal trade market, and due to the size of the Lower Mainland human population, the potential market is large. Poaching for sturgeon in the lower Fraser is conducted by angling, setline, or net. Nighttime poaching is typically from shore by angling, but has also been conducted by boat and with other methods. The province has been concerned about the handling of white sturgeon in the C&R fishery for more than a decade, with evidence that there is risk of injury and mortality, especially when handling large adult fish which can be much harder to handle in the dark. Further, it was brought to the attention of provincial fisheries staff by enforcement during the consultation that a sturgeon angler died in 2013 when a large sturgeon pulled him off a bridge onto an abutment while he was fishing in the dark.

In 2013, after several years of scoping the issue with stakeholders, the province decided to initiate formal consultation on the potential implementation of a nighttime closure to sturgeon fishing on non-tidal waters of the lower Fraser River, lower Pitt River, and Harrison River for the better management and protection of the species, and for the safety of anglers. Federal and provincial enforcement staff also recommended this closure as being the only way to effectively ensure that nighttime sturgeon poaching could be enforced. Upon further consultation with legal, regulatory, and stakeholder advisors, it was determined that it would be necessary to consult on a total fishing closure rather than a sturgeon only night fishing closure. The extent of the nighttime sturgeon fishery at the time was unknown, but fisheries and enforcement staff had observed that the majority of sturgeon angling occurs by boat during daylight hours. Also, numerous nighttime sturgeon poaching enforcement cases had recently proceeded to conviction, even with extensive education of the general public and anglers of the importance of protecting white sturgeon.

A number of concerns were identified during stakeholder consultation on the proposed lower Fraser nighttime closure, including concern that this would take "eyes and ears" off the river to watch for poachers, that enforcement was inadequate to ensure compliance, and that the closure should pertain to both tidal and non-tidal waters. Provincial fisheries staff indicated that they expected DFO to mirror the change for tidal waters. On April 1, 2015, the nighttime regulatory closure to all fishing in non-tidal waters of the lower Fraser, lower Pitt, and Harrison rivers came into effect with the timing of the closure extending from 1 hr after sunset to 1 hr before sunrise, which is consistent with other recreational night closures, and the provincial hunting regulations.

To date, DFO has not mirrored the nighttime fishing closure for the tidal waters of the lower Fraser River and Pitt River. Communication on social media appeared to be limited as a consequence of the closure, and no recent communications with regard to the closure have been received by provincial fisheries staff, which suggests that anglers and angling guides have adjusted their activities around the closure. Monitoring efforts are underway to identify compliance with the regulatory change and to assess the population-level responses.

Management Case Study: Mille Lacs Lake Walleye Night Fishing Closure.—Mille Lacs Lake is a 53,620 ha lake in north central Minnesota and is one of Minnesota's most important walleye (*S. vitreus*) fisheries averaging 3 million hours of angling pressure annually (Jensen 2013). Public interest in Mille Lacs management dates back to the late 1940s with concerns about declining catch rates and increased fishing pressure. The first documented concern over night fishing occurred in 1961 after decreased angling success was noted the previous year. In response to numerous stakeholder requests over several decades, the Minnesota Department of Natural Resources (MNDNR) enacted a night fishing ban in 1984 from 22:00 to 06:00 hrs for the first 4 wks of the open water season, which begins in early May. The next year, a size restriction limiting harvest of walleye >508 mm (total length) was also implemented. These regulations remained unchanged through 1996. The primary intent of the night closure was to redistribute harvest over the fishing season rather than reduce total harvest.

From 1984 to 1996, the median night harvest was about 15,000 kg (range 5000–50,000 kg) comprising about 7% of the total annual angler harvest, including estimated hooking mortality (Reeves and Bruesewitz 2007). In 1997, Mille Lacs became a shared fishery between state licensed anglers and Ojibwa (Chippewa) tribal fishers. From 1997 to 2013, the total allowable annual harvest of walleye was determined by a fixed exploitation policy using age-structured stock assessment model estimates of total population biomass and averaged 200,000 kg (harvested fish and hooking deaths). Tribal fishers declared a fixed quota each year, on average 25%–30% of the total allowable harvest, with the remainder allocated to state recreational anglers. The state recreational angling fishery was managed using size-based regulations and bag limits to remain within allocation. During this period, the spring night fishing ban remained in effect while 10 different size-based regulations and two different bag limits, along with mid-season changes to either more or less size restrictive regulations, were implemented to control harvest.

Despite intensive management, the population did not increase (Venturelli et al. 2014). In 2014, a suite of alternative regulations was presented to stakeholders and the open water season-long night fishing closure was the most supported additional restriction, followed by mandatory use of circle hooks and a more restrictive season-long night closure (18:00–06:00 hrs). What became evident is that night fishing regulation is one management tool and it is unlikely to work in isolation unless

Table 1. Research needs specific to recreational fisheries science and management at night.

- Identify fish habitat needs at night to ensure that critical habitats are protected and to inform various enhancement and restoration activities
- Determine the extent to which light attracts different life-stages and species to determine the relevance of regulations that ban light attraction and to exploit light to improve night assessment activities (e.g., as is done with larval light traps)
- Identify survey designs that accurately quantify catch and effort over 24 hrs given that without accurate quantification of catch and effort by day and night, management cannot be effective
- Examine the potential for selective effects of night vs day fishing (are we catching the "same" fish by day and night?)
- Characterize the "artificial light food web" to understand how light pollution influences key sportsfish and their prey (e.g., exigent need to study the fish–artificial light–foraging relationship)
- Determine if fish handling and associated injury, stress, and mortality are elevated at night in the context of catch-and-release fishing
- Evaluate the extent to which post-release predation is mediated by night
- Conduct social science surveys to understand angler perspectives on night fishing and associated regulations (usually bans)

combined with other tools (e.g., bag and slot limits and seasonal closures). Also relevant is that all of these management tools rely on projections of anticipated outcomes that do not necessarily occur due to interannual variability in catch rates and fishery conditions. Long-term monitoring to assess fish population responses to regulatory changes as well a human dimensions work to evaluate stakeholder perspectives are underway. What is clear is that night-specific regulations expand the toolbox for fisheries managers.

Synthesis and Conclusions

It is evident from our review that recreational fishing at night is popular, but not universally so. The sensory and foraging ecologies of some species provide anglers with unique opportunities to access fish during the night. To that end, the fishing industry has developed a variety of products intended to facilitate fish capture at night. In general, less is known about the ecology and biology of fishes at night, partly driven by the inherent challenges of studying fish in darkness. Fisheries management efforts can specifically target the night, often in the form of temporal closures or gear restrictions. When such management efforts are enacted, there may be additional resource needs and associated costs that need to be considered by natural resource management agencies, particularly related to assessment and compliance monitoring at night. The two case studies we presented exemplify high-profile fisheries for which night time fishery closures have been applied in an effort to reduce directed harvest (walleye), poaching (white sturgeon), and poor fish handling (both). The biological effectiveness of these closures is still being assessed (e.g., did fish populations respond as expected), but significant effort is also being devoted to understanding stakeholder perspectives and compliance.

With efforts by some anglers to be alone when fishing, one might anticipate that night fishing may become more popular in the future as some anglers attempt to avoid the masses that may fish during the day. We encourage the fisheries management community to think creatively about how nighttime recreational fishing can be promoted, but in a manner that is supported by effective stock assessment and management. There are a number of outstanding research needs that were identified throughout the review (see Table 1). Moving forward, we anticipate that the recreational fishing community may have more opportunities for fishing in the dark provided that management agencies can address the significant assessment and compliance monitoring challenges such that they are not "managing in the dark."

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