

1 **FISHING IN THE DARK – THE SCIENCE AND MANAGEMENT OF**
2 **RECREATIONAL FISHERIES AT NIGHT**

3
4 IN PREP FOR “SPECIAL ISSUE ON FISH @ NIGHT” IN BULLETIN OF MARINE
5 SCIENCE

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20 **Abstract**

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

41 Running Head: Recreational fishing in the dark

42 **Introduction**

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

58 Given the importance of recreational fishing, it is not surprising that in many
59 jurisdictions, particularly in developed countries, governance structures exist to support the
60 sustainable management of recreational fisheries. Typically underpinning such management
61 efforts are science-based fisheries assessment. In developing countries and emerging economies,
62 science capacity is often lacking and governance structures (in terms of policy instruments) fail
63 to provide natural resource agencies with the tools and support needed to actively manage
64 fisheries. At the core of recreational fisheries management are traditional harvest control

65 regulations such as bag limits and size limits (Johnson and Martinez 1995). However, effort
66 controls are gaining in popularity (e.g., protected areas, seasonal closures, Cox et al. 2003).
67 Recreational fisheries management is often regarded as a partnership between government and
68 various stakeholder groups through formal or informal co-management agreements (FAO 2012).
69 With adequate regulations related to harvest and effort control, along with requisite habitat
70 protection (see Lapointe et al. 2013), most recreational fisheries can be managed to achieve
71 multiple benefits.

72 Nighttime (and its associated darkness) is omnipresent around the globe and many fishes
73 can certainly be captured during nocturnal periods, reflecting species-specific differences in
74 sensory physiology and feeding activity. Quantifying the number of anglers who angle at night
75 has a number of practical challenges (e.g., safety and logistics of working on or near water at
76 night). From an enforcement perspective, night and its associated darkness can provide “cover”
77 for those that intend to not comply with regulations. From a science and management
78 perspective, the vast majority of staff effort is focused on daytime periods. Here we provide the
79 first synthesis on the science and management of recreational fisheries at night. First we describe
80 fishing at night from the perspective of a fish, exploring how species-specific sensory physiology
81 and biology contributes to vulnerability to capture. Next, we characterize the state of night
82 fishing, identifying examples of specific tactics used to target fish at night. Then we summarize
83 the science and assessment of fishing at night needed to support fisheries management. Finally,
84 we explore strategies used to manage fishing at night with a particular focus on policy
85 compliance challenges using several case studies where night-specific management regulations
86 have been implemented. With increasing recreational fishing effort on a global basis, it is our
87 hope that our synthesis will provide managers with information to achieve recreational fisheries

88 sustainability by managing fisheries around the clock, not just during daylight. We are global in
89 our approach, covering marine and inland recreational fisheries but limit our review to
90 recreational angling (i.e., fishing via hook and line). We recognize that depending on latitude
91 (e.g., polar regions) and season, night and darkness are not always aligned, but for the purpose of
92 this paper we take night to imply darkness at least in a relative sense compared to daytime
93 periods.

94 **Fishing at Night from a Fish's Perspective**

95 Predatory gamefishes demonstrate species-specific diurnal rhythms in both sensory
96 physiology and feeding activity (Reeb 2002). Physiological adaptations of gamefishes to low
97 light levels, including overcast conditions, crepuscular periods, and night, may explain why
98 catches of many species peak at these times. Midday clouds can drop aquatic light intensities by
99 one to two orders of magnitude; during crepuscular periods intensity can change roughly tenfold
100 every 10 minutes (Fig 1A). Natural nocturnal light levels are a million to a billion times dimmer
101 than those at high noon, depending on moon phase (Warrant 1999, Johnsen 2012). Many
102 predatory fishes forage visually, using rod photoreceptors during scotopic (dim/dark) conditions
103 to increase sensitivity and form monochromatic images, and cone photoreceptors under photopic
104 (bright) conditions to form high-resolution, contrasting images of prey. Nocturnal foragers have
105 large eyes, a high rod:cone ratio, slow vision, poor acuity, prevalent tapeta lucida, high luminous
106 sensitivity (Warrant 1999, Horodysky et al. 2008), and/or may have enhancements in
107 chemosensory and mechanosensory systems for food search (Pohlmann et al. 2004). Examples of
108 such fishes include walleye (*Sander vitreus*), adult brown trout (*Salmo trutta*) and bull trout
109 (*Salvelinus confluentus*), channel catfish (*Ictalurus punctatus*), weakfish (*Cynoscion regalis*),
110 and swordfish (*Xiphias gladius*). By contrast, predators of daylight hours have smaller eyes,

111 higher cone:rod ratios, faster vision, better acuity, wider chromatic sensitivity, and moderate
112 luminous sensitivity (Horodysky et al. 2008). Examples of these fishes include bonefish (*Albula*
113 spp.), striped bass (*Morone saxatilis*), yellow perch (*Perca flavescens*), and northern pike (*Esox*
114 *lucius*). Of course, the latter species can still be captured under low light levels.

115 Within a species, luminous sensitivity can be extended under falling light levels as
116 permitted by physical and physiological bounds by widening pupils, increasing temporal and
117 spatial summation of ganglion cells, and/or via circadian retinomotor movements that withdraw
118 the pigment epithelium protecting rod photoreceptors from daylight (Fig 1B, Warrant 1999).
119 However, because of unavoidable tradeoffs, physiological responses that increase sensitivity
120 come at the cost of slower temporal resolution, reductions in acuity due to reduced spatial
121 summation, and constrained chromatic sensitivity (Horodysky et al. 2010). Under natural low-
122 light conditions, diurnal predatory fishes may be forced to cease visual foraging when image
123 formation is impaired, and turn increasingly to encounter-based chemosensory, acoustic, and/or
124 mechanoreceptive cues to locate and track prey as per species-specific adaptations and abilities
125 (Hara and Zielinski 2006). Some dim-light and nocturnal foragers such as burbot (*Lota lota*) and
126 flathead catfish (*Pylodictis olivaris*) may cue predominantly on chemosensory cues (Døving and
127 Gemne 1965, Hinkens and Cochran 1988, Daugherty and Sutton 2005), which are dependent on
128 water flow, and may be less affected by aquatic photodynamism.

129 Crepuscular periods are brief photodynamic windows enveloping the night in which the
130 solar elevation is low, light intensity and spectra change rapidly, and many prey countershading
131 and camouflage strategies can be counteracted by predators and exploited by anglers (Fig 1C)
132 (Johnsen 2003, 2012). It is thus not surprising that much fishing effort is exerted, and angling
133 success experienced, at these times. Light intensity changes by roughly 2 log units between 0-5°

134 of solar elevation, as the sun is near the horizon (Johnsen 2003, 2012). Below the horizon, light
135 changes by 10^4 - 10^7 units from the time of first/last light (-18°) to sunrise/sunset (i.e., 0°) and is
136 intensely dominated by shorter (UV and blue) wavelengths (Warrant and Johnsen 2013). Once
137 the sun is more than 18° below the horizon (i.e. true night), the blue twilight is replaced by
138 dimmer and redder starlight, airglow, and zodiacal light (new moon), by a dim spectrum that
139 resembles slightly red-shifted daylight in spectral composition (full moon), or a combination
140 (intermediate moon phases) (Warrant and Johnsen 2013). At low solar elevation, the rising or
141 setting sun can illuminate the lateral flanks of animals to a much higher degree than the overhead
142 noon sun. Viewing backgrounds away from the low-elevation sun are dark/shaded, whereas
143 those into the sun are bright (Johnsen and Sosik 2003). When viewed away from the sun, dark-
144 flanked prey become slightly less cryptic than at noon, but the flanks of mirrored, light-colored,
145 countershaded prey contrast strongly against the dark background (Fig 1C, Johnsen 2003,
146 Johnsen and Sosik 2003). Conversely, when viewed into the plane of the low-elevation sun,
147 dark-flanked and countershaded prey contrast strongly against the bright background, and
148 mirrored and light-colored prey experience better crypsis (Fig 1C, Johnsen 2003). Mirrored
149 organisms can never be completely cryptic when backlit by the sun because this requires the
150 physical impossibility of a reflectance greater than one (Johnsen and Sosik 2003). In fact, both
151 mirrored and light-flanked prey block sunlight, leaving silhouettes that are darker than the
152 veiling spacelight.

153 During crepuscular periods, predators can increase the conspicuousness of prey by
154 searching in circular patterns relative to the low solar elevation to find prey: background optical
155 mismatches (Fig 1C), then driving them to the surface, where the above asymmetry of the
156 aquatic light field will be most pronounced (Johnsen 2003). Interestingly, countershading

157 coloration patterns that are effective at noon can leave prey highly conspicuous at dawn and
158 dusk, as either their dorsum or ventrum will contrast strongly against the optical background into
159 or away from the sun. Finally, predators transition between circling and encounter rate strategies
160 when light becomes a factor limiting image formation (early in dawn or late into dusk). Once all
161 sunlight is extirpated, the natural conditions of true night can impede schooling and visual
162 foraging in many fishes, depending on moon phase (Helfman 1993, Fréon et al. 1996). Diurnal
163 game fishes such as largemouth bass (*Micropterus salmoides*) may be able to visually forage
164 under a full moon's light intensity, but not under starlight typical of a new moon (McMahon and
165 Holanov 1995).

166 Objects viewed from below block downwelling light from the night sky and may be
167 silhouetted against the surface (Johnsen 2003), thus anglers fishing under waxing, waning, and
168 new moons often opt for large, dark, water-displacing lures to attract fish to the silhouette, sound
169 and vibration. Others select odoriferous baits that generate a chemical plume to stimulate
170 olfactory and gustatory systems. Chemical light sticks, where legal, may also be added to bait in
171 an attempt to enhance catchability. In commercial fisheries, Hazin et al. (2005) compared the
172 catch-per-unit effort of squid-baited hook baskets illuminated by light sticks to those without
173 light sticks for catching swordfish (*Xiphias gladius*) with an artisanal longline vessel fishing at
174 30-150 m depth. Hazin et al. (2005) found that using a light stick on alternating hooks (i.e. on
175 three out of six hooks) significantly increased CPUE relative to using no light stick or a light
176 stick on every hook. Similar evaluations of light sticks in recreational fisheries are lacking.

177 **Night Fishing**

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

194 Sometimes fishing is best without light, especially when target species have evolved to
195 feed in darkness and/or are photophobic. Nightingale et al. (2006) described how weakfish
196 (*Cynoscion regalis*) forage only above 0.5 lux and anglers avoid fishing during the full moon
197 because their targets are inactive. For other species, feeding/vulnerability can be enhanced during
198 full moon phases when visual predators have more light with which to perceive potential food
199 items ([Fig 2](#)). However, fish feed using many different senses (see above, Pavlov and Kasumyan
200 1990) meaning that visual cues are not entirely necessary for catching fish. New et al. (2001)

201 ablated the eyes of muskellunge (*Esox masquinongy*) and found that they used somatosensory
202 cues to inform their angles of prey attack. Benthic feeding species such as catfishes
203 (*Siluriformes*) feed at night using olfactory and gustatory cues, sweeping the benthos with
204 external tastebuds (such as on barbels) to inform feeding (Atema 1971). Anglers can fish at night
205 for these benthivores with passively fished set lines by sinking baited hooks to the benthos and
206 waiting for fish to ingest the bait, generally hooking themselves (often in the throat or stomach
207 because the hook is ingested with the bait). Fishing with set lines is illegal in some jurisdictions,
208 particularly because set lines can increase the probability of deep hooking and mortality of fish
209 that are captured. To indicate when a fish strikes, tools such as bells or alarms can be fixed to the
210 rod. Electronic bite alarms are marketed to carp (*Cyprinus carpio*) anglers that fish from shore at
211 night so that when they fall asleep with their bait set, the battery-powered alarm will sound to
212 indicate a strike. Setting baits under floats or bobbers that are reflective or glow-in-the dark can
213 also increase strike detection in the dark (Johnson 2013). Some manufacturers produce fishing
214 rods that have tips intended to glow at night (often in the presence of black light) to facilitate
215 strike detection. The angling industry (including the outdoor media) are acutely aware of the
216 market for night fishing with many books, videos, television segments and magazine articles on
217 the topic. There are also a number of charters advertised as being specific to fishing at night
218 (e.g., fishing off head-boats off of the shores of North Carolina and South Carolina for deepwater
219 reef fish; fishing for swordfish off of the Atlantic coast of Florida).

220 One of the oddest night-specific fisheries issues that emerges is for specialized carp
221 angling where it is common to place fish captured at night in “carp sacks” to hold the fish until
222 the daylight when photographic opportunities are better. However, during retention in the carp
223 sack the fish become quite vigorous so it is necessary to intentionally air expose the carp (often

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

229 **Night Science and Assessment**

230 Where fisheries management exists globally, the general governing principle is that the
231 management strategies follow a science-based approach. Differences among target species and
232 the behaviours anglers employ to catch fish vary widely among fisheries, such that research to
233 identify species-specific impacts due to recreational fishing have been recommended,
234 particularly for catch-and-release (C&R) fishing (e.g., Cooke and Suski 2005). Similarly, it
235 cannot be assumed that conditions that affect daylight fishing apply broadly to night fishing. Yet,
236 night fishing is often explicitly excluded from fisheries assessment surveys (e.g., Brouwer et al.
237 1997, Smallwood et al. 2006, Zeller et al. 2007), including the Marine Recreational Information
238 Program (MRIP) of the U.S. National Marine Fisheries Service that did not include night
239 sampling in their surveys until 2013. This lack of inclusion may reflect the position that night
240 fishing is not widely popular. In a study of the Majorca Island recreational fisheries, nighttime
241 anglers represented only 2.4 % of fishing activity (Morales-Nin et al. 2005), yet in a survey of
242 angling behaviours in the South African shore fishery, 54% of anglers interviewed indicated that
243 they participated in night fishing, and 34% of their fishing activity took place at night (Brouwer
244 et al. 1997), indicating that popularity of the practice is globally variable. The dearth of available
245 literature on night angling survey results therefore speaks to the presence of a knowledge gap,
246 and likely speaks to the challenges in conducting such surveys, rather than to a lack of interest or

247 need. Researchers may look to studies documenting impacts of devices and behaviours
248 commonly used to target fish at night to inform research priorities, but it must be determined
249 whether these results apply to fishing at night.

250 As discussed in the earlier sections, fish biology and behaviour is influenced by diel
251 patterns. Diel migrations, whether from benthic to littoral zones, from offshore to inshore
252 regions, or vertical migrations in the water column, can result in differences in species
253 composition between day and night (Bassett and Montgomery 2011). This suggests that there
254 may be potentially significant differences in expected outcomes of recreational fishing
255 behaviours. For example, the increased presence of predators in a nocturnal community may
256 result in an increase in post-release predation after a C&R event because predation rates can
257 increase at night (Danilowicz and Sale 1999). In a study of recreational bycatch affecting the
258 critically endangered grey nurse shark (*Caracharias taurus*) in Australia, no diel patterns in
259 hooking were found, though authors noted that *C. taurus* was the only predator in the area taking
260 bait at night (Robbins et al. 2013), a finding that also raises the potential implication of diel
261 patterns in recreational bycatch. Tropical mangrove estuaries are predominantly comprised of
262 nocturnal fish (Ley and Halliday 2007), and a third of fish fauna in any ecosystem may be
263 nocturnal (Helfman 1978, cited in Bassett and Montgomery 2011), supporting the idea that
264 conditions for night fishing may be different, and species assemblages at night may differ.
265 Further, diel variations in catchability have been noted for some species (Benoît and Swain
266 2003), which could potentially impact recommendations for catch limits.

267 Night fishing may result in different species-specific impacts due to changes in key
268 angling variables, such as extended handling times and air exposure as a result of reduced
269 visibility in darkness. Rates of deep hooking, injury, and post-release mortality may also be tied

270 to reduced visibility as anglers may be slower to register bites, particularly if using ‘passive’
271 techniques such as bobbers (Lennox et al. 2015) or set lines. Moreover, handling and unhooking
272 times can increase at night as a result of poor visibility. Differences in angling methods between
273 day and night could result in different hooking mortality rates for released fish that are
274 independent of difference in handling time due to poor visibility. Anecdotally, night fishing
275 involves more use of artificial lights and scent-based attractants than day fishing. There is much
276 variability among species in response to light (i.e. differences among and within species
277 according to life stage) and there is a high degree of plasticity in these responses (Nightingale et
278 al. 2006), which could influence the extent to which anglers using light can directly or indirectly
279 impact populations. Further study of recreational fishing at night can inform regulations for night
280 fishing; for example, the use of circle hooks may be warranted to reduce deep hooking associated
281 with using passive fishing techniques at night (Cooke and Suski 2004).

282 Differences in angling communities and angler behaviour at night should be another integral
283 component of night surveys, including attempts to understand motivation and external
284 relationships with other users. For example, Arlinghaus (2005) noted that there might be conflict
285 among nighttime recreational fishers in areas where these activities overlap with some types of
286 commercial fishing (e.g., those that use fyke nets). Differences may also exist within the angling
287 community: in the Maldives, recreational fishing is not popular among locals, focusing mainly
288 on tourists, yet locals do participate in recreational night fishing (FAO Fisheries and Aquaculture
289 Department 2009), which suggests that angling communities may exhibit diel variation in
290 composition in some areas. This conclusion is supported by the suggestion to relax the ban on
291 night fishing in urban Berlin as a way to promote urban fishing experiences, because night

292 fishing is more popular with urban than rural anglers (Arlinghaus et al. 2008). To some extent,
293 this pattern may be driven by the prevalence of anthropogenic illumination.

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

305 New technologies, such as the use of remote and infrared cameras, may be helpful in
306 alleviating some of the safety concerns associated with night surveys. Remote cameras using
307 infrared to observe shore-based angling activities at night found that camera placement was
308 integral to ensuring that the number of people in a party could be identified, and to identifying
309 which activity types were taking place (Smallwood et al. 2011). Conversely, a study conducted
310 to identify night assemblages found that use of infrared light (as opposed to white light) resulted
311 in improved surveys because infrared light allowed researchers to distinguish among individuals
312 more effectively (Harvey et al. 2012). In a study comparing underwater assessment techniques
313 using bait and infrared video to conduct underwater surveys, the authors found that olfactory-
314 driven species arrived at video sites sooner, whereas non-olfactory driven species were captured

315 more readily in traditional underwater survey techniques (using SCUBA and/or snorkel, Bassett
316 and Montgomery 2011). The authors concluded that the type of survey will yield different
317 species-specific encounter and catchability depending upon the sensory capabilities of the
318 organisms (Bassett and Montgomery 2011).

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

332 **Management at Night**

333 Fisheries management activities can often be categorized as managing habitat, managing
334 people, and managing fish(es) (Krueger and Decker 1999, Arlinghaus et al. 2015a). Here we
335 briefly discuss the relevance of night to those three elements of recreational fisheries
336 management. We also provide two recent high-profile case studies that involved regulating

337 recreational angling activities for white sturgeon (*Acipenser transmontanus*) and walleye (*Sander*
338 *vitreus*).

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

354 Regulations surrounding night fishing are also variable, the activity is permitted in some
355 areas of Portugal but prohibited in others such as the Parque Natural do Sudoeste Alentejano e
356 Costa Vicentina (Veiga et al. 2010); is banned entirely in Greece; but is widely permitted in
357 Cyprus, where licenses are only required if fishers intend to spearfish at night (Pawson et al.
358 2008). In the Back Bay National Wildlife Refuge (and indeed in all such refuges) in the USA,
359 night fishing activities were banned (See USFWS 2009). However, local angling groups lobbied

360 successfully for opening limited night fishing opportunities for striped bass (*Morone saxatilis*). A
361 special licence was required to fund the additional staff time (for assessment, management and
362 enforcement) to ensure that the fishery was properly regulated and monitored. A practical aspect
363 of any efforts to limit nighttime fishing involves defining “nighttime” in a manner that is
364 enforceable. Typically nighttime periods are identified relative to “published” sunrise and sunset
365 periods (e.g., a closure from dusk till dawn starting 1 hour after sunset until 1 hour before
366 sunrise). Other common regulations relevant to night involve placing restrictions on specific
367 gears. For example, use of artificial lights (for fish attraction) are prohibited in many
368 jurisdictions. Also typically restricted are lures/baits that contain a light source but lures that
369 “glow” (e.g., using glowing paint) tend to be allowed.

370 **Management Case Study – Lower Fraser River Sturgeon Night Fishing Closure**

371 The Fraser River is a large river system in British Columbia (BC), Canada that originates
372 near the Alberta border and drains a significant portion of the province. The lower Fraser River
373 comprises the 180+ km section from its mouth upstream to Hells Gate in the Fraser Canyon, and
374 supports large populations of all five species of Pacific salmon (*Oncorhynchus* spp.), Steelhead
375 (*O. mykiss*), Coastal Cutthroat Trout (*O. clarki*), bull trout, and White Sturgeon (*Acipenser*
376 *transmontanus*). The Lower Mainland, which includes the lower Fraser and BCs largest
377 metropolitan city (Vancouver), also supports BC’s largest human population. The number of
378 federal and provincial fishery enforcement staff is small relative to the size of the human
379 population, the extent of the fisheries, and area to enforce. The lower Fraser currently supports
380 important cultural and multi-million dollar First Nations (FN), commercial and recreational
381 salmon fisheries, and a multi-million dollar recreational catch and release White Sturgeon
382 fishery.

383 The lower Fraser River is split into two jurisdictions: the river is designated as tidal
384 downstream of the CPR rail Bridge at Mission BC, and non-tidal upstream of the bridge.
385 Fisheries and Oceans Canada (DFO) manages and regulates all fisheries in tidal waters. FN,
386 recreational and commercial Pacific salmon fisheries, in both tidal and non-tidal waters, are also
387 managed by DFO. Tidal and non-tidal nighttime angling closures on the lower Fraser, and some
388 tributaries, were implemented by DFO to better manage the recreational salmon fisheries,
389 including the Sockeye Salmon fishery. The nighttime closure includes one hour after sunset until
390 one hour before sunrise, and was implemented in 2002.

391 The White Sturgeon fishery on the lower Fraser has been a catch and release only fishery
392 since the early 1990s, and has grown significantly since the late-1990s. However, recent studies
393 (Nelson et al. 2014) indicated that the population was not growing as expected. The province has
394 had concerns with respect to sturgeon night fishing for more than a decade because White
395 Sturgeon typically feed in the dark, making them vulnerable to capture by angling at night.
396 However, darkness is also the primary time when poachers operate on the lower Fraser. Due to
397 its high value for its flesh and its eggs, White Sturgeon can bring large sums in the illegal trade
398 market, and due to the size of the Lower Mainland human population, the potential market is
399 large. Poaching for sturgeon in the lower Fraser is conducted by angling, setline, or net.
400 Nighttime poaching is typically from shore by angling, but has also been conducted by boat and
401 with other methods. The province has been concerned about the handling of White Sturgeon in
402 the catch and release fishery for more than a decade, with evidence that there is risk of injury and
403 mortality, especially when handling large adult fish which can be much harder to handle in the
404 dark. Further, it was brought to the attention of provincial fisheries staff by enforcement during

405 the consultation that a sturgeon angler died in 2013 when a large sturgeon pulled him off a
406 bridge onto an abutment while he was fishing in the dark.

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

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

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

434 **Management Case Study – Mille Lacs Lake Walleye Night Fishing Closure**

435 Mille Lacs Lake is a 53,620 ha lake in north central Minnesota and is one of Minnesota's
436 most important walleye (*Sander vitreus*) fisheries averaging 3 million hours of angling pressure
437 annually (Jensen 2013). Public interest in Mille Lacs management dates back to the late 1940s
438 with concerns about declining catch rates and increased fishing pressure. The first documented
439 concern over night fishing occurred in 1961 after decreased angling success was noted the
440 previous year. In response to numerous stakeholder requests over several decades, the
441 Minnesota Department of Natural Resources (MNDNR) enacted a night fishing ban in 1984
442 from 10 PM to 6 AM for the first 4 weeks of the open water season, which begins in early May.
443 The next year, a size restriction limiting harvest of walleye over 508 mm was also implemented.
444 These regulations remained unchanged through 1996. The primary intent of the night closure
445 was to redistribute harvest over the fishing season rather than reduce total harvest.

446 From 1984 to 1996, the median night harvest was about 15,000 KG (range 5,000 to
447 50,000 KG) comprising about 7% of the total annual angler harvest, including estimated hooking
448 mortality (Reeves and Bruesewitz 2007). In 1997, Mille Lacs became a shared fishery between
449 state licensed anglers and Ojibwa (Chippewa) tribal fishers. From 1997 to 2013, the total

450 allowable annual harvest of walleye was determined by a fixed exploitation policy using age-
451 structured stock assessment model estimates of total population biomass and averaged 200,000
452 KG (harvested fish and hooking deaths). Tribal fishers declared a fixed quota each year, on
453 average 25-30% of the total allowable harvest, with the remainder allocated to state recreational
454 anglers. The state recreational angling fishery was managed using size-based regulations and bag
455 limits to remain within allocation. During this period, the spring night fishing ban remained in
456 effect while 10 different size-based regulations and two different bag limits, along with mid-
457 season changes to either more or less size restrictive regulations, were implemented to control
458 harvest.

459 Despite intensive management the population did not increase (Venturelli et al. 2014). In
460 2014, a suite of alternative regulations was presented to stakeholders and the open water season-
461 long night fishing closure was the most supported additional restriction, followed by mandatory
462 use of circle hooks and a more restrictive season-long night closure (8 PM to 6 AM). What
463 became evident is that night fishing regulation is one management tool and it is unlikely to work
464 in isolation unless combined with other tools (e.g., bag and slot limits and seasonal closures).
465 Also relevant is that all of these management tools rely on projections of anticipated outcomes
466 that do not necessarily occur due to interannual variability in catch rates and fishery conditions.
467 Long-term monitoring to assess fish population responses to regulatory changes as well a human
468 dimensions work to evaluate stakeholder perspectives are underway. What is clear is that night-
469 specific regulations expand the toolbox for fisheries managers.

470 **Synthesis and Conclusions**

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

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

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502

503 **References**

504 Arlinghaus R. 2005. A conceptual framework to identify and understand conflicts in recreational
505 fisheries systems, with implications for sustainable management. *Aquatic Resources, Culture and*
506 *Development*. 1(2):145–174. <http://dx.doi.org/10.1079/ARC200511>

507

508 Arlinghaus R, Bork M, Fladung E. 2008. Understanding the heterogeneity of recreational anglers
509 across an urban–rural gradient in a metropolitan area (Berlin, Germany), with implications for
510 fisheries management. *Fish Res*. 92(1):53–62. <http://dx.doi.org/10.1016/j.fishres.2007.12.012>

511

512 Arlinghaus R, Cooke SJ. 2009. Recreational fishing: socio-economic importance, conservation
513 issues and management challenges. Pages 39-58 in B. Dickson, J. Hutton, and B. Adams, Eds.
514 *Recreational Hunting, Conservation and Rural Livelihoods: Science and Practice*. Blackwell
515 Publishing, Oxford.

516

517 Arlinghaus R, Krause J. 2013. Wisdom of the crowd and natural resource management. *Trends*
518 *Ecol Evol*. 28(1):8–11. <http://dx.doi.org/10.1016/j.tree.2012.10.009>

519

520 Arlinghaus R, Lorenzen K, Johnson BM, Cooke SJ, Cowx IG. 2015a. Managing freshwater
521 fisheries: addressing habitat, people and fish. In: Craig J, editor. *Freshwater Fisheries Ecology*.
522 UK: Blackwell Science. p. 557–579.

523

524 Arlinghaus R, Tillner R, Bork M. 2015b. Explaining participation rates in recreational fishing

525 across industrialised countries. *Fisheries Manag Ecol.* 22(1):45–55.

526 <http://dx.doi.org/10.1111/fme.12075>

527

528 Atema J. 1971. Structures and functions of the sense of taste in the catfish (*Ictalurus*

529 *natalis*). *Brain Behav Evol.* 4(4): 273-294.

530

531 Bassett DK, Montgomery JC. 2011. Investigating nocturnal fish populations in situ using baited

532 underwater video: with special reference to their olfactory capabilities. *J Exp Mar Biol Ecol.*

533 409(1):194–199. <http://dx.doi.org/10.1016/j.jembe.2011.08.019>

534

535 Benoît HP, Swain DP. 2003. Accounting for length-and depth-dependent diel variation in

536 catchability of fish and invertebrates in an annual bottom-trawl survey. *Ices J Mar Sci.*

537 60(6):1298–1317. [http://dx.doi.org/10.1016/S1054-3139\(03\)00124-3](http://dx.doi.org/10.1016/S1054-3139(03)00124-3)

538

539 Ben-Yami M. 1976. Fishing with light. *FAO Fishing Manuals*. Farnham Surrey (UK): Fishing

540 News Books Ltd.

541

542 Ben-Yami M. 1988. *Attracting Fish with Light*. *FAO Training Series no. 14*. Rome: FAO.

543

544 Brouwer SL, Mann BQ, Lamberth SJ, Sauer WHH, Erasmus C. 1997. A survey of the South

545 African shore-angling fishery. *S Afr J Marine Sc.* 18(1):165–177.

546 <http://dx.doi.org/10.2989/025776197784161126>

547

548 Browder R. 2012. Fishing lights at night. In-Fisherman. Available from: [http://www.in-](http://www.in-fisherman.com/bass/fishing-lights-at-night/)
549 [fisherman.com/bass/fishing-lights-at-night/](http://www.in-fisherman.com/bass/fishing-lights-at-night/)
550
551 Cooke SJ, Cowx IG. 2004. The role of recreational fishing in global fish crises.
552 *BioScience*. 54(9): 857-859. 10.1641/0006-3568(2004)054[0857:TRORFI]2.0.CO
553
554 Cooke SJ, Suski CD. 2004. Are circle hooks an effective tool for conserving marine and
555 freshwater recreational catch-and-release fisheries?. *Aquat Conserv*. 14(3): 299-326.
556 10.1002/aqc.614
557
558 Cooke SJ, Suski CD. 2005. Do we need species-specific guidelines for catch-and-release
559 recreational angling to effectively conserve diverse fishery resources?. *Biodivers Conserv* 14(5):
560 1195-1209. 10.1007/s10531-004-7845-0
561
562 Cooke SJ, Cowx IG. 2006. Contrasting recreational and commercial fishing: searching for
563 common issues to promote unified conservation of fisheries resources and aquatic
564 environments. *Biol Conserv*. 128(1), 93-108. doi:10.1016/j.biocon.2005.09.019
565
566 Cooke SJ Hogan ZS, Butcher PA, Stokesburry MJW, Raghavan R, Gallagher AJ, Hammerschlag
567 N, Danylchuk AJ. 2016. Angling for endangered fish: Conservation problem or conservation
568 action? *Fish Fish* 17:249-265.
569
570 Cox SP, Walters CJ, Post JR. 2003. A model-based evaluation of active management of

571 recreational fishing effort. *N Am J Fish Manage.* 23(4):1294–1302.
572 <http://dx.doi.org/10.1577/M01-228AM>
573

574 Danilowicz BS, Sale PF. 1999. Relative intensity of predation on the french grunt, *Haemulon*
575 *flavolineatum*, during diurnal, dusk, and nocturnal periods on a coral reef. *Mar Biol.* 133(2):337–
576 343. <http://dx.doi.org/10.1007/s002270050472>
577

578 Daugherty DJ, Sutton TM. 2005. Diel movement patterns and habitat use of flathead catfish in
579 the lower St. Joseph River, Michigan. *J Freshwater Ecol.* 20(1):1–8.
580 <http://dx.doi.org/10.1080/02705060.2005.9664930>
581

582 Døving KB, Gemne G. 1965. Electrophysiological and histological properties of the olfactory
583 tract of the burbot (*Lota lota* L.). *J Neurophysiol.* 28(1):139–153.
584

585 Emery AR. 1973. Preliminary comparisons of day and night habits of freshwater fish in Ontario
586 lakes. *J Fish Res Board Can.* 30(6):761–774. <http://dx.doi.org/10.1139/f73-131>
587

588 FAO Fisheries and Aquaculture Department. 2009. Fishery and Aquaculture Country Profiles:
589 The Republic of Maldives. Rome: FAO Fisheries and Aquaculture Department. Available from:
590 <http://www.fao.org/fishery/facp/MDV/en>
591

592 Fréon P, Gerlotto F, Soria M. 1996. Diel variability of school structure with special reference to
593 transition periods. *Ices J Mar Sci.* 53(2):459–464. <http://dx.doi.org/10.1006/jmsc.1996.0065>

594

595 Hamilton RJ, Giningele M, Aswani S, Ecochard JL. 2012. Fishing in the dark-local knowledge,
596 night spearfishing and spawning aggregations in the Western Solomon Islands. *Biol Conserv.*
597 145(1):246–257. <http://dx.doi.org/10.1016/j.biocon.2011.11.020>

598

599 Hara TJ, Zielinski BS. 2006. *Fish physiology: Sensory systems neuroscience*. New York:
600 Elsevier Press.

601

602 Harvey ES, Butler JJ, McLean DL, Shand J. 2012. Contrasting habitat use of diurnal and
603 nocturnal fish assemblages in temperate Western Australia. *J Exp Mar Biol Ecol.* 426:78–86.
604 <http://dx.doi.org/10.1016/j.jembe.2012.05.019>

605

606 Hazin HG, Hazin FHV, Travassos P, Erzini K. 2005. Effect of light-sticks and electrolume
607 attractors on surface-longline catches of swordfish (*Xiphias gladius*, Linnaeus, 1959) in the
608 southwest equatorial Atlantic. *Fish Res.* 72(2):271–277.
609 <http://dx.doi.org/10.1016/j.fishres.2004.10.003>

610

611 Helfman GS. 1978. Patterns of community structure in fishes: summary and overview. *Environ*
612 *Biol Fish.* 3:129–148. <http://dx.doi.org/10.1007/BF00006313>

613

614 Helfman GS. 1993. Fish behaviour by day, night, and twilight. In: Pitcher TJ, editor. *Behaviour*
615 *of Teleost Fishes*. 2nd ed. London: Chapman and Hall. p. 479–512.

616

617 Hinkens E, Cochran PA. 1988. Taste buds on the pelvic fin rays of the burbot, *Lota lota* (L.). J
618 Fish Biol. 32(6):975. <http://dx.doi.org/10.1111/j.1095-8649.1988.tb05441.x>
619

620 Horodysky AZ, Brill RW, Warrant EJ, Musick JA, Latour RJ. 2008. Comparative visual function
621 in five sciaenid fishes. J Exp Biol. 211(22):3601–3612. <http://dx.doi.org/10.1242/jeb.023358>
622

623 Horodysky AZ, Brill RW, Warrant EJ, Musick JA, Latour RJ. 2010. Comparative visual function
624 in four piscivorous fishes inhabiting Chesapeake Bay. J Exp Biol. 213(10):1751–1761.
625 <http://dx.doi.org/10.1242/jeb.038117>
626

627 Jensen EJ. 2013. Completion Report: Large lake assessment report for Mille Lacs Lake 2011.
628 Minnesota Department of Natural Resources, St. Paul. Available from:
629 <http://files.dnr.state.mn.us/areas/fisheries/aitkin/mille-lacs-creel.pdf>
630

631 Johnson BM, Martinez PJ. 1995. Selecting harvest regulations for recreational fisheries:
632 opportunities for research/management cooperation. Fisheries. 20(10): 22-29.
633

634 Johannes RE, Neis B. 2007. The value of anecdote. In: Haggan N, Neis B, Baird IG, editors.
635 Fishers' Knowledge in Fisheries Science and Management. Paris: UNESCO Publishing. p. 41–
636 58.
637

638 Johnsen S. 2003. Lifting the cloak of invisibility: the effects of changing optical conditions on
639 pelagic cypsis. Integr Comp Biol. 43(4):580–590. <http://dx.doi.org/10.1093/icb/43.4.580>

640

641 Johnsen S, Sosik HM. 2003. Cryptic coloration and mirrored sides as camouflage strategies in
642 near-surface pelagic habitats: Implications for foraging and predator avoidance. *Limnol*
643 *Oceanogr.* 48(3):1277–1288. <http://dx.doi.org/10.4319/lo.2003.48.3.1277>

644

645 Johnsen S. 2012. *The optics of life: a biologist's guide to light in nature*. Princeton NJ: Princeton
646 University Press.

647

648 Johnson D. 2013. Best bobbers for night fishing. In-Fisherman. Available from: [http://www.in-](http://www.in-fisherman.com/gear-accessories/best-bobbers-for-night-fishing/)
649 [fisherman.com/gear-accessories/best-bobbers-for-night-fishing/](http://www.in-fisherman.com/gear-accessories/best-bobbers-for-night-fishing/)

650

651 Krueger CC, Decker DJ. 1999. The process of fisheries management. In: Kohler CC, Hubert
652 WA, editors. *Inland fisheries management in North America*. 2nd ed. Bethesda: American
653 Fisheries Society. p. 31–59.

654

655 Lapointe NW, Cooke SJ, Imhof JG, Boisclair D, Casselman JM, Curry RA, Langer OE,
656 McLaughlin RL, Minns CK, Post JR, Power M, Rasmussen JB, Reynolds JD, Richardson JS,
657 Tonn WM, Power M. 2013. Principles for ensuring healthy and productive freshwater
658 ecosystems that support sustainable fisheries. *Env Rev.* 22(2): 110-134. [dx.doi.org/10.1139/er-](http://dx.doi.org/10.1139/er-2013-0038)
659 [2013-0038](http://dx.doi.org/10.1139/er-2013-0038)

660

661 Lennox RJ, Whoriskey K, Crossin GT, Cooke SJ. 2015. Influence of angler hook-set behaviour

662 relative to hook type on capture success and incidences of deep hooking and injury in a teleost
663 fish. *Fish Res.* 164:201–205. <http://dx.doi.org/10.1016/j.fishres.2014.11.015>

664

665 Lewin WC, Arlinghaus R, Mehner T. 2006. Documented and potential biological impacts of
666 recreational fishing: insights for management and conservation. *Rev Fish Sci.* 14(4): 305-367.

667

668 Ley J, Halliday JA. 2007. Diel variation in mangrove fish abundances and trophic guilds of
669 northeastern australian estuaries with a proposed trophodynamic model. *Bull Mar Sci.*

670 80(3):681–720.

671

672 Mazur MM, Beauchamp DA. 2006. Linking piscivory to spatial-temporal distributions of pelagic
673 prey fish with a visual foraging model. *J Fish Biol.* 69(1):151–175.

674 <http://dx.doi.org/10.1111/j.1095-8649.2006.01075.x>

675

676 McMahon TE, Holanov SH.1995. Foraging success of largemouth bass at different light
677 intensities: implications for time and depth of foraging. *J Fish Biol.* 46(5):759–767.

678 <http://dx.doi.org/10.1111/j.1095-8649.1995.tb01599.x>

679

680 Morales-Nin B, Moranta J, Garcí'a C, Tugores MP, Grau AM, Riera F, Cerda` M. 2005. The
681 recreational fishery off Majorca Island (western Mediterranean): some implications for coastal
682 resource management. *Ices J Mar Sci.* 62(4):727–739.

683 <http://dx.doi.org/10.1016/j.icesjms.2005.01.022>

684

685 Munz FW, McFarland WN. 1977. Evolutionary adaptations of fishes to the photic environment.
686 In: Crescitelli F, editor. Handbook of Sensory Physiology Vol 7/5: The Visual System in
687 Vertebrates. p: 193–275.
688

689 Nelson TC, Gazey WJ, Robichaud D, English KK, Mochizuki T. 2014. Status of White Sturgeon
690 in the lower Fraser River: Report on the findings of the Lower Fraser River White Sturgeon
691 Monitoring and Assessment Program 2013. Summary report. Sidney BC: LGL Limited.
692 Available from: http://www.frasersturgeon.com/media/LFRWS_Summary_2013.pdf.
693

694 New JG, Fewkes LA, Khan AN. 2001. Strike feeding behavior in the muskellunge, *Esox*
695 *masquinongy*: contributions of the lateral line and visual sensory systems. *J Exp Biol.*
696 204(6):1207–1221.
697

698 Nightingale B, Longcore T, Simenstad CA. 2006. Artificial night lighting and fishes. In: Rich C,
699 Longcore T, editors. Ecological consequences of artificial night lighting. Washington DC: Island
700 Press. p. 257–276.
701

702 Paragamian VL. 1989. A comparison of day and night electrofishing: size structure and catch per
703 unit effort for smallmouth bass. *N Am J Fish Manage.* 9(4):500–503.
704 [http://dx.doi.org/10.1577/1548-8675\(1989\)009<0500:ACODAN>2.3.CO;2](http://dx.doi.org/10.1577/1548-8675(1989)009<0500:ACODAN>2.3.CO;2)
705

706 Pavlov DS, Kasumyan AO. 1990. Sensory principles of the feeding behavior of fishes. *J*
707 *Ichthyol.* 30(6):77–93.

708

709 Pawson MG, Glenn H, Padda G. 2008. The definition of marine recreational fishing in Europe.

710 Mar Policy. 32(3):339–350. <http://dx.doi.org/10.1016/j.marpol.2007.07.001>

711

712 Pohlmann K, Atema J, Breithaupt T. 2004. The importance of the lateral line in nocturnal

713 predation of piscivorous catfish. J Exp Biol. 207(17):2971–2978.

714 <http://dx.doi.org/10.1242/jeb.01129>

715

716 Pope KL, Willis DW. 1996. Seasonal influences on freshwater fisheries sampling data. Rev Fish

717 Sci. 4(1): 57-73.

718

719 Post JR, Sullivan M, Cox S, Lester NP, Walters CJ, Parkinson EA, Paul AJ, Jackson L, Shuter B.

720 2002. Canada's recreational fisheries: the invisible collapse?. Fisheries. 27(1): 6-17.

721

722 Quinn S. 2014. Night fishing largemouth bass. In-Fisherman. Available from: [http://www.in-](http://www.in-fisherman.com/bass/largemouth-bass/night-fishing-largemouth-bass/)

723 [fisherman.com/bass/largemouth-bass/night-fishing-largemouth-bass/](http://www.in-fisherman.com/bass/largemouth-bass/night-fishing-largemouth-bass/).

724

725 Rapp T, Hallermann J, Cooke SJ, Hetz SK, Wuertz S, Arlinghaus R. 2012. Physiological and

726 behavioural consequences of capture and retention in carp sacks on common carp (*Cyprinus*

727 *carpio* L.), with implications for catch-and-release recreational fishing. Fish Res. 125-126: 57-

728 68. doi:10.1016/j.fishres.2012.01.025

729

730 Reebbs SG. 2002. Plasticity of diel and circadian activity rhythms in fishes. *Rev Fish Biol Fisher.*
731 12(4):349–371. <http://dx.doi.org/10.1023/A:1025371804611>
732

733 Reeves KA, Bruesewitz RE. 2007. Factors influencing the hooking mortality of Walleyes caught
734 by recreational anglers on Mille Lacs, Minnesota. *N Amer J Fish Manage* 27:443-452.
735

736 Reid DD, Montgomery SS. 2005. Creel survey based estimation of recreational harvest of
737 penaeid prawns in four southeastern Australian estuaries and comparison with commercial
738 catches. *Fish Res.* 74(1):169–185.
739

740 Robbins WD, Peddemors VM, Broadhurst MK, Gray CA. 2013. Hooked on fishing?
741 Recreational angling interactions with the Critically Endangered grey nurse shark *Carcharias*
742 *taurus* in eastern Australia. *Endang Species Res.* 21:161–170. <http://dx.doi.org/10.3354/esr00520>
743

744 Smallwood CB, Beckley LE, Sumner NR. 2006. Shore-based recreational angling in the Rottneest
745 Island Reserve, Western Australia: spatial and temporal distribution of catch and fishing effort.
746 *Pac Conserv Biol.* 12(3):238–251. <http://dx.doi.org/10.1071/PC060238>
747

748 Smallwood CB, Pollock KH, Wise BS, Hall NG, Gaughan DJ. 2011. Quantifying recreational
749 fishing catch and effort: a pilot study of shore-based fishers in the Perth Metropolitan area.
750 Fisheries Research Report No. 216. Final NRM Report - Project No. 09040. Department of
751 Fisheries. Available from: http://www.fish.wa.gov.au/Documents/research_reports/fr216.pdf.
752

753 Tufts BL, Holden J, DeMille M. 2015. Benefits arising from sustainable use of North America's
754 fishery resources: economic and conservation impacts of recreational angling. *Int J Environ Stud.*
755 72(5): 850-868. 10.1080/00207233.2015.1022987
756

757 USFWS. 2009. Recreational Fishing Management Plan. Back Bay National Wildlife Refuge.
758 Virginia: U.S. Department of the Interior. Fish and Wildlife Service. Available from:
759 [http://www.fws.gov/northeast/planning/back%20bay/pdf/draft_ccp/15w_Appendix%20H_Recre](http://www.fws.gov/northeast/planning/back%20bay/pdf/draft_ccp/15w_Appendix%20H_Recreational_Fishing_Management_Plan(709KB).pdf)
760 [ational_Fishing_Management_Plan\(709KB\).pdf](http://www.fws.gov/northeast/planning/back%20bay/pdf/draft_ccp/15w_Appendix%20H_Recreational_Fishing_Management_Plan(709KB).pdf)
761

762 Veiga P, Ribeiro J, Goncalves JMS, Erzini K. 2010. Quantifying recreational shore angling catch
763 and harvest in southern Portugal (north-east Atlantic Ocean): implications for conservation and
764 integrated fisheries management. *J Fish Biol.* 76(9):2216–2237. [http://dx.doi.org/10.1111/j.1095-](http://dx.doi.org/10.1111/j.1095-8649.2010.02665.x)
765 [8649.2010.02665.x](http://dx.doi.org/10.1111/j.1095-8649.2010.02665.x)
766

767 UN FAO. 2012. Recreational fisheries: FAO Technical Guidelines for Responsible Fisheries.
768 No. 13. Rome. 176 pp. (Written under contract by R. Arlinghaus, S.J. Cooke and B. Johnson)
769

770 Venturelli P, Bence J, Brendan T, Lester N, Rudstam L. 2014. Mille Lacs Lake Walleye Blue
771 Ribbon Panel Data Review and Recommendations for Future Data Collection and Management.
772 Prepared for Minnesota DNR. Available from:
773 [https://fwcb.cfans.umn.edu/sites/fwcb.cfans.umn.edu/files/venturelli_blue_ribbon_panel_review.](https://fwcb.cfans.umn.edu/sites/fwcb.cfans.umn.edu/files/venturelli_blue_ribbon_panel_review.pdf)
774 [pdf](https://fwcb.cfans.umn.edu/sites/fwcb.cfans.umn.edu/files/venturelli_blue_ribbon_panel_review.pdf)
775

776 Warrant EW. 1999. Seeing better at night: life style, eye design and the optimum strategy of
777 spatial and temporal summation. *Vision Res.* 39(9):1611–1630. <http://dx.doi.org/10.1016/S0042->
778 [6989\(98\)00262-4](http://dx.doi.org/10.1016/S0042-6989(98)00262-4)

779

780 Warrant EW, Johnsen S. 2013. Vision and the light environment. *Curr Biol.* 23:990–994.
781 <http://dx.doi.org/10.1016/j.cub.2013.10.019>

782

783 Zeller D, Booth S, Davis G, Pauly D. 2007. Re-estimation of small-scale fishery catches for US
784 flag-associated island areas in the western Pacific: the last 50 years. *Fish B-Noaa.* 105(2):266–
785 277.

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

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Research Needs
<p>-Identify fish habitat needs at night to ensure that critical habitats are protected and to inform various enhancement and restoration activities</p>
<p>-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)</p>
<p>-Identify survey designs that accurately quantify catch and effort over 24 hours given that without accurate quantification of catch and effort by day and night, management cannot be effective</p>
<p>-Examine the potential for selective effects of night vs. day fishing (Are we catching the “same” fish by day and night?)</p>
<p>-Characterize the “artificial light food web” to understand how light pollution influences key sportfish and their prey (e.g., exigent need to study the fish- artificial light–foraging relationship)</p>
<p>-Determine if fish handling and associated injury, stress and mortality are elevated at night in the context of catch-and-release fishing</p>
<p>-Evaluate the extent to which post-release predation is mediated by night</p>

-Conduct social science surveys to understand angler perspectives on night fishing and associated regulations (usually bans)

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792

793 **Figure Captions**

794

795 **Figure 1.** Mechanistic examination of light conditions, ecophysiological processes, and
796 behavioural strategies during crepuscular periods. A) Changes in light intensity during dawn and
797 dusk. B) Mechanistic pathways (blue arrows) of changes in light intensity at dusk on physiology
798 and behaviour, with feedbacks (dashed grey arrows). C) Effects of low solar elevation and
799 changing light intensities characteristic of crepuscular periods on prey visual contrast and
800 behavioural foraging strategies of a predator (following Johnsen 2003; Johnsen and Sosik 2003).

801

802 **Figure 2.** Night fishing under natural and anthropogenically influenced conditions. Human
803 artificial lighting can increase nocturnal light intensities to within 10^4 units of high noon, leading
804 to changes in fish aggregation, available sensory modalities, foraging strategies, and catchability
805 (q). Management strategies for natural and anthropogenically-influenced nocturnal fisheries
806 should consider spatiotemporal properties, terminal gears, and size and bag limits. SS = species
807 specific. Senses are: Audition (A), Gustation (G), Mechanoreception (M), Olfaction (O), and
808 Vision (V).

809

810 **Figure 3.** Two categories of anthropogenic artificial light, with influences on aquatic habitats. A)
811 general illumination of the urban night sky can increase aquatic light up to 10,000 times brighter
812 than the new moon, enabling visual foraging by piscivores such as cutthroat trout (Mazur and
813 Beauchamp 2006). B) Point source illumination typical of docks, piers, bridges, marinas, and
814 waterfront restaurants. Light is far more limited and concentrated by point sources, increasing
815 asymmetries of prey contrast under the light and predator crypsis in the shadow lines. Both

816 artificial light conditions increase nocturnal foraging and catchability of predators that would not
817 be able to forage visually under natural conditions.

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