IGIUGIG VILLAGE COUNCIL
#1 Airport Way
Igiugig, AK 99613-4008
Phone: (907) 533-3211
Fax: (907) 533-3217
www.igiugig.com
e-mail: Igiugig.vc@gmail.com

May 10, 2022

VIA E-Filing

Ms. Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street NE
Washington, DC 20426

Subject: Igiugig Hydrokinetic Project (FERC No. 13511)
2021 Fish Monitoring Report

Dear Secretary Bose:

Igiugig Village Council (IVC), owner and operator of the Igiugig Hydrokinetic Project (FERC No. 13511) (Project), herein provides the 2021 Fish Monitoring Report in accordance with Federal Energy Regulatory Commission (FERC or Commission) License Article 402. Additionally, in accordance with License Article 403, IVC held a virtual Adaptive Management Team (AMT) meeting on April 1, 2022. The purpose of the meeting was to review 2021 Project operations, discuss 2021 Fish Monitoring Report results, and to review Project operation and monitoring plans for the 2022 Sockeye Salmon smolt and adult priority migration periods. The AMT meeting presentation and meeting notes are provided within the attached 2021 Fish Monitoring Report package.

Project Status and 2022 Operations and Monitoring Plans

IVC operated the RivGen2.0 device until August 2021 when, in partnership with Ocean Renewable Power Company, Inc. (ORPC), the device was removed as part of completion of a U.S. Department of Energy (DOE) Water Power Technology Office project. ORPC is presently retrofitting the RivGen2.0 device in Anchorage, Alaska with next generation turbines and with the intent of redeploying the device in August 2022. The RivGen2.1 device was installed in the fall of 2021 and following commissioning activities has been continuously operating since early 2022. The two licensed devices are planned to jointly operate at the Project site beginning in August 2022.

During the 2021 salmon priority periods, IVC operated the RivGen2.0 device in accordance with license and permitting conditions. Comprehensive monitoring in 2021 that included local indigenous knowledge, visual observations by IVC, ORPC, and Alaska Department of Fish and Game (ADF&G), and video fish monitoring by the University of Alaska Fairbanks (UAF) indicated no evidence of smolt injuries or mortality and very small numbers of interactions with the turbine components. In addition, no interactions with adult salmon were observed.

Based on results of 2021 monitoring and discussions held during the April 1 AMT meeting, IVC proposes the following operations and monitoring for the single RivGen2.1 device that will be present during the 2022 salmon migration priority periods:

- IVC will utilize local indigenous knowledge, observations, and communication with scientific and regulatory entities to determine Project operations. IVC will utilize its Tribal authority and knowledge to determine RivGen operations during the salmon priority periods.

- IVC will operate the RivGen device continuously (or as conditions allow) throughout the Sockeye smolt and adult migration periods. Project personnel will be available at all times while the turbine is operating during the smolt peak outmigration period. If negative effects to smolts, such as injury or mortality, are observed operation will be curtailed, and ADF&G and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) will be consulted.

- End priority period monitoring for adult salmon as adults have not been documented to interact with the RivGen device.

- Work with the Pacific Northwest National Laboratory (PNNL) and Aquacoustics, LLC to assist with implementation of a separate DOE-funded Triton Initiative hydroacoustic monitoring study. The proposed study will deploy a split-beam sonar directly upstream of the RivGen device for an approximate 10-day period during the smolt migration. Hydroacoustic data will inform development of encounter rate models for the device and also provide further information on smolt presence, distribution, and trajectory as they approach the RivGen device. Though this study is not proposed for formal inclusion into the Fish Monitoring Plan, IVC/ORPC believe this will provide further, additional information on device/smolt interactions.

IVC/ORPC will consult with the AMT regarding 2022 operations and monitoring results. Results from 2022 will be utilized to inform plans for 2023 salmon priority period operations and monitoring activities surrounding two active RivGen devices.

Article 402 Fish Monitoring Plan Modification Requests

In accordance with Article 402, the new RivGen2.1 device is outfitted with upstream and downstream cameras in the same configuration as the RivGen 2.0 device. Unfortunately, communications with the cameras have been lost and due to winter conditions, inspection and maintenance on the cameras has not been possible. Though IVC desires to further troubleshoot the cameras prior to the smolt outmigration period, IVC realizes that environmental conditions may not allow for work on the cameras to occur prior to the smolt run. As such, IVC requests a deviation from required video monitoring during the 2022 smolt outmigration period. To supplement monitoring information, IVC proposes to utilize drones to collect video footage, if conditions allow, to monitor the peak outmigration in addition to the presence of on-site personnel.

Additionally, based on local indigenous knowledge, field observations, and 2021 UAF data, IVC proposes to modify the Fish Monitoring Plan to end adult salmon priority period monitoring as adult salmon have not been documented to interact with the RivGen device.

Conclusion

IVC presented its 2022 operations and monitoring plan to federal and state regulators who constitute the AMT during the April 1 meeting. There were no objections to IVC's proposal and meeting minutes were circulated for concurrence. IVC very much appreciates the adaptive approach surrounding this pilot license. If you have any questions regarding this submission, please contact me by telephone at (907) 533-3211 or Nathan Johnson by telephone at (207) 221-6254 or by email, njohnson@orpc.co.

Sincerely,

AlexAnna Salmon

AlexAnna Salmon
President, Igiugig Village Council

Cc:
Nathan Johnson, ORPC
Katie Sellers Reynolds, ORPC

Attachment - 2021 Fish Monitoring Report

2021 Fish Monitoring Report

IGIUGIG HYDROKINETIC PROJECT
FERC PROJECT NO. P-13511

May 4, 2022

Prepared by:

Igiugig Village Council
P.O. Box 4008
Igiugig, Alaska 99613
Phone (907) 533-3211

Ocean Renewable Power Company, Inc.
254 Commercial St., Suite 119B
Portland, Maine 04101
Phone (207) 772-770

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Background

On May 23, 2019, the Federal Energy Regulatory Commission (FERC) issued the Igiugig Village Council (Igiugig Village) a 10-year pilot project license (P-13511) to construct, operate and maintain a 70-kilowatt hydrokinetic project in the Kvichak River. The hydrokinetic pilot project license enables Ocean Renewable Power Company, Inc. (ORPC) and Igiugig Village to test new hydrokinetic technologies and confirm its environmental effects or lack thereof without compromising FERC oversight or agency and stakeholder input. Phase I of the project, a single 35-kilowatt ORPC RivGen® Power System, was installed in fall 2019. Under the FERC license Igiugig Village is required to implement a Fish Monitoring Plan to monitor the effects of project operations on fisheries, including juvenile and adult sockeye salmon.

The Fish Monitoring Plan includes provisions for monitoring fish interactions with the RivGen® device using underwater cameras and reporting results summaries. During juvenile (smolt) outmigration (May 21-June 10) and adult migration (June 25-July 15) priority periods, project personnel are required to be on site and review underwater camera video with sufficient frequency to detect adverse interactions with the turbines and shut down the turbine if needed. Fish monitoring during the 2021 priority periods was conducted by faculty and staff from the University of Alaska Fairbanks (UAF) College of Fisheries and Ocean Science.

Igiugig Village is also required to implement an Adaptive Management Plan which includes provisions for annual project review meetings to discuss monitoring results and address other effects on fisheries resources with regulators. In 2021, ORPC held Adaptive Management Team (AMT) meetings on May 13 and June 2 to review project operations and management. On May 13, the AMT was informed of preparations for 2021 fish monitoring. At the time of this meeting, Igiugig Village and ORPC were addressing issues with the upstream camera as well as EyeSea autodetection software functionality while UAF faculty and staff were preparing for on-site fish monitoring during the May 20 to June 11 smolt priority period. During this period, project personnel demonstrated their ability to adhere to the terms of the Fish Monitoring Plan, stalling the turbine after a suspected negative fish interaction and returning to normal operations after approval from the Alaska Department of Fish and Game (ADF&G). During the June 2 AMT meeting, the AMT was informed of preliminary fish monitoring results, including inferred direct fish foil interactions, referred to as “blade strikes” by UAF. Following consultation, Igiugig Village proceeded with the fish monitoring field effort as outlined in the Fish Monitoring Plan with support from the AMT.

Local Indigenous Perspective

The Village of Igiugig is traditionally, culturally, and economically connected to Sockeye Salmon. The tribe occupies an archeological district spanning 21 known sites, dating as far back to 8,000 years ago, with Sockeye Salmon as a keystone species for survival. Today, the community directly stewards a land base which includes 81 miles of salmon spawning streams, which support all five species of salmon. This resource is essential to the Igyararmiut (people of Igiugig) subsistence way of life, and recreational fishing in the watershed, as well as commercial fishing in the Bristol Bay region where many residents of Igiugig make their annual income. Throughout the development of this hydrokinetic energy project, it has been fundamental to Igiugig Village to honor this relationship and continue their stewardship of the Sockeye Salmon population. Igiugig Village will not sacrifice the Kvichak River’s resource and its fish for hydrokinetic energy, or any form of renewable energy. 2021 field observations and UAF monitoring will inform strategies to mitigate any effects to Sockeye Salmon and optimize hydrokinetic energy production for this project. Igiugig Village is confident these results provide evidence to support the continued co-existence of a hydrokinetic energy project in the Kvichak River and effective stewardship of the Sockeye Salmon population. Local historical knowledge of the smolt migration, supplemented by recent studies, has provided Igiugig Village with the ability to make informed decisions on device operation to account for annual timing of the event and predictable diurnal fluctuations in fish densities.

Field Observations

Field observations were made during 2021 Sockeye Salmon smolt and adult priority periods to supplement camera monitoring conducted by UAF and provide a broader perspective on fish presence and behavior. On May 25, 2021, Igiugig Village and ADF&G staff toured the Kvichak River and RivGen site. On May 26, 2021, ORPC, IVC and ADF&G staff performed on-water visual observations and image collection from an AquaVu camera over the side of a vessel as well as from an aerial drone. Visual observations and camera/drone images indicated the vast majority of smolt were present in the top meter of the water column, rather than in deeper waters where the RivGen® is situated (Figure 1 & Figure 2).

Figure 1. Sockeye Salmon smolt transiting above the RivGen. Photo taken with an AquaVu camera on May 26, 2021.

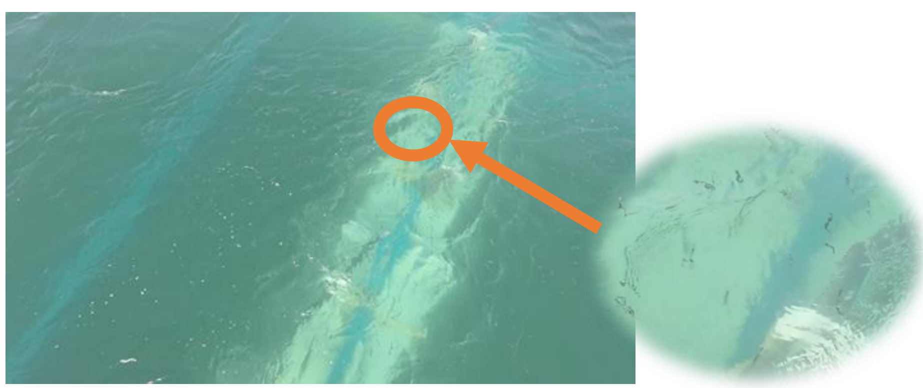


Figure 2. Sockeye Salmon smolt transiting above the RivGen. Photo taken with drone camera on May 26, 2021.

During the 9:00 AM observation period (i.e. 9:00-9:10 AM) on May 26, the Igiugig Village, ORPC, and ADF&G team observed one large pulse of smolt at the water surface from an eddy nearby the port side of the RivGen®. Photos from video taken from the AquaVu camera indicate that at least 191 smolt traveled past the RivGen® during this period (Figure 3). Only 6 potential fish events were observed with fish monitoring cameras on the RivGen® during this same monitoring period, underscoring the limited amount of fish that occur at the device depth. Beyond this specific event, the on-water team observed salmon smolt in large groups traveling close to the surface of the water. Highlighting behavior in Figure 1, smolt were observed to actively avoid obstacles in their path, in this case the AquaVu camera. In this picture one smolt can be seen swimming upstream away from the camera lens, lending to their ability to control their course even in fast areas of the river.

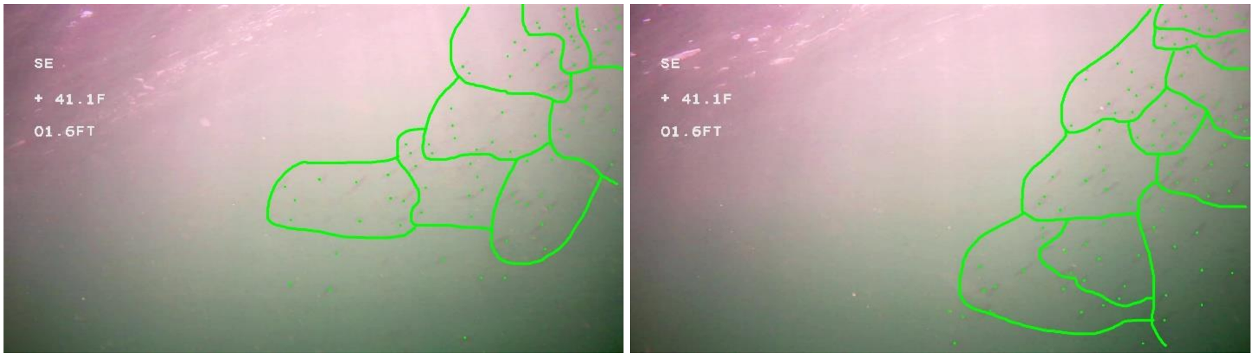


Figure 3. Sockeye Salmon Smolt counted in AquaVu imagery collected during the 9 AM monitoring period on May 26, 2021. 87 smolt were counted in the image to the left and 104 smolt were counted in the image to the right. (Green lines are drawn around groups of ten smolt)

In addition to observations of fish near the device, no signs of predation by birds or other predators were observed downstream of the RivGen that could be indicative of fish mortalities or compromising injuries.

UAF Monitoring

In accordance with the Fish Monitoring Plan goals, the team at UAF conducted a study which sought to characterize the interactions between the ORPC RivGen turbine and Kvichak River Sockeye Salmon during the species' juvenile and adult freshwater migrations. Monitoring Plan objectives include:

1. Document the presence and timing of fishes at the RivGen device by species and life stage
2. Characterize salmon movements past the RivGen device during migration periods
3. Describe the behavioral response of salmon that come into the vicinity of the RivGen device
4. Describe any observable acute effects from contact with the RivGen device, including disorientation, injury, or mortality during salmon migrations

By viewing real time video imagery, the UAF team was able to quantify the number of Sockeye Salmon that interact with the turbine and assess the behaviors/outcome of these interactions. Below represents an example observed smolt interaction.

Figure 4. Example camera image reviewed by the UAF team, taken on May 22, 2021. This smolt swimming past the RivGen foil would be classified as a fish event resulting in "normal" orientation.

A total of 2,445 Sockeye Salmon smolts were identified passing through the field of view of cameras placed immediately downstream of the RivGen during the late May to mid-June smolt priority period. The majority (>80%) of these observed events occurred over a short (5-day) time period from late-May to early-June, during the hours of 00:00–04:00 which corresponded to hours of complete darkness. Fish were observed passing through or near the RivGen device in both normal and disoriented manners, with the rotational status/speed of the RivGen appearing to influence passage behavior. No adult Sockeye Salmon were observed near the turbine. The full UAF Fish Monitoring Report is included as Attachment 1.

Historical Sockeye Salmon Counts

Beginning in 2008, the Bristol Bay Science and Research Institute (BBSRI) has conducted annual Sockeye Salmon smolt counts in the Kvichak River using a sonar system. Prior to BBSRI, ADF&G performed smolt counts for several decades. BBSRI performs annual smolt sampling with incline plane traps to collect biological data by capturing 600 smolt per night during the identified priority period (bbsri.org) However, Sockeye Salmon smolt counts were not conducted by BBSRI in 2021. Previous years indicate that smolt outmigration counts can be highly variable; between 2008 and 2015, according to BBSRI's estimates, smolt outmigration abundance ranged from 29.3 to 64.5 million individuals as shown in Figure 5.

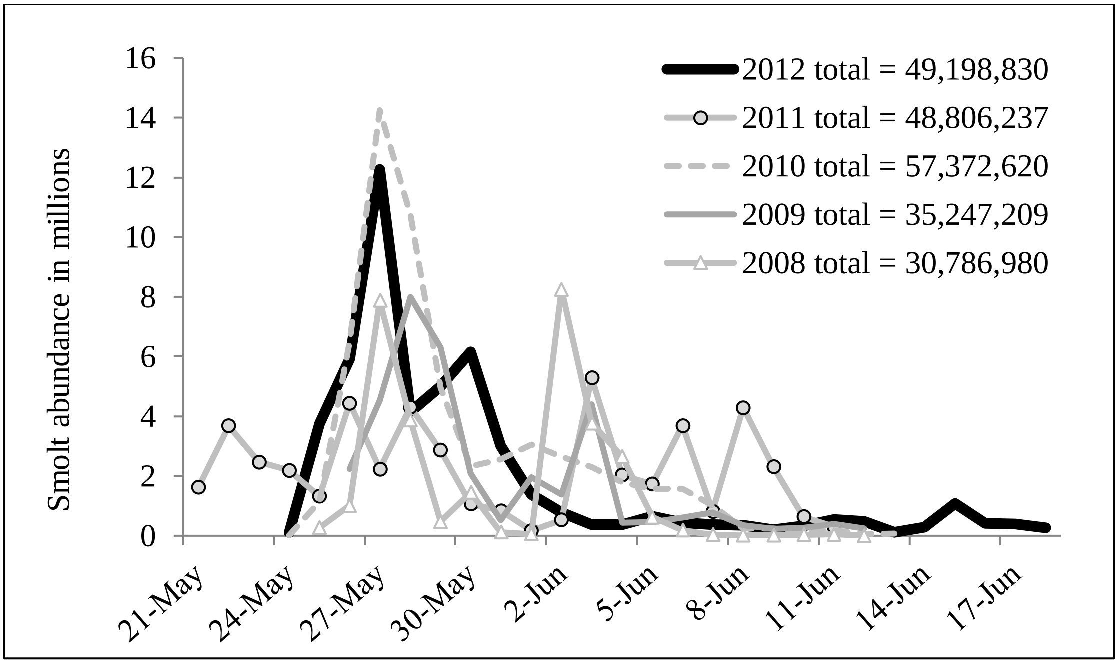


Figure 5. Estimated daily sockeye salmon smolt abundance, Kvichak River, 2008 – 2012. Source: LGL

Therefore, any extrapolation of total smolt interactions with the device in 2021 by the UAF team would be difficult to contextualize to the overall population of smolt transiting through the Kvichak River to understand proportional impacts. Nonetheless, we infer that the proportion of Sockeye Salmon smolt that interact with the RivGen® turbine (estimated at 201,759 in 2021) is approximately two orders of magnitude smaller than the typical total population of smolt outmigrating through the Kvichak River.

ADF&G, however, did perform adult salmon counts in 2021. Of an estimated 4,307,640 fish migrating past the RivGen, none were observed interacting with the RivGen. The upstream migration corridor of adult Sockeye Salmon is known to be close to shore (<10 m) which does not overlap with the placement of the RivGen in the river's thalweg. This finding is corroborated with aerial drone footage taken during the 2020 adult migration, which showed adult Sockeye Salmon navigation close to the shoreline of the Kvichak River. This finding is also corroborated with previous fish interaction studies with a previous iteration of the RivGen in 2014 by Nemeth, Priest and Patterson and in 2015 by Priest and Nemeth. In rare documented interactions with adult Sockeye Salmon they appeared to mill behind the device but actively avoid it.

Annual Adaptive Management Team Meeting

On April 1, 2022, IVC and ORPC reviewed 2021 operations data and monitoring results with the Igiugig Hydrokinetic Project's Adaptive Management Team (AMT). Meeting participants included representatives from Alaska Department of Fish and Game, Alaska Department of Natural Resources, U.S. Fish and Wildlife Service, National Oceanographic and Atmospheric Administration, U.S. Coast Guard, as well as UAF, Lake and Peninsula Borough of Alaska, and the Pacific Northwest National Laboratory. The agenda for the meeting included:

- Introductions
- 2021 Operations Overview

- 2021 Fish Monitoring Results
- 2022 Fish Monitoring
- Recommendations/Next Steps

AMT discussions were supportive of IVC's progress with the Fish Monitoring Plans and study results. The AMT presentation is included in Attachment 2 and the meeting minutes in Attachment 3.

Conclusions

Fish monitoring in 2021 provided a unique opportunity to combine local indigenous knowledge, visual observations, historical fish counts and near device video monitoring. The UAF study provides some of the first high resolution, field-based imagery of fish interactions with an active hydrokinetic turbine. The limited number of Sockeye Salmon smolt interactions and lack of adult Sockeye Salmon interactions support the continued co-existence of this hydrokinetic energy project and a thriving Sockeye Salmon population in the Kvichak River. This information is important for the understanding the potential impacts of these devices on socially and culturally important fisheries and helps to inform strategies to mitigate impacts of emerging energy projects on fishes.

Igiugig Village believes these fish monitoring results do not indicate negative effects to the Sockeye Salmon population. No interactions with adult Sockeye Salmon were observed during this monitoring effort. The proportion of Sockeye Salmon smolt interacting with the RivGen® observed during this monitoring effort is small and the degree of injury or mortality resultant from direct foil interactions remains unknown. These results and recommendations for future operations were presented to federal and state regulators, comprising the project's Adaptive Management Team, on April 1, 2022.

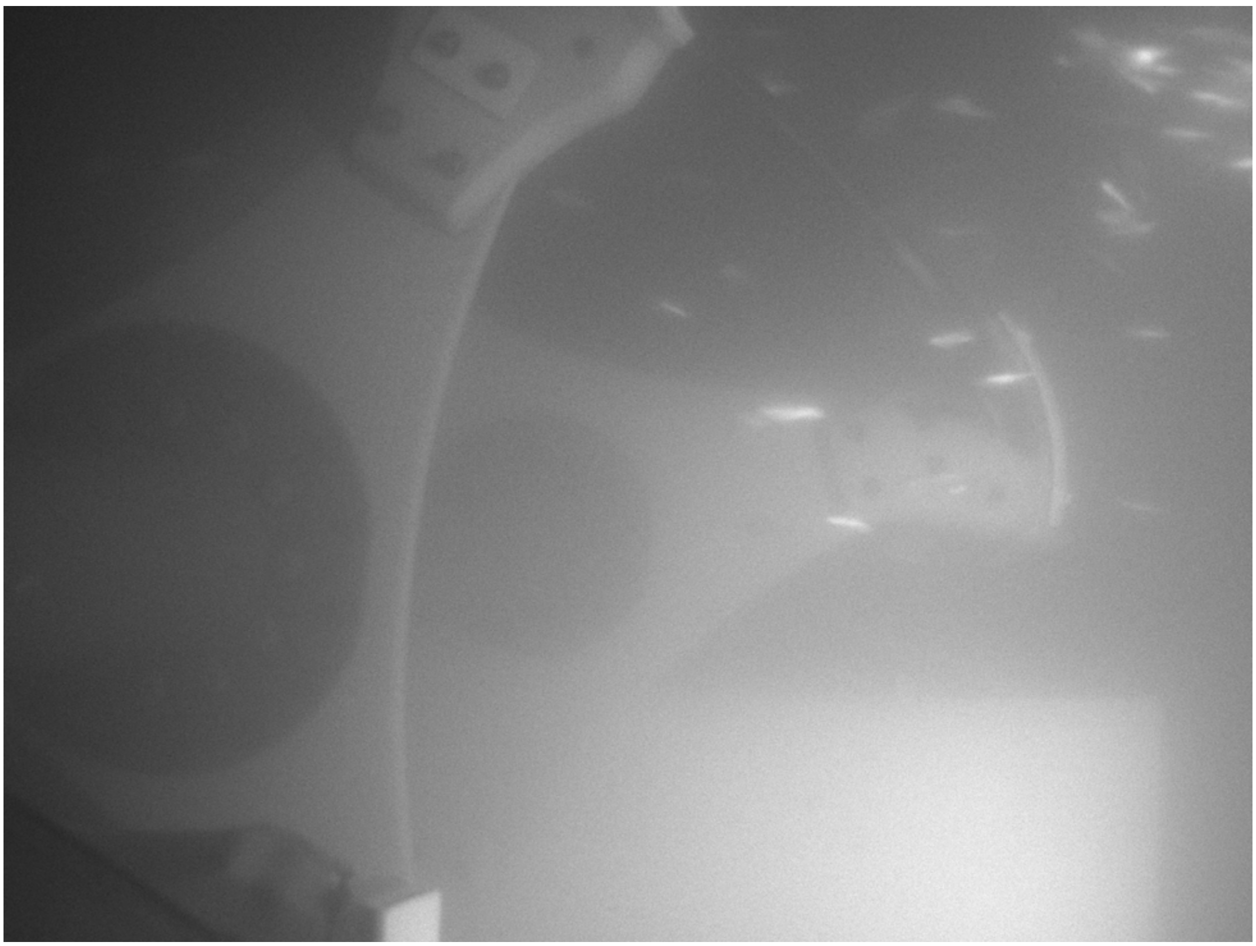
Attachment 1

Characterizing fish interactions with a hydrokinetic turbine in the Kvichak River during the Sockeye Salmon Oncorhynchus nerka spring smolt and summer adult migration periods.

College of Fisheries and Ocean Sciences
University of Alaska Fairbanks
2150 Koyukuk Dr., 245 O'Neill Bldg.
Fairbanks, AK 99775-7220

Characterizing fish interactions with a hydrokinetic turbine in the Kvichak River during the Sockeye Salmon *Oncorhynchus nerka* spring smolt and summer adult migration periods

Michael B. Courtney, Austin J. Flanigan, Mary Hostetter, Andrew C. Seitz



Prepared for Ocean Renewable Power Company and Igiugig Village Council by the University of Alaska Fairbanks, College of Fisheries and Ocean Sciences

Suggested Citation: Courtney, M.B., A.J. Flanigan, M. Hostetter, and A.C. Seitz. 2021. Characterizing fish interactions with a hydrokinetic turbine in the Kvichak River during the Sockeye Salmon *Oncorhynchus nerka* spring smolt and summer adult migration periods. Final report for Ocean Renewable Power Company and Igiugig Village Council, 32 pp.

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Abstract

The development of in-river hydrokinetic turbines has been motivated by the desire to reduce diesel fuel reliance, energy production costs, and greenhouse gas emissions. For most in-river turbines, the taxa of highest concern regarding contacting the device is fishes, yet few studies have assessed fish interactions with hydrokinetic turbines in riverine environments. Therefore, this study sought to characterize the interactions between the ORPC RivGen® turbine with Sockeye Salmon from one of the most productive populations in the world, that in the Kvichak River. In addition to large scale subsistence and commercial fisheries, the Sockeye Salmon is vital to the well-being of many Indigenous communities in western Alaska, including the village of Igiugig, AK, which lies at the headwaters of the Kvichak River, adjacent to the RivGen® site. Because of the Igiugig's strong historical, cultural and social connection to Sockeye Salmon, an understanding of its presence and behaviors is of utmost importance to current and future generations of residents. By viewing real time video imagery, our objectives were to quantify the number of Sockeye Salmon that interact with the turbine and assess the behaviors/outcome of these interactions during the species' juvenile (i.e., smolt) and adult freshwater migrations. Over the smolt (21 May to 10 June) and adult (25 June to 15 July) monitoring periods, a total of 2,445 Sockeye Salmon smolts were identified passing through the field of view of cameras placed immediately downstream of the RivGen®. The majority (>80%) of these observed events occurred over a short (5-day) time period from late-May to early-June, during the hours of 0000–0400 which corresponded to hours of complete darkness. Fish were observed passing through or near the RivGen® device in both normal and disoriented manners, with the rotational status/speed of the RivGen® appearing to influence passage behavior. In addition to documenting disoriented behaviors in fish, blade strikes on fish were observed, all of which occurred when the turbine was rotating at high "production" speeds. After temporally and spatially extrapolating the observed fish interactions to account for our sub-sampling, our results suggest that the RivGen® interacted with ~200,000 juvenile Sockeye Salmon, leading to an estimated ~41,000 disoriented behaviors and ~2700 blade strikes. In contrast to observations of Sockeye Salmon smolt, no adult sockeye salmon were observed near the turbine. While it was out of the scope of this study to conduct biopsies on observed blade strikes, the ultimate fate and number of injuries/mortalities is of upmost importance when considering impacts to fisheries. It is important to note that although this study contained many limitations and caveats, it provides some of the first high resolution, field-based imagery of fish interactions with an active hydrokinetic turbine, thus adding to the sparse knowledge base of fish interactions with emerging riverine hydrokinetic devices. This information is important for the understanding the potential impacts of these devices on socially and culturally important fisheries, and may inform strategies to mitigate impacts of emerging energy projects on fishes.

Introduction

The development of renewable energy resources has been motivated by the desire to reduce diesel fuel reliance, energy production costs, and greenhouse gas emissions. Traditional hydropower has been a common method of clean energy production, but the reliance on damming and impounding river drainages has resulted in large scale impacts on aquatic ecosystems (Cada et al. 2007). As such, recent efforts have explored hydrokinetic energy production, which unlike traditional hydropower, uses natural water movement in rivers and tidal areas to produce electricity without the use of dams or impoundments (Castro-Santos and Haro 2015; Seitz et al. 2011; Viehman and Zydlewski 2015). To harness this energy, hydrokinetic turbines with hydrofoil blades are placed perpendicular to flowing water, which forces them to spin or oscillate. While these devices are designed to minimize impacts on aquatic ecosystems, the rotors and blades of these hydrokinetic turbines still have the potential to interact with aquatic organisms. Currently, these potential impacts remain largely undocumented (Copping et al. 2021; Sparling et al. 2020).

For most in-river turbines, fishes are the animals of highest concern in relation to potential impacts. A few studies have assessed fish interactions with hydrokinetic turbines, and have mainly relied on hydroacoustic techniques and laboratory-based flume experiments. The primary objectives of these studies have been to characterize fish avoidance and survival probability (Grippo et al. 2017; Shen et al. 2016). Avoidance rates in most studies have been high, but some fishes still pass through the device and risk colliding with or being struck by blades. Most avoidance behavior studies have focused on adult fishes, which have a greater capacity to swim against or across water currents, potentially resulting in higher degrees of avoidance behavior than juveniles (Schweizer et al. 2012). For example, adult Pacific salmon (*Oncorhynchus* spp.) were shown to rarely interact with a river turbine (Matzner et al. 2017), but juvenile Atlantic salmon (*Salmo salar*) in a flume study displayed a limited capacity to avoid a turbine (Castro-Santos and Haro 2015). Avoidance behavior can also be influenced by river conditions, where faster flow rates and higher turbidity are correlated to a reduction in the ability of fishes to avoid hydrokinetic devices (Hammar et al. 2013). Flume studies have been used to predict blade strike and survival probabilities, which have found low blade strike probabilities and subsequently high survival rates that generally vary with fish size and species (EPRI 2011; Hammar et al. 2015). Individual devices are likely to have differing rates of fish interactions, where higher rotational speeds increase blade strike probabilities (Amaral et al. 2015).

While past research has shown relatively small effects of hydrokinetic turbines on fish species, the research has been limited in geographic and taxonomic scope, making transferability of conclusions to other habitats and species unknown. Fish behavior and survival are likely specific to a number of different factors, including fish species and life stage, water conditions, and design of each hydrokinetic device. Compared to worldwide fish diversity and the emerging field of hydrokinetic energy development, interactions between relatively few fish species and hydrokinetic turbine designs have been evaluated. As a result, knowledge about blade strike and survival probabilities for fish passing through hydrokinetic devices is sparse, particularly for relatively fast spinning turbines. One such turbine is the Ocean Renewable Power Company's (ORPC) RivGen® device. The RivGen® is a hydrokinetic turbine designed for fast moving river currents, spinning at production speeds of >60 rpm. One of these devices was deployed in the Kvichak River, Alaska adjacent to the village of Igiugig.

The Kvichak River is located in Southwest Alaska, where it drains Iliamna Lake by flowing 106 km to Bristol Bay (Fig. 1). Bristol Bay supports the largest Sockeye Salmon (*Oncorhynchus nerka*) fishery in the world, and the Kvichak system alone has annual adult spawning abundances ranging from 2.1 to 7.3 (mean 4.1) million individuals over the last 10 (2012–2021) years (Salomone et al. 2019), even after fishery removals. Subsequently, each spring, tens of millions (29–61 million as estimated from sonar arrays during 2008–2015) of Sockeye Salmon smolts migrate down the Kvichak River from Iliamna Lake to the ocean (Nemeth et al. 2014a; Priest et al. 2015; Wade et al. 2013; Wade et al. 2012; Wade et al. 2010), requiring them to migrate past the ORPC Rivgen®. Because Sockeye Salmon is an essential resource in the region, supporting subsistence (Halas and Neufeld 2018), recreational (Dye and Schwanke 2018), and commercial fisheries (Salomone et al. 2018), understanding these interactions is required by the agencies responsible for Sockeye Salmon management as part of the Federal Energy Regulatory Commission licensing process. Additionally, Igiugig, who is the primary beneficiary of the renewable power from the hydrokinetic turbine, is a community with strong traditional, social and cultural connections to Sockeye Salmon. It is important to Igiugig that studies increase the understanding of Sockeye Salmon presence and behaviors near the hydrokinetic turbine so the integrity of the population can be maintained and the connections between the community and Sockeye Salmon are honored. Therefore, the goal of this study was to characterize the interactions between Sockeye Salmon and the ORPC RivGen® during the downstream smolt migration to the ocean and upstream adult migration to spawning grounds. To accomplish this goal, our objectives were to view video imagery taken by underwater cameras to 1) quantify the number of fish that interact with the turbine and 2) assess the behaviors/outcomes of these interactions.

Methods

Study Site:

The RivGen® was installed in the Kvichak River near the village of Igiugig, approximately 2 rkm downstream from the mouth of Iliamna Lake (Fig. 1) (ORPC 2018). The overall dimensions of the device, including substructure, were 15.9-m length, 14.5-m wide, and 3.5-m tall while the dimensions of the spinning component were approximately 10-m length, and 1.8-m diameter (Fig. 2). The device was placed at the center of the river channel, approximately 30 m from the right river bank when looking downstream, with the substructure anchored to the riverbed (Fig. 2). The water depth at the RivGen® site was approximately 5 m, with mean velocities of ~2.5 m/s (Thomas et al. 2014). The top of the blades was located between 2.3 (mean high water) and 1.2 m (mean low water) below the surface of the water column (Fig. 2). Submerged power and fiber optic cables ran from the RivGen® along the riverbed to a shore station approximately 300 m southeast of the device. All fish monitoring efforts from this study were conducted from this shore station.

Camera and image acquisition

Fish monitoring was conducted by obtaining video imagery taken by underwater cameras affixed to the chassis of the RivGen® pontoons (ORPC 2018). A total of four cameras were mounted on the device's port pontoon, with duplicate sets placed on the upriver and downriver sides of the spinning blades (ORPC 2018). Each set of cameras included an Allied Vision Prosilica GT 1600 (https://www.alliedvision.com/en/camera-selector/detail/prosilica-gt/1600/), and a FLIR Blackfly S Mono 3.2 MP GigE Vision (https://www.flir.com/products/blackfly-s-gige/) camera. Each camera pair was positioned 1.5 m in front of and behind the hub (0.9 m in front of and behind the leading and trailing edges of the blades) of the turbine, and cameras had a 25° field of view (Fig. 2). In addition to cameras, artificial lights were installed adjacent to cameras, 4 m from the turbine hub, to aid fish monitoring during periods of low light conditions (Fig. 2). High resolution images captured from underwater cameras at 9–14 frames per second were relayed from the cameras to the shore station, via a fiber optic cable, where the images were displayed in real-time on a computer monitor through custom software (StereoVision) and stored on hard drives.

Fish monitoring periods

Monitoring was conducted during two priority periods: the Sockeye Salmon smolt outmigration (May 21 to June 10), and the adult upriver migration (June 25 to July 15). These time periods are thought to be peak passage times for smolt and adult Sockeye Salmon based on previous monitoring (Nemeth et al. 2014a; Salomone et al. 2018; Wade et al. 2013). During these time periods, fish interactions were monitored for 10 minutes at the top of each hour, for each hour of the day. At the start of each monitoring event, the water visibility was ranked on a scale of 0–5 (Figure S1). Additionally, the operational mode of the RivGen® was recorded, which included stationary (<1 rpm), cogging (~2 rpm), and production (~60 rpm) modes.

During each 10-min monitoring event, reviewers recorded the timestamp of each potential fish event in real-time (i.e., when a fish or other object passed through the video imagery, usually at very high speed), by pressing a keyboard button that saved times in an Excel spreadsheet, via a macro called 'Fish Clickmatic.' At the end of each 10-min monitoring event, the archived images for each potential fish event were reviewed in slow motion to determine whether each potential fish event was actually a fish or debris. If there was any doubt about whether an object in the video frames was a fish or not, due to a variety of potential issues including occasional blurry imagery, dark ambient light or far-field objects, the object was not assigned as a fish. After confirming individual fish events, they were categorized in two behavior types, including 'normal orientation' and 'disoriented.' Normal orientation was assigned when fish passed through the turbine footprint dorsal-side up while maintaining equilibrium (Fig. 3). Disoriented was assigned when a fish was observed in an unusual posture (i.e., not dorsal-side up) and had apparent loss of equilibrium (Fig. 4). In addition to classifying orientation, each fish event was closely inspected to identify potential blade strikes. Blade strikes were assigned when it appeared that a fish came into direct physical contact with rotating components of the turbine device, followed by an abrupt change in its movement trajectory in subsequent imagery (Fig. 5). Inferred blade strikes were reviewed carefully by multiple reviewers, before confirming this classification. After examining individual fish events, summaries for each 10-minute monitoring event were tallied as the 1) number of total fish events, 2) number of fish events classified as disoriented, and 3) number of blade strikes. For the majority of fish events, the small size of fish and the resolution of cameras made it feasible to discern fish vs. debris, but difficult to positively discern fish species, as both Sockeye Salmon and threespine sticklebacks *Gasterosteus aculeatus* are common in the Kvichak River. However, for the events when fish species was discerned, the vast majority were Sockeye Salmon. Additionally, Sockeye Salmon smolts are known to occupy the fastest part of the river, while Threespine Stickleback are thought to mainly occur in slower water. Following these observations, all fish for which species identification was not possible were assumed to be juvenile Sockeye Salmon (Fig. S2). Observations of threespine sticklebacks *Gasterosteus aculeatus* were recorded, but not used in analyses, as they were very rare.

Total cumulative fish events

To determine the hypothetical number of total fish interactions with the RivGen® device during the priority monitoring periods, the existing fishing monitoring data were extrapolated to account for 10-minute monitoring periods and partial monitoring of the entire frontal area of the spinning components as result of the limited field of view of the cameras. For temporal extrapolation, the fish interactions (i.e., no. fish events, no. disoriented, no. blade strikes in 10-minute monitoring events) were multiplied by six to scale up to hourly counts. For spatial extrapolation, the extrapolated numbers of fish interactions per hour were divided by the proportion of the frontal area of the spinning components of the device that was observed by cameras (i.e., area observed by cameras/frontal area of spinning components). The area observed by cameras was calculated as the area of a sector $\frac{1}{2} r^2 ø$, where the radius, r, was in meters, and ø, was the angle of the camera view in radians. Radius distances were estimated by comparing camera image visibility to fixed structures on the turbine of known distances. The radius for area scanned was estimated as 1.5 m for visibility class 1, 2.5 m for visibility class 2, 3 m for visibility class 3, 4 m for visibility class 4, and 5 m for visibility class 5 (Table 1) (Fig. 1). The frontal area of the turbine footprint was calculated as the area of a rectangle (10 m x 1.8 m; Fig. 2).

Results

Summary of monitoring periods

From 21 May to 10 June, and June 25 to July 15, 2021, observers were on site for 42 days (1,008 hrs), during which 168 hours of video imagery were reviewed in real-time. During the monitoring periods, both upstream cameras were not operational; thus, only downstream camera images were analyzed. Water visibility throughout the monitoring period varied, with 31.3% of counts categorized as visibility 0, 19.0% as visibility 1, 22.4% as visibility 2, 22.9% as visibility 3, 2.4% as visibility 4, and 0% as visibility 5 (Fig. 6a; Fig. 7a). The remainder of counts (2.0%) were not assigned water visibility assignments, due to cameras being offline (Fig. 6a; Fig. 7a). During the monitoring periods, the percentage of time at different rotational speeds was 18.8% for stationary mode, 28.8% for cogging mode, and 52.5% for production mode (Fig. 6b; Fig. 6b). After periods of time with poor visibility (i.e., water visibility class 0) or when cameras were offline were excluded, 66.7% of the monitoring periods had sufficient water quality and camera resolution to allow for fish monitoring analyses (Fig. 6c; Fig. 7c).

Observed fish

Over both priority monitoring periods (smolt, adult), a total of 2,445 fish were identified in imagery collected by the downstream cameras, excluding 34 threespine stickleback that were positively identified and not used in analyses. Of these events, 2,374 (97%) occurred during the smolt period, and 71 (3%) occurred during the adult period (Fig. 6d; Fig. 7d). The majority of identified fish events occurred while the turbine was in stationary mode. Specifically, of the 2,445 observed fish events, 68.3% (1,670 fish) occurred when the turbine was in stationary mode, compared to 18.2% (446 fish) in cogging mode, and 13.5% (329 fish) in production mode (Table 2). All observed fish were inferred to be relatively small (<150 mm in length) and no adult Pacific salmon was observed during either monitoring period.

Timing of fish interactions

The timing of observed fish events was skewed towards distinct dates within priority monitoring periods and hours of the day. Specifically, 74% of the observed fish events occurred over a 5-day period (May 30 to June 3) (Fig. 7d). Furthermore, while fish were observed through all hours of the day, the majority (80%) of these events occurred during the hours of 0000–0400, which corresponded to hours of complete darkness (Fig. 8). During these date/times of high fish passage, it was common to observe hundreds of Sockeye Salmon smolt passing in 10-minute counts (Fig. 9).

Outcomes of fish interactions

Over both monitoring periods during all turbine spinning modes, of the 2,445 fish observed, 18% (440 fish) were disoriented (Table 2). When evaluating the relationship between disoriented behavior and turbine spinning mode, 66% of the fish (218 disoriented/329 total fish observations) were disoriented when the turbine was in production mode, 38% of the fish (168 disoriented/446 total fish observations fish) were disoriented when the turbine was in cogging mode, and 3% of the fish (54 disoriented/1670 total fish observations) were disoriented when the turbine was in stationary mode (Table 2). In addition to disoriented fish, 38 blade strikes on fish were observed, all of which occurred at production speed (Table 2).

Cumulative fish interactions

Not accounting for portions of the monitoring periods that were unable to be monitored due to poor water visibility or camera malfunction, the RivGen® device hypothetically interacted with 201,759 small fish (e.g., zero adult Pacific salmon) over both priority monitoring periods, based on extrapolating fish events to a full hour and to the entire frontal area of the spinning components (Fig. 10). Of these hypothetical interactions, 41,046 fish were estimated to be disoriented, and an estimated 2,727 blade strikes occurred (Fig. 10). Of all the hypothetical fish interactions based on extrapolations, 96% of the fish events, 85% of the disoriented fish, and 84% of the blade strikes were estimated to occur during the smolt monitoring period in late-May/early-June (Fig. 10).

Discussion

Summary

In this report, we provide some of the first field-based observations of fish interactions with an active hydrokinetic device. High resolution cameras were able to capture thousands of real-time fish observations, providing useful insights in the daily and hourly timing of fish interactions, immediate outcomes of interactions, and blade strikes. This new information adds to the sparse knowledge base of fish interactions with riverine hydrokinetic devices. This information is important for the understanding the potential impact of these devices on fisheries, and may inform strategies to mitigate impacts of emerging energy projects on fishes.

Juvenile Sockeye Salmon

We estimate that hundreds of thousands of Sockeye Salmon smolt interacted with the RivGen® device deployed in the Kvichak River. This estimated level of interaction is likely explained by outmigration behavior (Wade et al. 2013; Wade et al. 2012; Wade et al. 2010) and sheer abundance (Nemeth et al. 2014a) of Sockeye Salmon smolts. Past research using bottom-mounted, up-looking sonar arrays reported that the highest density of Sockeye Salmon smolts occurs in the portions of the river with the deepest depths and fastest water velocity, such as where the RivGen® device was placed (Nemeth et al. 2014a; Priest et al. 2015; Wade et al. 2013; Wade et al. 2012; Wade et al. 2010). In these areas, Sockeye Salmon smolts had the highest densities in surface waters above the depths of the RivGen® device, but smolts also were observed in deeper depths at lower densities. The fact that tens of millions of Sockeye Salmon smolts annually migrate in deep, fast portions of the river likely explains why hundreds of thousands of them were estimated to interact with the device, even if their density is relatively low at the depths of the RivGen® device.

During the smolt monitoring period, the majority (73%) of the observed fish events occurred during a narrow time frame (~5 days) in late May and early June. This finding is similar to past research programs on Sockeye Salmon in the Kvichak River (Nemeth et al. 2014a; Priest et al. 2015; Wade et al. 2013; Wade et al. 2012; Wade et al. 2010) that documented peak smolt outmigration timing to be similar among years, and to occur in late May and early June, with the majority of smolt passing by within a narrow time period (~4–10 days) (Nemeth et al. 2014a; Priest et al. 2015; Wade et al. 2013; Wade et al. 2012; Wade et al. 2010).

Adult Sockeye Salmon

No adult Sockeye Salmon were observed to interact with the RivGen® device during their upstream migration, even though an estimated 4,307,640 (calculated from ADFG tower counts) fish migrated past the RivGen® during the adult monitoring period. Absence of adult Sockeye Salmon near the RivGen® device is not surprising, and is likely due to a combination of several factors, including device placement, migration behaviors of adults, and the cameras' angles of view used in this study. The upstream migration corridor of adult Sockeye Salmon is known to be close to shore (<10 m) which does not overlap with the placement of the RivGen® (~30 m from right river bank) (Woody 2007). Furthermore, the angles of view of the downstream cameras would only detect an adult Sockeye Salmon that swam within approximately ~0.5 m of the downstream side of the turbine blades. Past fish monitoring efforts near the RivGen®, with addition cameras and different fields of view, have documented, albeit rare, adult Pacific salmon, including Chum Salmon (*O. keta*), Pink Salmon (*O. gorbuscha*), and Sockeye Salmon (Nemeth et al. 2014b; Priest and Nemeth 2015). In these rare events, adults were observed to briefly mill behind the device, but actively avoid it. Based on results from this study and past research, hydrokinetic devices deployed in the main channel of the Kvichak River are likely to have few if any interactions with migrating adult Sockeye Salmon. Even if the adult Sockeye Salmon migration corridor overlaps with hydrokinetic devices, because of their large size, downstream approach and strong swimming abilities compared to juveniles, they are likely able to effectively navigate around such devices (Hammar et al. 2015; Matzner et al. 2017; Schweizer et al. 2011; Schweizer et al. 2012; Shen et al. 2016). However, it is important to note that these interpretations may not be valid for different watersheds, species or life stages.

Disoriented fish behaviors

In this study, we reported many observations of fish passing through or near the RivGen® device in a disoriented manner. In these cases, it appeared that fishes were unable to control their swimming posture, and were either upside down, or 'tumbling' through the device. Disoriented behavior was nearly absent when the turbine was stationary, but common in cogging mode, and prevalent in production mode. Preliminary analyses on past RivGen® deployments (2015) have suggested that some juvenile Pacific salmon appeared to pass near or through the turbine in a disoriented posture (Priest and Nemeth 2015). The observed disoriented behaviors of fish in this study are likely influenced by the turbulence and flow characteristics (sheer stress and pressure differentials) caused by the RivGen® device. Regardless of the causes of fish disorientation, results from this study suggest that even at slow speed (i.e., cogging mode), the RivGen will likely lead to a non-trivial portion of entrained fish becoming disoriented. Because of the narrow area of camera view, the ultimate fate of disoriented fish, including whether they recovered normal posture and if so, the time necessary to do so, is currently unknown and a priority for future research.

Avoidance behaviors

Most observed fish events occurred when the RivGen® device was in stationary mode. These results are likely due to the turbine spinning mode schedule and avoidance behavior by fish when the turbine was spinning. The spinning mode of the RivGen was governed as a compromise to vary the speed throughout the monitoring period to understand fish interactions during different modes of operation, and to avoid spinning during times of high fish passage and poor water visibility. As a result, the turbine was usually placed in stationary mode during the time period of high Sockeye Salmon smolt passage that occurred in hours of darkness. Given this, it is not understood if the high passage rates during the stationary mode resulted from outmigration timing, turbine spinning mode or a combination of both. Past monitoring efforts near the RivGen® device (Matzner et al. 2017) have documented several behaviors, including active avoidance (e.g., avoid above, avoid below turbine, avoid reverse) and passive passage. Past research conducted elsewhere has shown that when hydrokinetic devices are actively rotating, fish presence, passage, and entrainment decrease (Amaral et al. 2015; Bevelhimer et al. 2017; Castro-Santos and Haro 2015; Hammar et al. 2013; Viehman and Zydlewski 2015; Viehman et al. 2015). This is likely due to fish being able to detect and initiate avoidance tactics at further distances. Collectively, these results may indicate that some Sockeye Salmon smolts are able to detect and actively navigate away from spinning turbines. Upstream cameras would be helpful in evaluating the total sum of fish interactions, possible avoidance behaviors, and the proportion of fish that are entrained into the RivGen® device in relation to its spinning status.

Blade strikes and collisions

Of the fish observed during production mode, approximately 12% experienced blade strikes. Possible blade strikes have been suggested in previous RivGen® deployments, but due to poor camera image quality, these events were not confirmed (Matzner et al. 2017). The frequency of blade strikes in this study is much higher than that in previous research that has concluded that fish/turbine collisions and blade strikes are rare in free-flowing environments (Copping et al. 2021; Hammar et al. 2015; Matzner et al. 2017; Shen et al. 2016). Blade strike frequency in this study is difficult to directly compare to these previous estimates, as these studies were conducted on different life stages of different fish species while they interacted with different turbines in different environments. However, given the size and rotational speed of the RivGen®, in relation to the size (Nemeth et al. 2014) and swim speed (Wade et al. 2010) of Sockeye Salmon smolt, our estimated frequency of observed blade strikes is consistent with simple estimates of blade encounter probability. For example, if we assume that a typical sockeye smolt is approximately 100 mm long (Nemeth et al. 2014) and travels at the same velocity of the water (~2.5 m/s; Wade et al. 2010), the blade encounter probability would be approximately 12% for the downstream edge of the three-blade RivGen® rotating at 60 rpm. Because capturing fish struck by blades was out of the scope of this study, we were unable to conduct autopsies on them. As such, the ultimate outcome of the observed blade strikes is unknown, which is of upmost importance when considering impacts of hydrokinetic devices on fisheries. Observed fish strikes in this study add to the current base of knowledge of near-field fish/turbine interactions, a subject that remains poorly understood and has been identified as a research priority for understanding impacts of hydrokinetic devices on aquatic fauna (Copping et al. 2021; Sparling et al. 2020).

Artificial lights

During this study we used artificial lights for observations during hours of darkness, which could have biased the results by causing avoidance or attraction to the lights. Past research has documented both avoidance and attraction behaviors of fishes to artificial lights, which varies among species, habitats and wavelengths (Geoffroy et al. 2021; Marchesan et al. 2005; Stickney 1969). In this study, visually documenting fish interactions during periods of darkness required the use of artificial lights as other methods of observing fish lack the resolution to detect fish orientation and near-field events such as blade strikes. Future research on the role of artificial lights on Sockeye Salmon smolt behavior should be conducted to understand potential biases introduced by artificial lights when evaluating fish/turbine interactions (Matzner et al. 2017).

Caveats

This study contained many limitations and caveats. Upstream cameras were inoperable during the monitoring periods, thus we only observed fish that passed through or very close to the device, not fish that were able to avoid the device. Fish are likely interacting with the leading edge of the turbine, but because we were not able to observe this portion of the device, the degree to which these interactions occur is not understood. Upstream cameras would be useful for examining avoidance behaviors of fish, providing a more comprehensive understanding of fish interactions with the device. Additionally, poor water visibility disqualified 33.3% of the video imagery from analyses. This hindrance highlights one of the many difficulties in real-time, field-based observational studies (Matzner et al. 2017; Shen et al. 2016). Interpolation of fish events for time periods of poor visibility was not conducted, due to the large differences in fish passage related to hour of day and day of year (i.e., there are large peaks in migration timing over just a few days), and because observed disorientation and blade strikes events were linked to turbine spinning mode, which was inconsistent throughout the study. Furthermore, some observed events could not be assigned as fish vs. debris with certainty, so they were discarded from analyses. Because of all of these limitations, the number of fish events reported in this study is likely considerably lower than the true number of fish interactions.

Population level effects

The results of this study should be considered in the context of the greater Kvichak River Sockeye Salmon population, which requires some assumptions and a conservative approach. Assuming a 13% smolt-to-adult survival of Sockeye Salmon (Quinn 2018), the estimated ~200,000 Sockeye Salmon smolts that interacted with the device would translate into approximately 26,000 adult equivalents that may be affected by these interactions. With a current escapement goal of 2–10 million adults, the calculated number of adult equivalents that may be affected by the interactions with the turbine is 0.3–1.3% of the annual adult Sockeye Salmon escapement goal. Following this same rationale, the estimated ~41,000 Sockeye Salmon smolts that were disoriented after passing through the device would translate into approximately 5,300 adult equivalents, which is 0.05–0.3% of the annual adult Sockeye Salmon escapement goal. Finally, the estimated ~2,700 Sockeye Salmon smolts that experienced blade strikes would translate into approximately 351 adult equivalents, which is 0.004–0.018% of the annual adult Sockeye Salmon escapement goal. There are several important considerations when interpreting these estimates, namely that these estimates are based on the turbine spinning modes during monitoring periods (19% stationary, 29% cogging and 52% production), only 67% of the monitoring periods were suitable for observing fish, interpolated estimates were not made for unmonitored periods, and the turbine was placed in stationary mode during peak outmigration times. Therefore, the estimates of interactions, disoriented behaviors and blade strikes are likely considerably less than those if the device remained in production speed during the entire smolt outmigration.

The ultimate outcomes of interactions, disoriented behaviors and blade strikes are unknown because of the limited field of view of the cameras. Although we are not able to make statements about direct mortality, it is important to consider delayed mortality as well. Specifically, many fish interactions seen in the video imagery resulted in disoriented behavior and blade strikes with unknown fates. Speculation about the ultimate fate of disoriented and stricken fish is not contained herein, but delayed mortality caused by factors such as mechanical pressure changes or predation while disoriented should be determined in the future, allowing quantification of the cumulative mortality and true impact of interactions.

Management implications

Regardless of the fates and outcomes of fish/turbine interactions in this study, our results provide useful insights for natural resource managers. For example, results of this study suggest that simple management tactics such as placing the turbine in stationary mode during times of relatively high passage, including the few days of peak smolt outmigration and/or during peak smolt passage times during hours of darkness, could drastically reduce the number fish/device interactions resulting in disorientation and blade strikes. Other possible conservation plans such as reducing the RivGen® operating speed during Sockeye Salmon priority periods may decrease the number of interactions leading to disorientation and blade strikes (Amaral et al. 2015; Bevelhimer et al. 2019). In contrast to the observations documented during the smolt monitoring period of this study, fish events were rarely observed during the adult monitoring period. Given this, these results suggest that RivGen® is likely to have few interactions and little impact on fishes during time periods outside the spring smolt season, similar to previous inferences on RivGen deployments on the Kvichak River (Matzner et al. 2017; Nemeth et al. 2014b; Priest and Nemeth 2015).

Conclusion

While we only studied interactions between fish and a hydrokinetic turbine from one location, the information collected in this study provides some of the first high resolution, field-based imagery of fish interactions with an active hydrokinetic turbine. Due to caveats documented in this study, and the overall limited amount of research that has been conducted on this emerging technology, many uncertainties remain about fish and turbine interactions. For example, to date, all fish/turbine interaction studies have only examined fish behavior with one turbine device, and few have scaled fish interactions to the population level. In the future, there are plans to operate two RivGen® devices in the Kvichak River. Therefore, future work should be conducted to assess the fisheries interactions with multiple devices, which has been highlighted as a future need/direction for hydrokinetic energy projects (Copping et al. 2021; Dadswell et al. 2018).

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Table 1. Water visibility assignments during the smolt and adult Sockeye Salmon periods in the Kvichak River, Alaska.

Data with water visibility 0, and NA were not used in data analyses.

Water visibility class	Percentage of monitoring period	Used in analyses	Observable distance (m)
NA	2.0%	No	0
0	31.3%	No	0
1	19.0%	Yes	1.5
2	22.4%	Yes	2.5
3	22.9%	Yes	3
4	2.4%	Yes	4
5	0.0%	Yes	5

Table 2. Fish events and their outcomes, in relation to turbine deployment mode. Parentheses represent extrapolated estimates scaling to a full hour and frontal area of the turbine.

Turbine mode	No. fish events	No. disorientation	No. blade strikes
Stationary	1,670 (119,180)	54 (5,459)	0 (0)
Cogging	446 (59,789)	168 (20,204)	0 (0)
Production	329 (22,790)	218 (15,383)	38 (2,727)
Totals	2,445 (201,759)	440 (41,046)	38 (2,727)

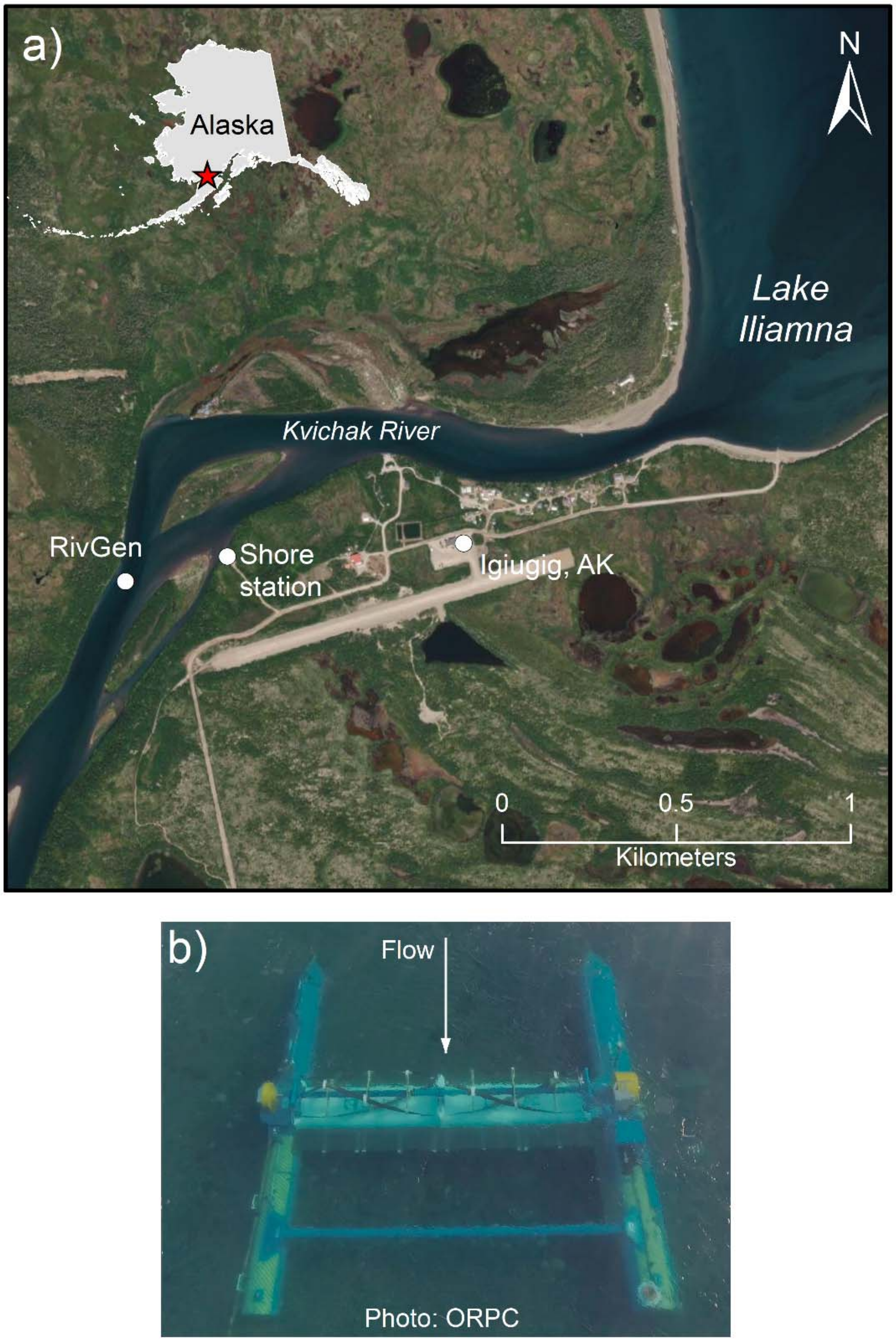


Figure 1. a) Map of study site on the Kvichak River, near Igiugig, AK, and b) aerial image of deployed RivGen® turbine device. Locations of the shore station and RivGen® are noted. Red star in upper left-hand corner depicts the location of the study site, in relation to the state of Alaska.

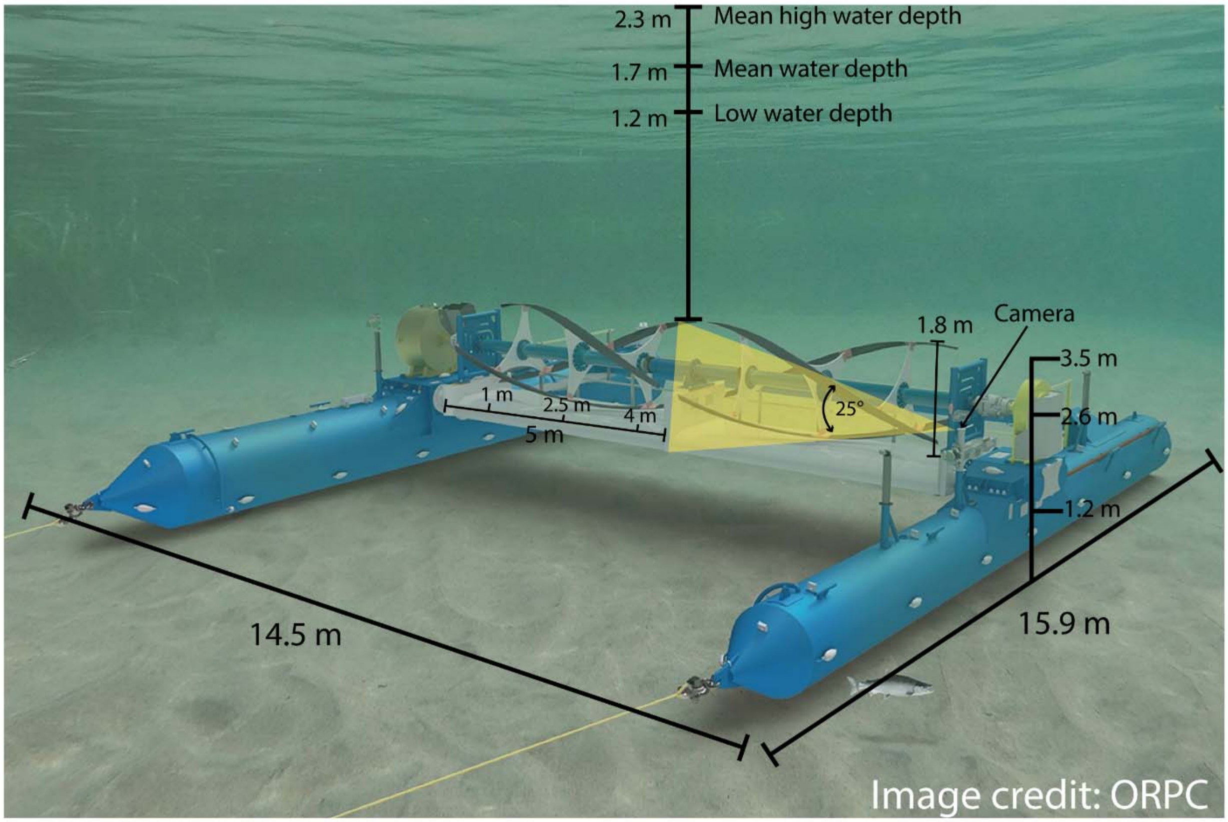


Figure 2. Schematic and dimensions of Ocean Renewable Power Company's RivGen®
hydrokinetic device.

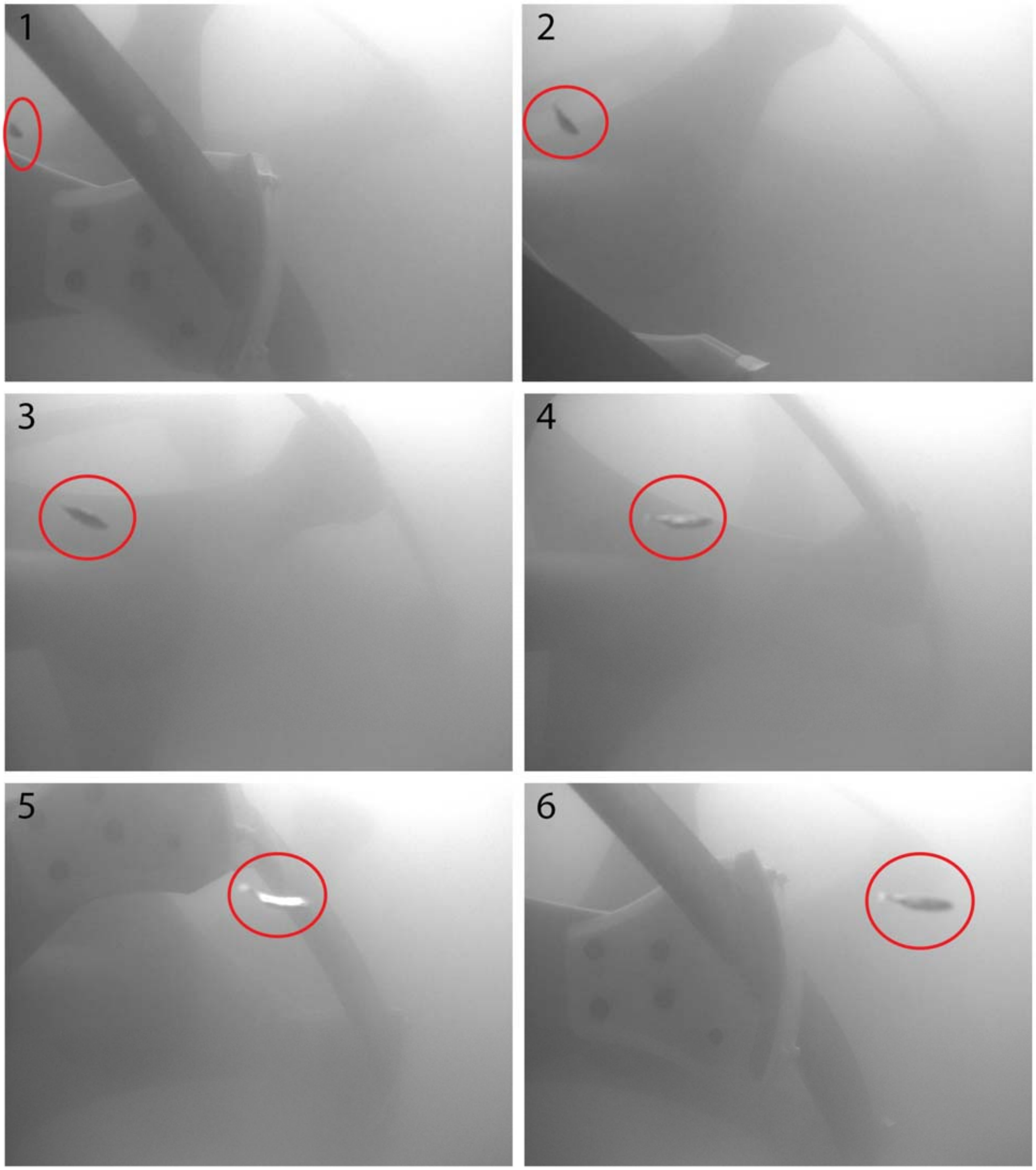


Figure 3. Example of a fish event resulting in “normal” orientation. Each image is labeled (upper left-hand corner) with the order of the sequence of images. In these cases, the fish passed through the turbine passively, and appeared to have normal swimming control and body orientation.

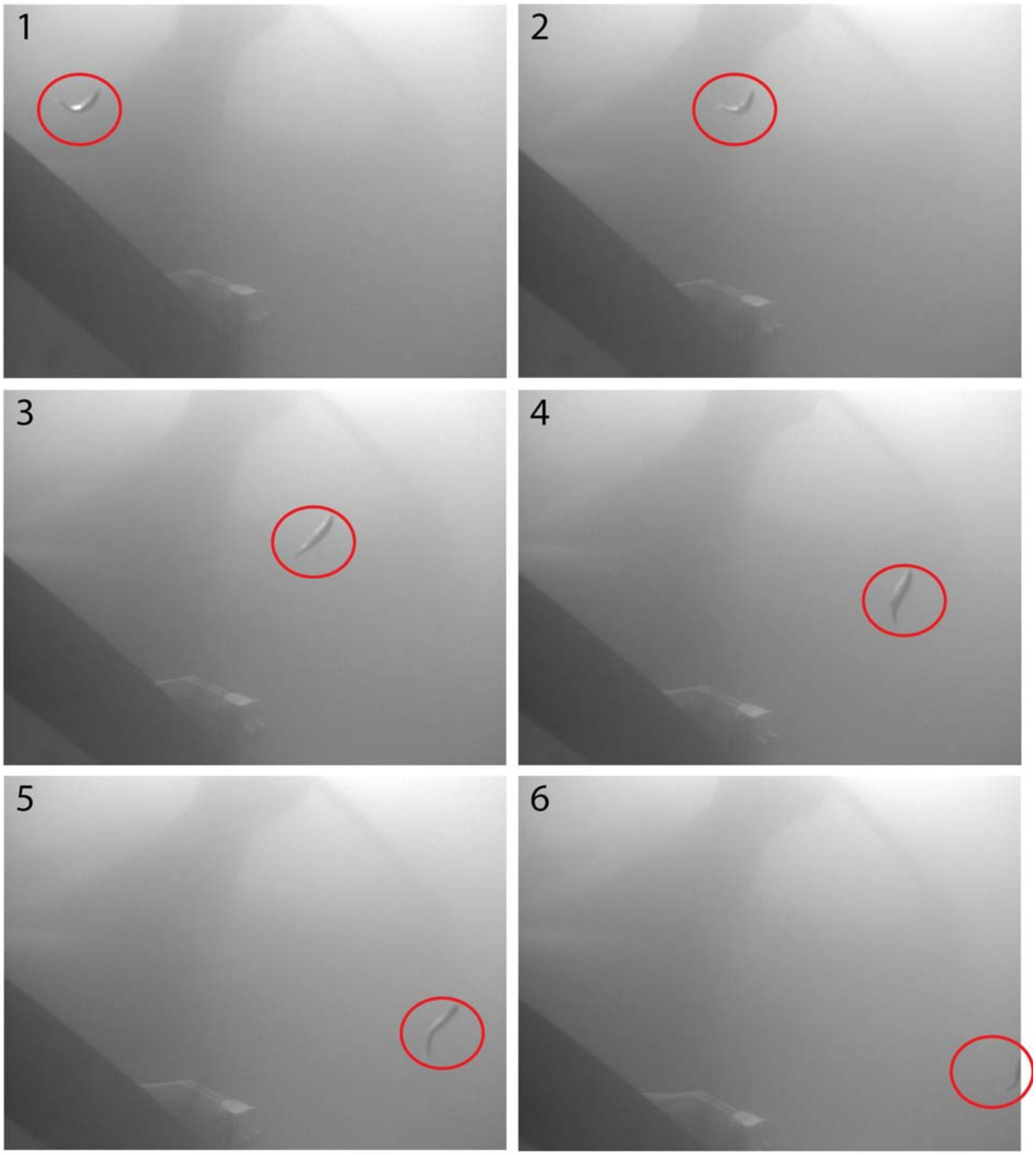


Figure 4. Example of a fish event resulting in “disoriented’ behavior. Each image is labeled (upper left-hand corner) with the order of the sequence of images. Fish events categorized as ‘disoriented,’ were observed in an unusual posture (i.e., not dorsal-side up), including apparent loss of equilibrium, or swimming control.

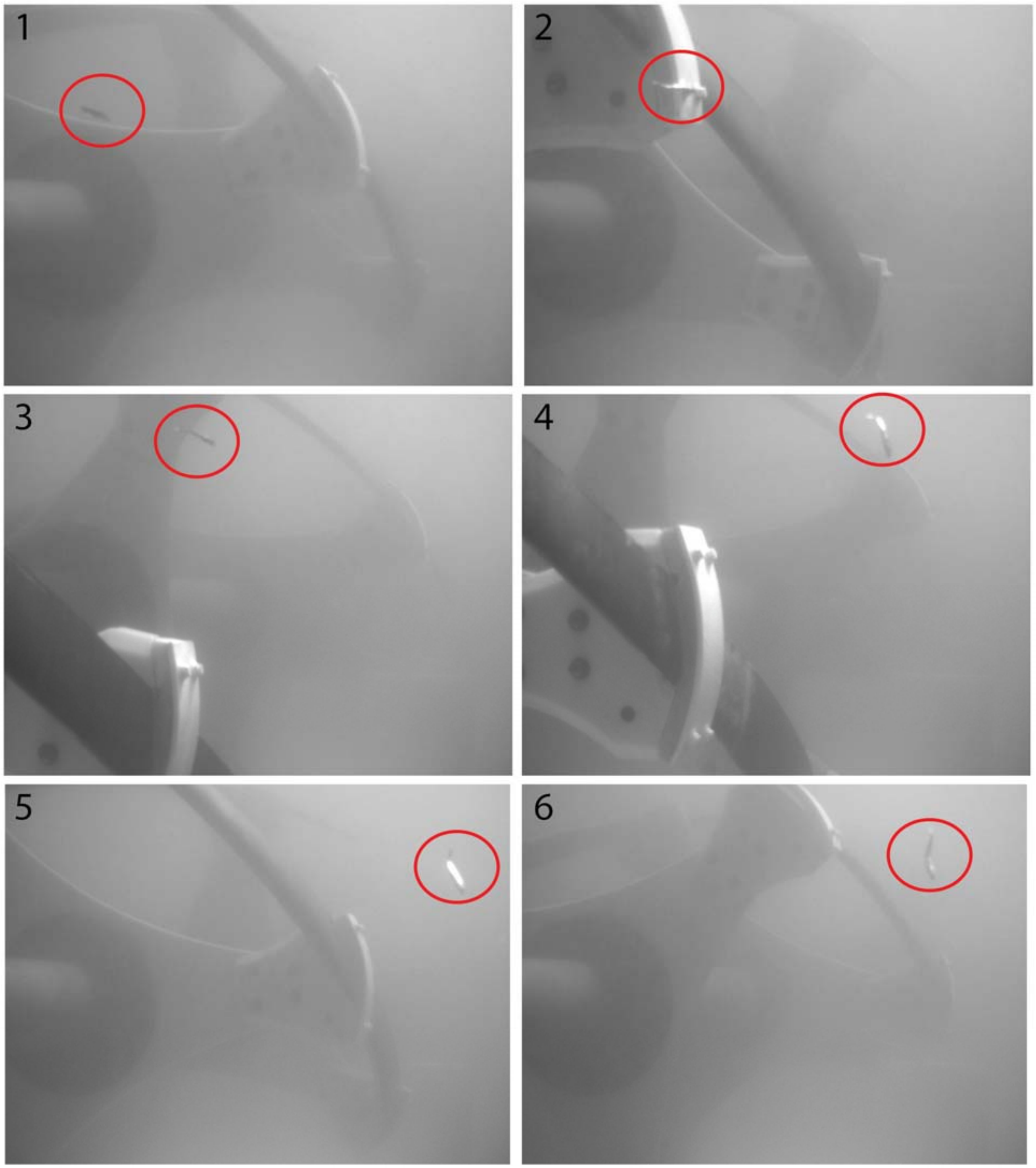


Figure 5. Example of fish event resulting in blade strike. Each image is labeled (upper left-hand corner) with the order of the sequence of images. Blade strikes were assigned when it was inferred that the fish had come into direct contact with device struts or the foils.

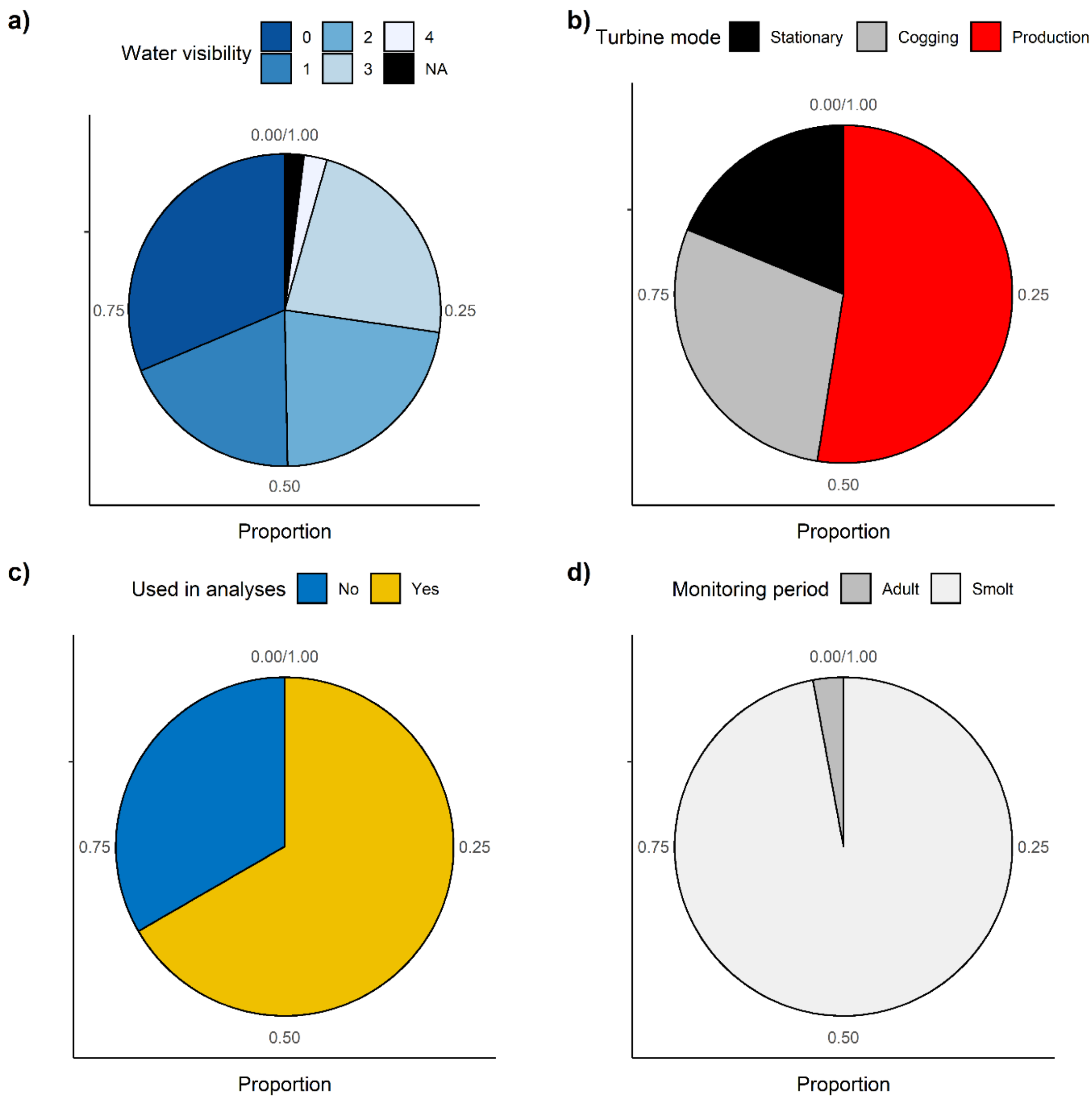


Figure 6. Proportion of water visibility assignments a), turbine spinning mode b), and data used for analyses c) during the smolt and adult Sockeye Salmon monitoring periods. Panel d) denotes the proportions of observed fish during the smolt (21 May to 10 June) and adult (25 June to 15 July) monitoring periods. NA values for panel a) denote time periods in which monitoring cameras were offline.

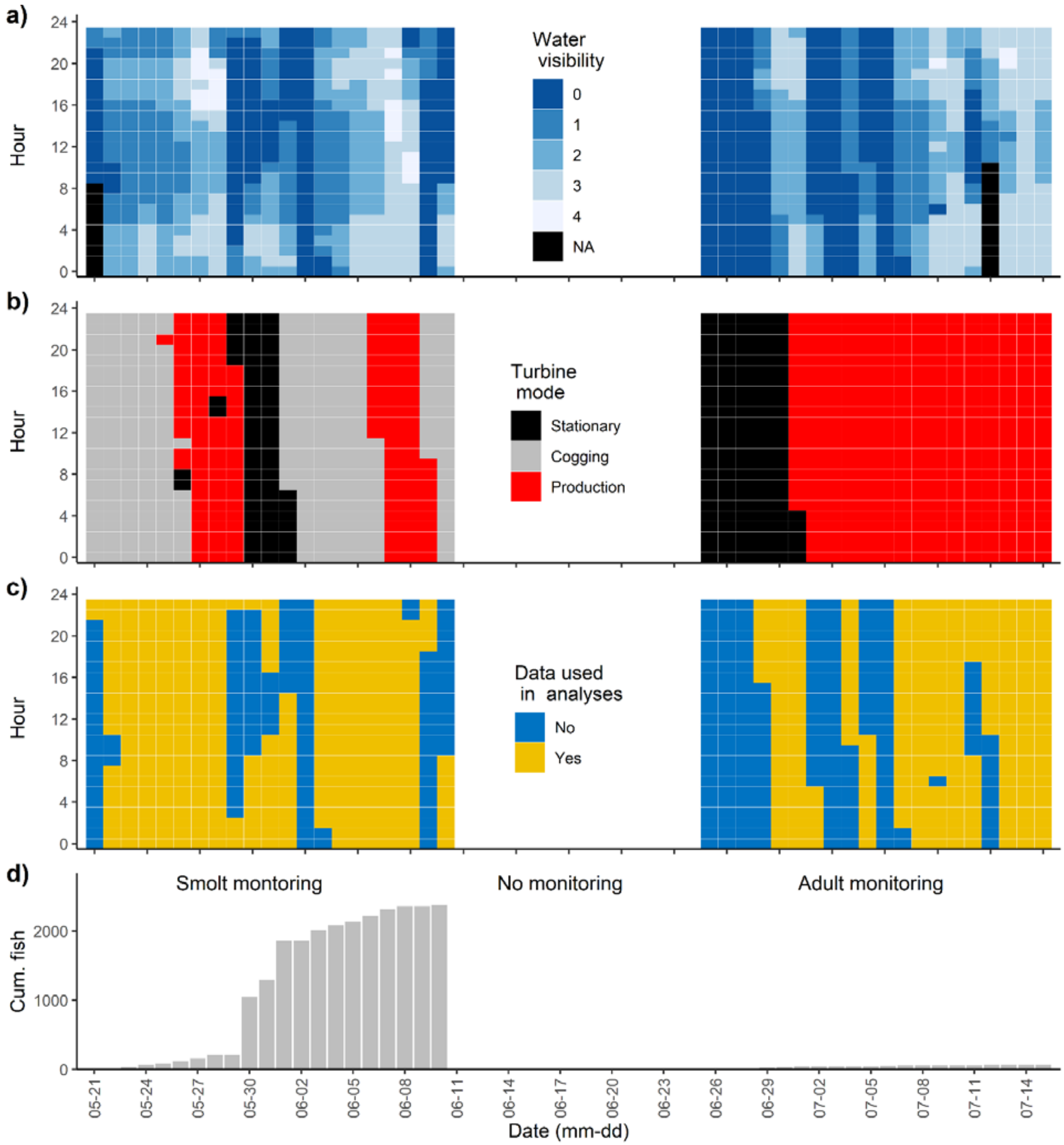


Figure 7. Hourly water visibility assignments a), turbine spinning mode b), and data used in analyses c) during the smolt and adult Sockeye Salmon monitoring periods. Panel d) denotes the daily number of cumulative fish events of this study, by smolt and adult monitoring periods. NA values for panel a) denote time periods in which monitoring cameras were offline.

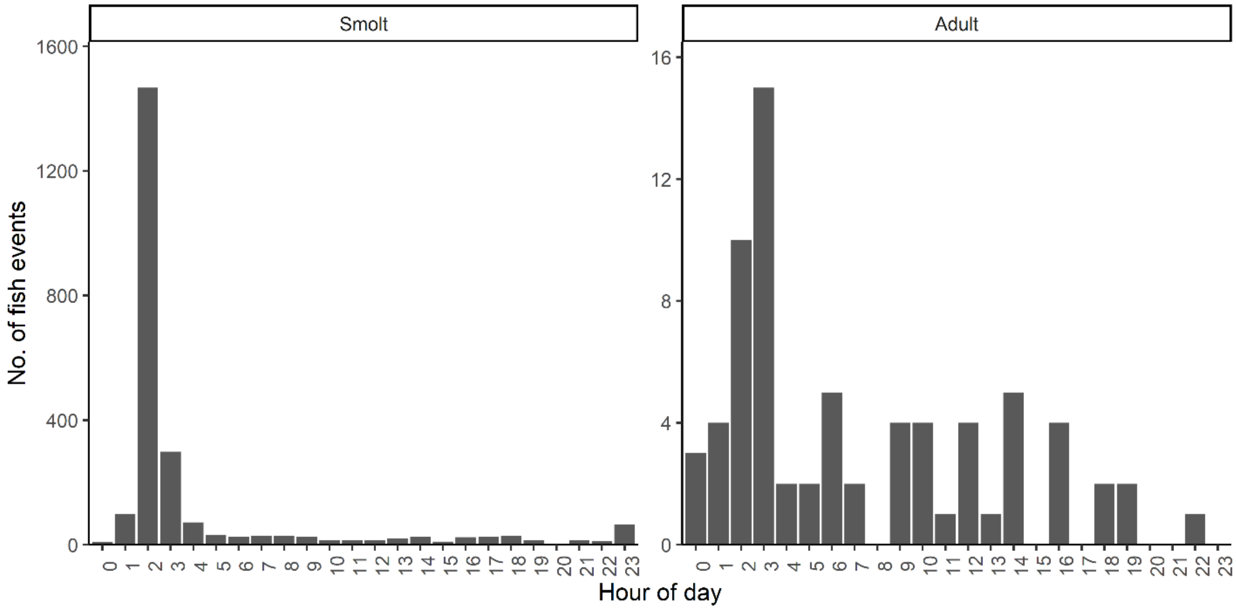


Figure 8. Number of fish events, by hour of the day, for smolt (left panel) and adult (right panel) Sockeye Salmon monitoring periods. Note y-axis scale differs between left and right panels.

Figure 9. Example of a high fish passage event observed in this study. Each image is labeled (upper left-hand corner) with the order of the sequence of images. These events were captured on 30 May 2021 at 0200 hrs, when the RivGen® was in stationary mode.

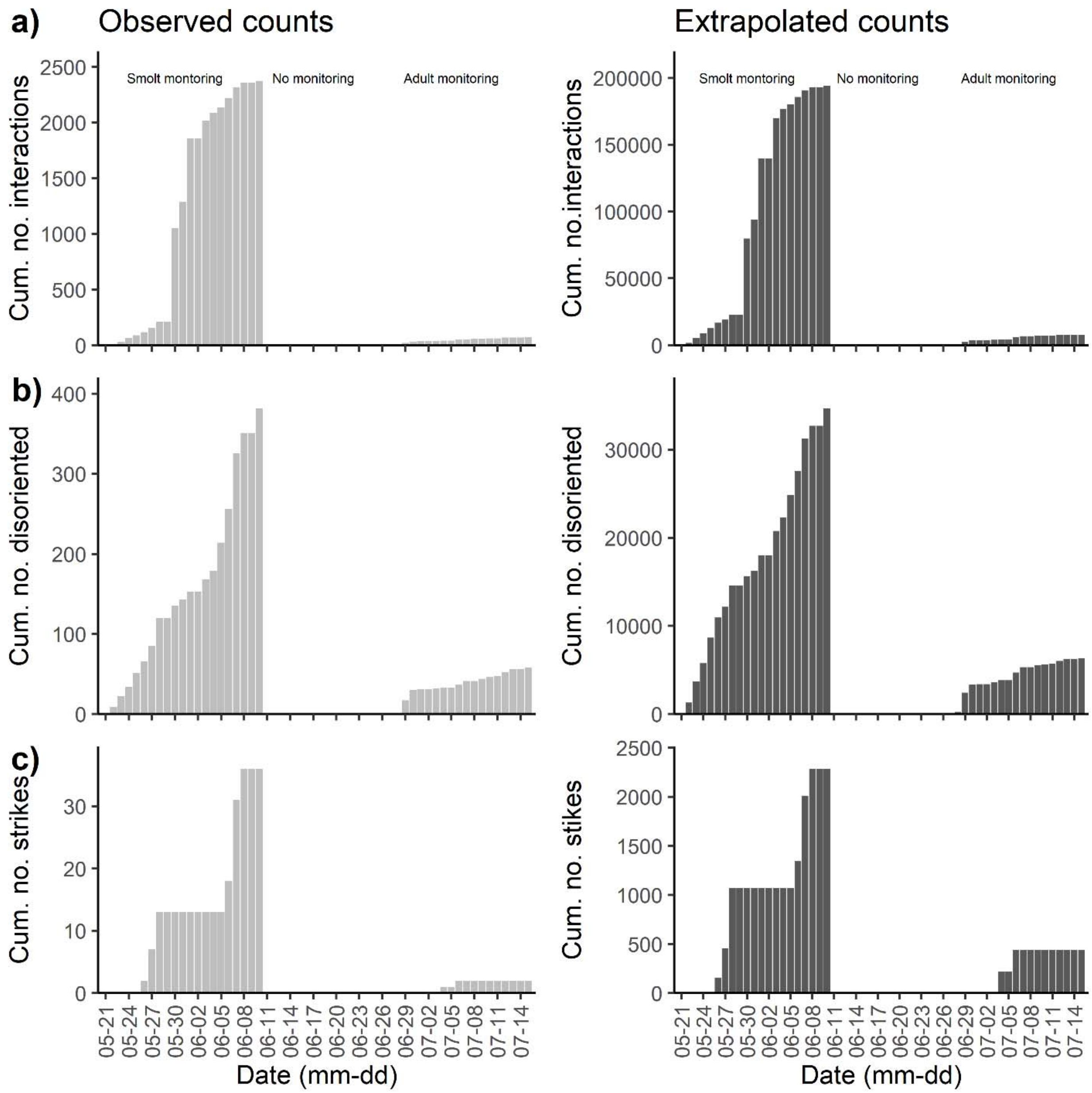


Figure 10. Daily cumulative number of interactions (top panels), number of disoriented fish events (middle panels), and number of blade strikes (bottom panels), from observed a) and extrapolated b) fish monitoring counts. Note that y-axis scale differs between panels.

Supplementary material

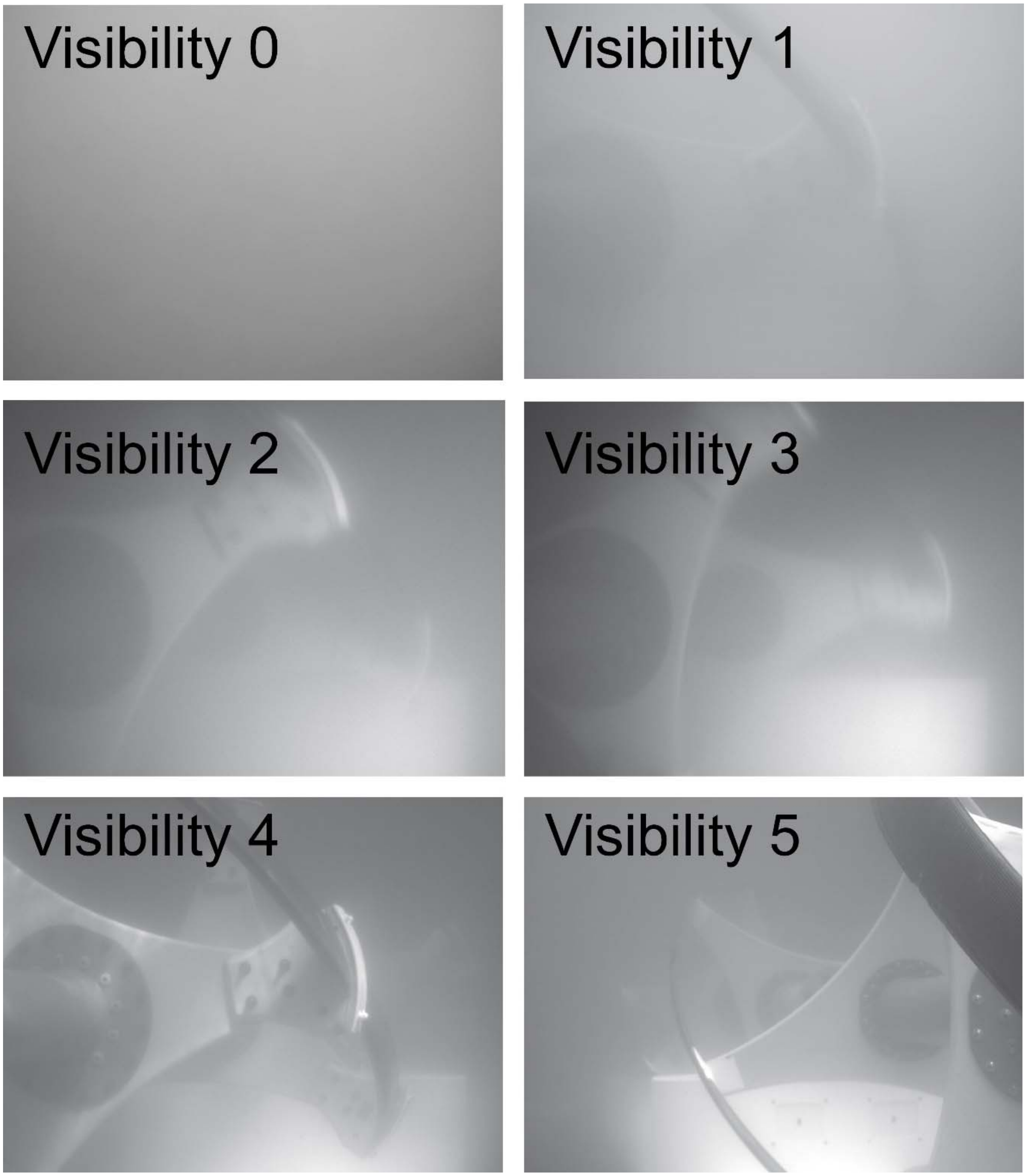


Figure S1. Example of water visibility categories used in this study. Not water visibility category 5, was not observed during the monitoring period of this report.

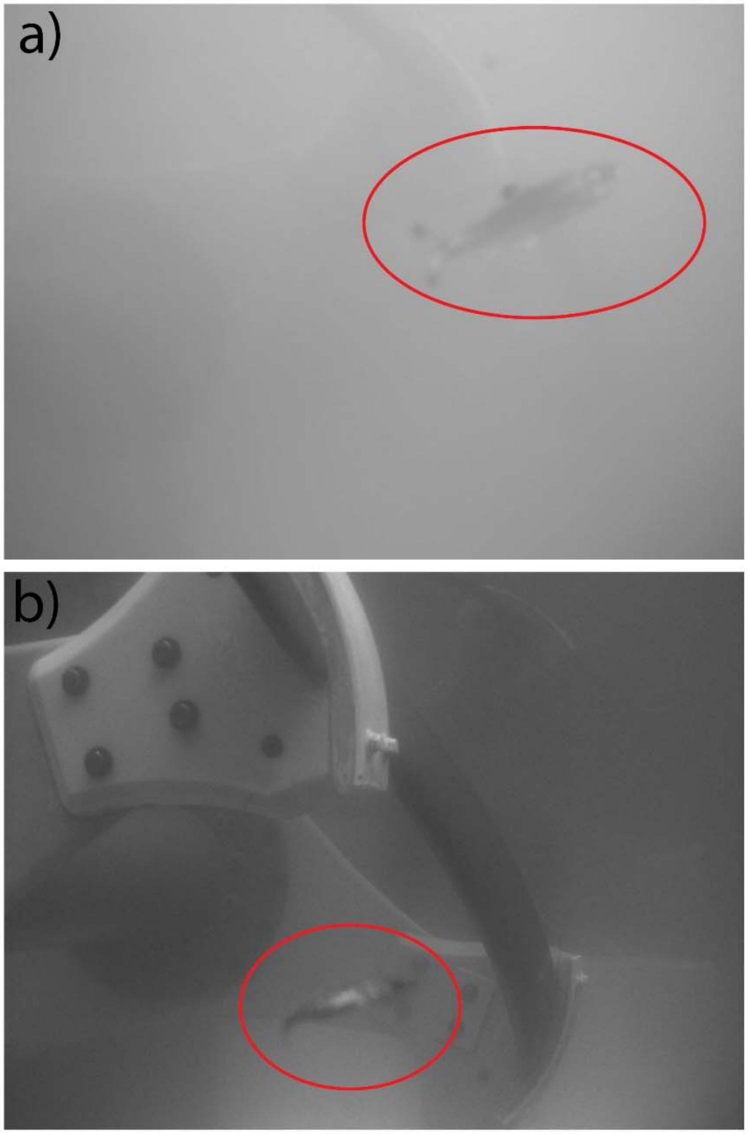


Figure S2. Example of a Sockeye Salmon smolt a) and a threespine stickleback b) passing through a stationary RivGen® turbine in the Kvichak River, Alaska.

Attachment 2

Adaptive Management Team Meeting Presentation, April 1, 2022

Igiugig Hydrokinetic Project
FERC Project: P-13511
Adaptive Management Team Meeting

April 1, 2022

Agenda

Agenda

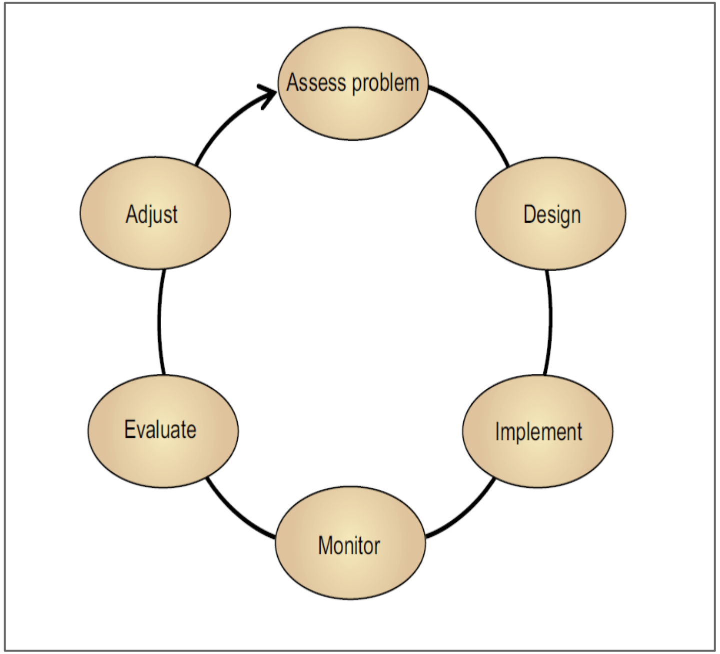
- Introductions
- 2021 Operations Overview
- 2021 Fish Monitoring Results
  - Local Indigenous knowledge
  - Visual observations
  - UAF monitoring
  - Historical smolt counts
- 2022 Fish Monitoring
  - Monitoring and operational plans/considerations
- Recommendations/Next Steps
  - Second device to be installed in August

FERC Pilot Project License

- Allows for electrical generation while testing technology and/or evaluating sites
- Preserves all major licensing elements of the Integrated Licensing Process (ILP) in an expedited manner
- Protects the environment
  - ➢ Short license term and small footprint
  - ➢ Reporting during construction period
  - ➢ Monitoring
    - Fish Monitoring Plan
    - Adaptive Management Plan
  - ➢ Project shutdown or removal if harmful
    - Safeguard Plans

Adaptive Management

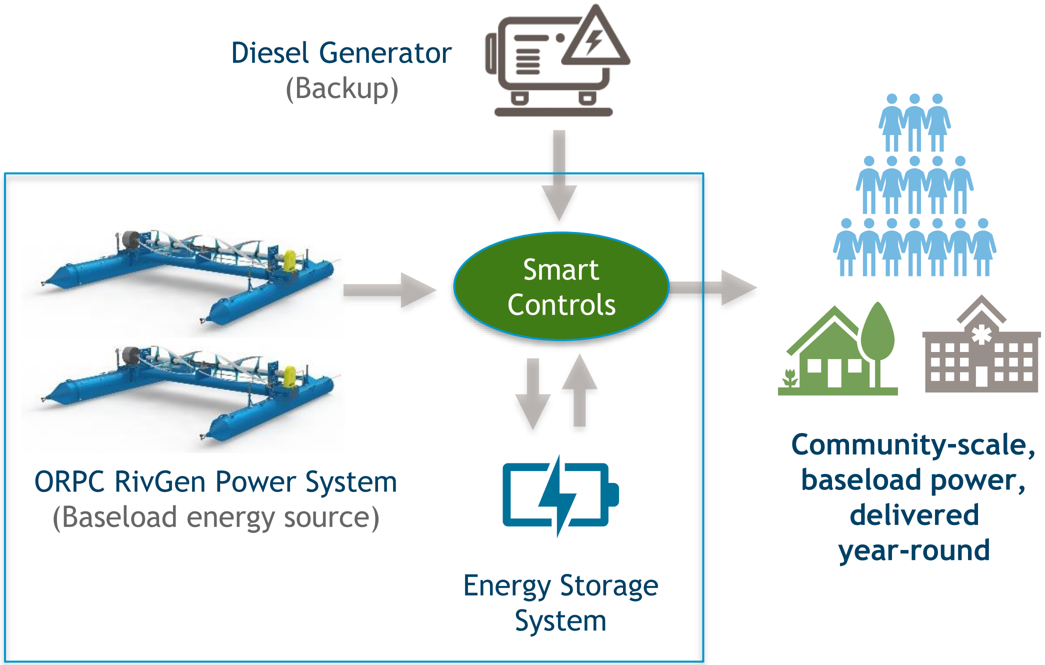
- To generate science-based information for managers, agencies, and stakeholders
- To establish a mechanism to assess the effectiveness of the Fish Monitoring Plan included in IVC's FERC pilot project license
- To provide guidance on changes to monitoring requirements
- To effectively communicate agency recommendations for changes to the FERC pilot project license
- To convert information into effective and timely management decisions
- To involve the public to help provide management direction



2021 Operations Overview

ORPC's Microgrid Product Delivers Baseload Renewable Energy from Free-flowing Rivers and Tides

- A RivGen-powered smart microgrid can relegate diesel generators to backup only
- RivGen provides constant, predictable power (baseload)
- Energy storage and smart controls, coupled with RivGen baseload power, improve the value proposition of intermittent sources like wind and solar



Phase 1: RivGen2.0 Operations

ORPC

Performance Highlights

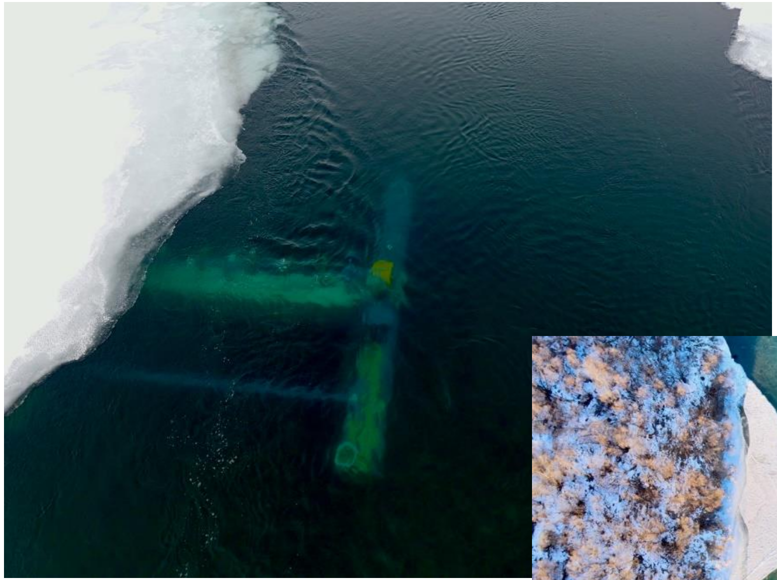
- Deployed for 21 consecutive months
- Over 17 million turbine rotations
- No observed negative effects to environment
- Survived multiple Alaskan winters (-40 C), frazil ice event and break-up of over 2 feet of lake ice flowing over it
- 2020 planned inspection and maintenance event occurred with support from local workforce and with strict COVID-19 protocols in place

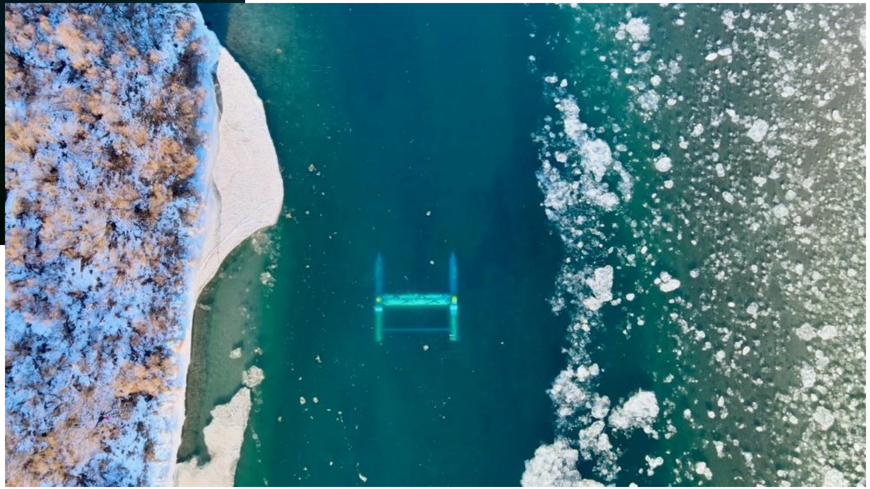
Drone video: https://www.youtube.com/watch?v=BgNXgPpK2Co

Phase 1: RivGen2.0 Winter Operations

Device continued to operate after multiple ice events including:

- Frazil ice accumulation
- Downstream ice dams and subsequent freezing over of the Kvichak River
- Lake Iliamna ice break up

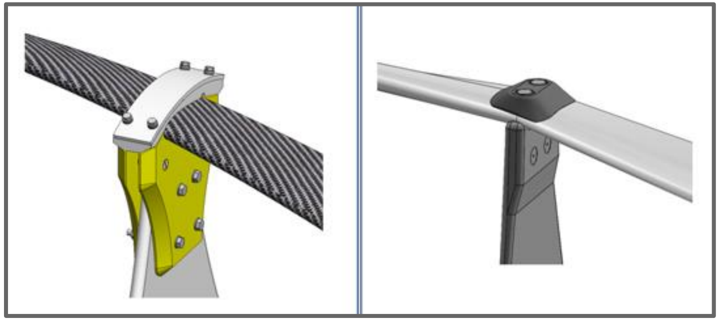




RivGen2.0 Operations – Lessons Learned

Inspection

- Device continued to operate despite significant interaction with ice
- Repairable crack discovered along mid-spar of chassis in single portside “bay.” New design used for RivGen2.1
- Physical damage occurred to upstream cameras. New shielded design incorporated into RivGen2.1
- RivGen2.1 ballast system adjusted to minimize frazil ice effects
- New foil vendor and joint design resulting in improved performance.



Phase 2: RivGen2.1 Build and Transport

Phase 2: RivGen2.0 Inspection/RivGen 2.1 Re-assembly in Igiugig

The RivGen2.0 device is in Anchorage to retrofit with next generation turbines. ORPC plans to reinstall the device in August 2022 downstream of the RivGen2.1

Phase 2: Battery Energy Storage System

- Installed fall 2021, commissioning in November/December
- Ability to be grid following or forming
- Rated for 253 kWh, 125kW inverter

A Remarkable Achievement in Partnership with the Community of Igiugig, Alaska

Watch the video: https://youtu.be/GxjELfnX5xc

2021 Fish Monitoring Results

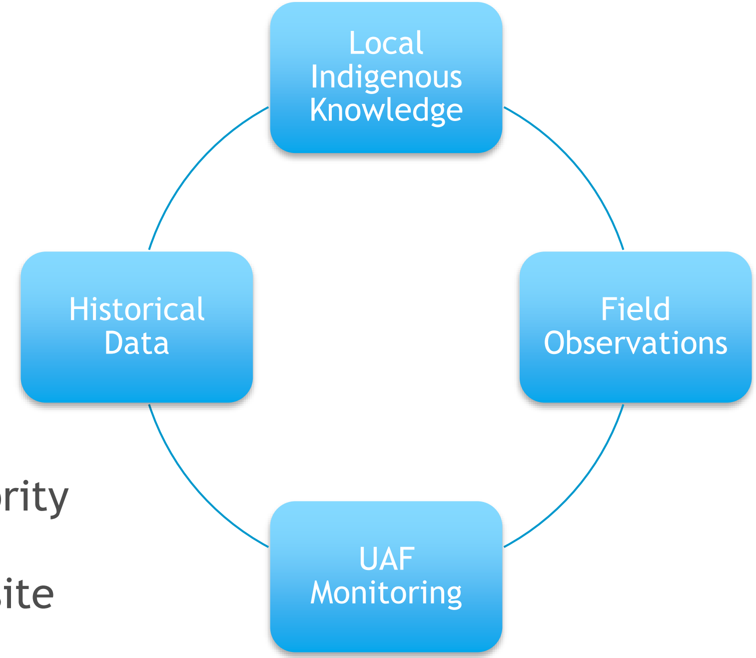
Igiugig, Alaska Fish Monitoring

License and Permit Requirements

- 10-year pilot license
- Fish Monitoring Plan to determine effects to salmon populations
  - May 21-June 10 for smolt
  - June 25-July15 for adult
- Review of methods and results with Adaptive Management Team

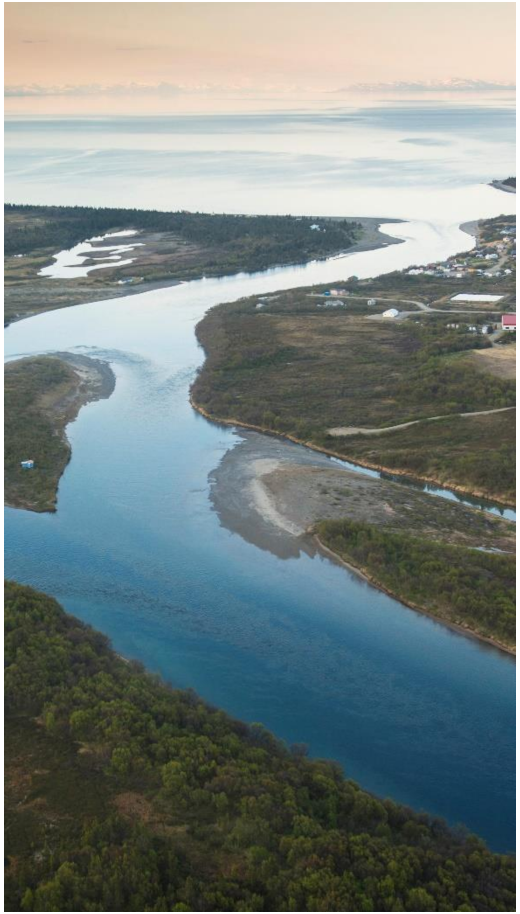
2021 Monitoring

- Downstream camera pair operational through priority periods
- University of Alaska Fairbanks (UAF) biologists onsite for entire priority period
- Alaska Department of Fish and Game (ADF&G) representative onsite during smolt priority period



Local Indigenous Knowledge

- The Village of Igiugig is traditionally, culturally, and economically connected to Salmon
- The tribe occupies an archeological district spanning 21 known sites, dating as far back to 8,000 years ago, with Sockeye Salmon as a keystone species for survival
- Local historical knowledge of the smolt migration, supplemented by recent studies, has provided Igiugig Village with the ability to make informed decisions on device operation to account for annual timing of the event and predictable diurnal fluctuations in fish densities



ORPC

Field Observations

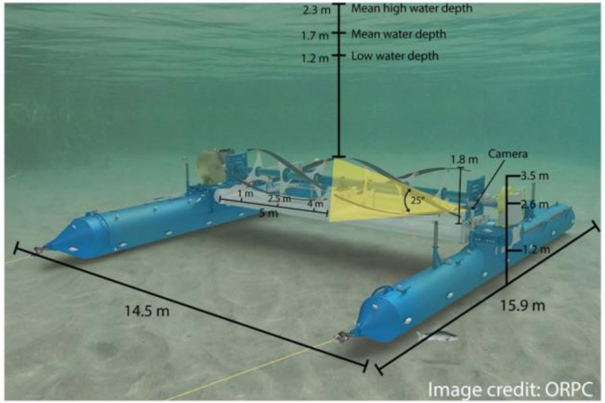
Smolt

- On water and aerial observations were made by Igiugig Village Council (IVC), ORPC, and ADF&G
- 3rd party annual smolt count did not occur in 2021
- Large quantities of smolt passed around and above RivGen
    - Elevated in water column upstream of device
    - Appeared to descend after passing device
- No observed smolt mortality
- No observed predation
    - Arctic Tern actively hunting in the area
    - No concentration of predators near or downstream of device, though white chassis may break camouflage
- RivGen occupies a relatively small width of the river

Adults

- No interactions observed

UAF Monitoring



Methods

- Video imagery via underwater cameras
- Downstream pair only
- 25° FOV, 5m DOF dependent on water quality
- Artificial light utilized at night

Findings (Smolt, Extrapolated)

- ~200,000 individual interactions
- ~41,000 disoriented (may or may not be due to device)
- ~2,700 direct interactions or "strikes"
    - Would translate into 351 adult equivalents (0.004-0.018% of the annual adult Sockeye Salmon escapement goal)
- No observed mortality, further research needed

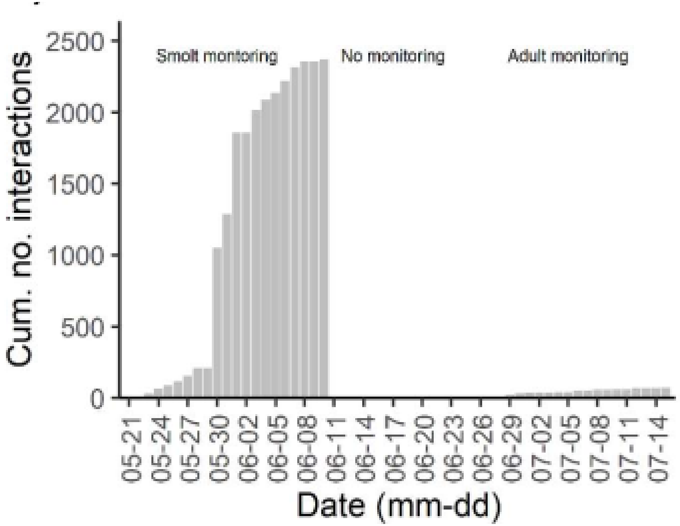
Findings (Adult Salmon)

- No adult interactions observed

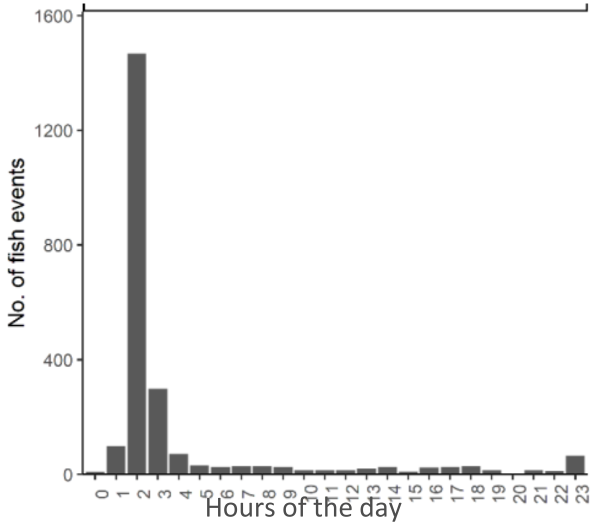
ORPC

UAF Monitoring – Smolt Timing

Smolt Observations (Daily)



Smolt Observations (Hourly)

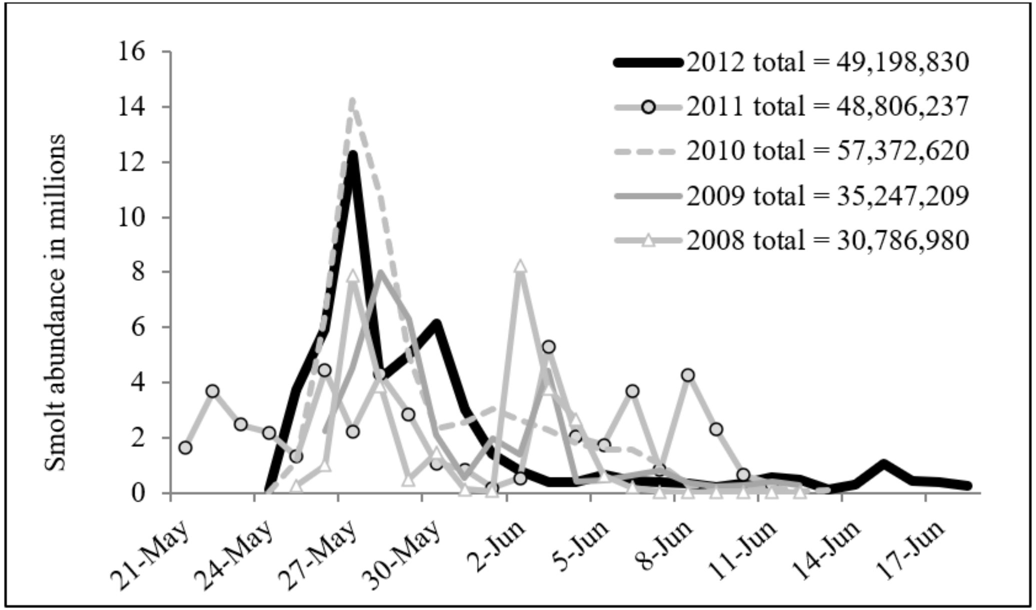


On the Kvichak River, the entire duration of the run is 2-3 weeks long, *with the majority of fish out-migrating in the last week of May*. From 2008 – 2012, greater than 85% of total smolts were detected in a period of 9 days, with 4-day peaks during this time accounting for > 50 percent. (Nemeth 2014)

Historical Sockeye Smolt Counts

<u>Bristol Bay Science and Research Institute (BBSRI)</u>

- Typically collect annual data, did not in 2021
- Collect 600 smolt samples per night (mortalities)
- Smolt abundance determined with sonar
- Majority of smolt travel downstream at night over a short period of days



Estimated daily sockeye salmon smolt abundance, Kvichak River, 2008 – 2012. Source: LGL

Conclusions

- 2021 monitoring supports local indigenous knowledge and historical information on the Sockeye smolt outmigration
    - ➢ Majority of run occurs during a 7 to 10-day period
    - ➢ Concentration of smolt occurs between 00:00 and 04:00
- Estimated smolt/structure interactions incredibly small
- No evidence of injury or mortality based on video monitoring & observations
- No impact to adults

Discussion of Results

2022 Fish Monitoring

Monitoring Status

Cameras

- Unable to communicate with device cameras due to unknown reasons

Software

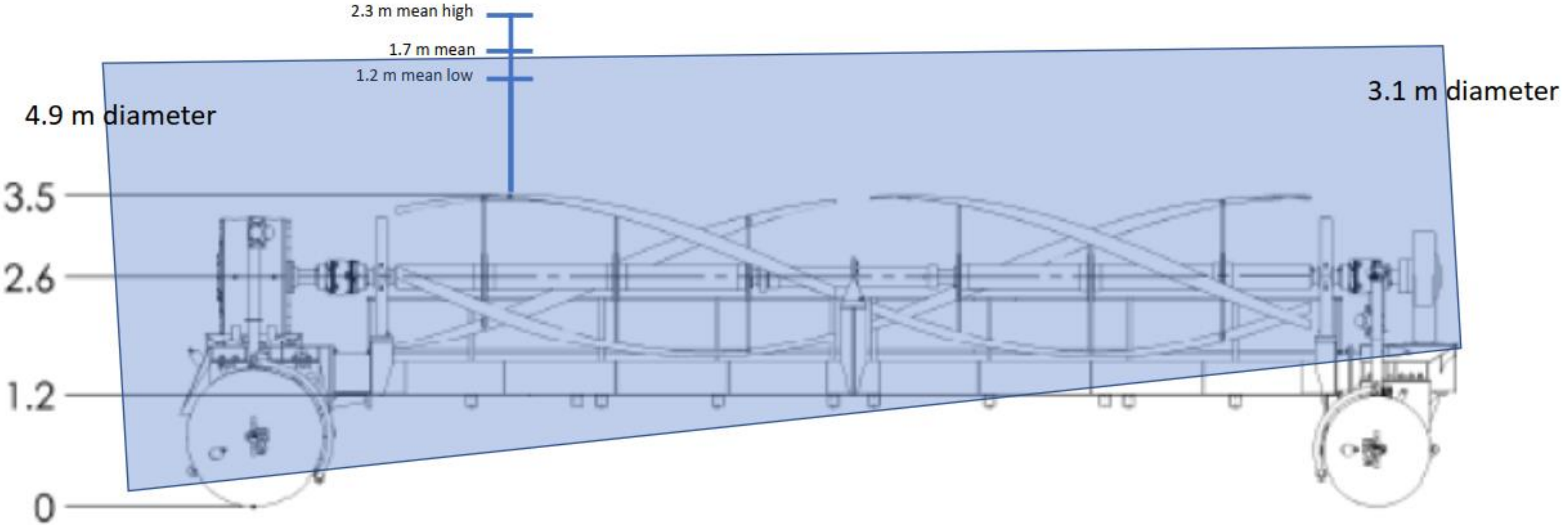
- Challenges with EyeSea operation
- DOE TEAMER funding has been secured to test a new automatic detection system
- New software has potential to be used with sonar or video

Hydroacoustic Monitoring

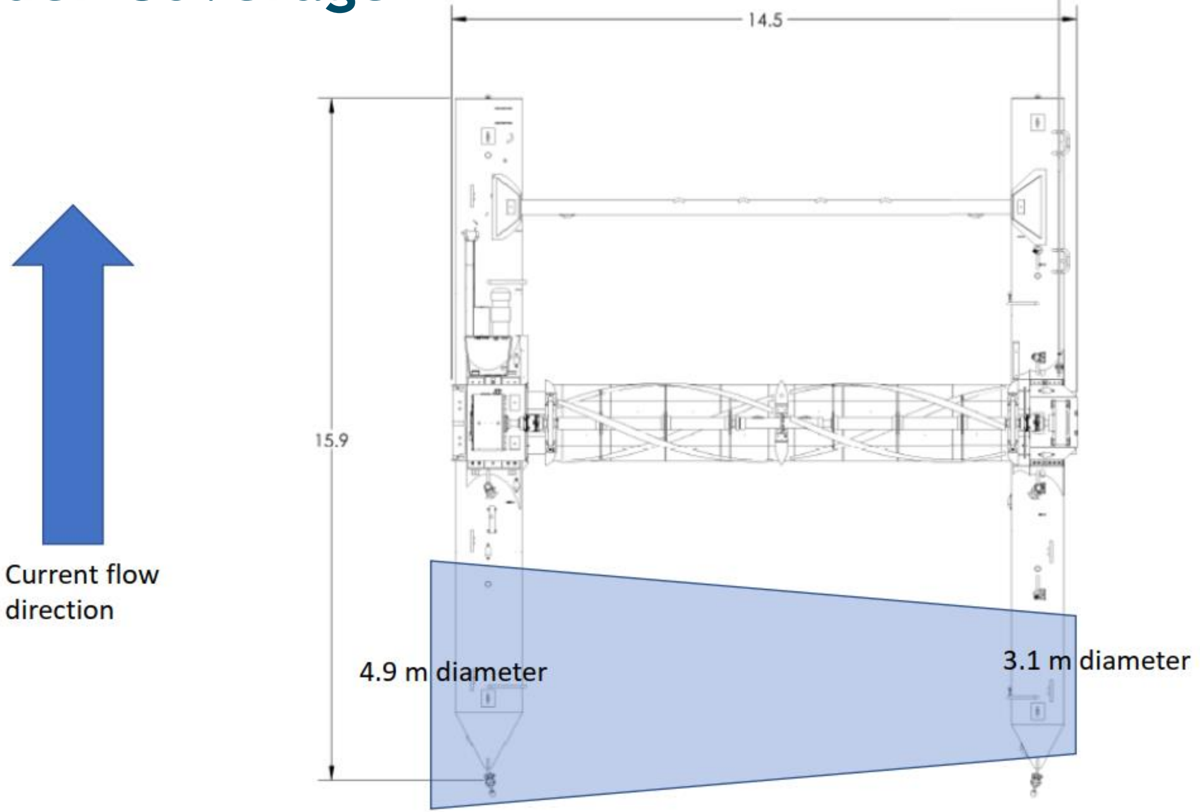
- Led by **DOE-funded** Triton Initiative at the Pacific Northwest National Laboratory (PNNL) collaborating with Aquacoustics, LLC.
  - ➢ ORPC has conducted similar work at a tidal energy site in Maine
- Side looking split-beam sonar from shallow water near bank directly upstream of the RivGen2.1 device
- Will occur over an approximately 10-day period during the smolt run
- Monitoring results to inform encounter rate models
- Advantages
  - ➢ Provide information on smolt presence, distribution, and trajectory as they approach turbine
  - ➢ Not device-based monitoring
  - ➢ No need for lights; ability to monitor in turbid water
- Limitations
  - ➢ Not for individual fish detection or direct turbine/fish interaction
  - ➢ Possible bias in density estimate relative to smolt spatial distribution

Hydroacoustic Monitoring Echosounder Coverage

Diameter of beam at range = 2Rtan(Θ/2)
R = range; Θ = 7 degrees; R1 = 25 m and R2 = 40 m



Hydroacoustic Monitoring Echosounder Coverage



Recommendations/Next Steps

Recommendations for 2022 Monitoring

- IVC is confident in its authority to determine RivGen operations during salmon priority periods. This would be accomplished through local indigenous knowledge, observations, and communication with scientific and regulatory entities.
- End priority period monitoring for adult salmon.
- IVC and ORPC are supportive of hydroacoustic monitoring during 2022 smolt outmigration (PNNL and Aquacoustics). Planning and logistics are underway to accomplish work this spring.

Considerations for 2023 Monitoring

- The product of 2022 operations and monitoring is anticipated to inform planning for operating/monitoring two devices in 2023

- IVC will meet with the AMT to review 2022 results and consult on an operation plan and study needs for the 2023 field season

Next Steps

Activity	Timeframe
Distribute Meeting Minutes for AMT Review & Acceptance	Early April 2022
File 2021 Fish Monitoring Report & Summary of AMT Meeting with FERC/Distribute to Stakeholders	Early April 2022
Amend ADF&G Fish Habitat Permit (Extended to May 20, 2022)	May 2022
Hydroacoustic Monitoring During Smolt Outmigration	End of May/Early June 2022
Deploy Second RivGen Device	August 2022
Data Analysis/Collaboratively Develop Study Plan for 2023 (Two Devices)	Winter 2022/2023

Thank You


Climate Change Solutions
Clean Jobs
Domestic supply chain for huge global export market
ORPC
Energy Equity & Environmental Justice

Attachment 3

Adaptive Management Team Meeting Minutes, April 1, 2022

Igiugig Hydrokinetic Project P-13511
Adaptive Management Team Virtual Meeting
April 1, 2022
10-11 AM Alaska Standard Time

Attendees: Karl Hill (IVC), AlexAnna Salmon (IVC), Nate Johnson (ORPC), Katie Sellers Reynolds (ORPC), Ryan Tyler (ORPC), Merrick Jackinsky (ORPC), Marie Caspard (ORPC), Nathan Hill (Lake and Peninsula Borough), Andy Seitz (UAF), Kevin Keith (ADF&G), Josh Brekken (ADF&G), Travis Elison (ADF&G), Ron Benkert (ADF&G), Clint Gundelfinger (ADNR), Carl Reese (ADNR), Douglass Cooper (USFWS), Sean Eagan (NOAA), Todd Buck (USCG), Garrett Staines (PNNL)

IVC: Igiugig Village Council, ORPC: Ocean Renewable Power Company, UAF: University of Alaska Fairbanks, ADF&G: Alaska Department of Fish and Game, ADNR: Alaska Department of Natural Resources, USFWS: U.S. Fish and Wildlife Service, NOAA: National Oceanic and Atmospheric Administration, USCG: U.S. Coast Guard, PNNL: Pacific Northwest National Laboratory

Agenda:

- Introductions
- 2021 Operations Overview
- 2021 Fish Monitoring Results
- 2022 Fish Monitoring
- Recommendations/Next Steps

Comments and Questions:

<u>2021 Operations Overview (slides 6-15): Nathan Johnson, ORPC with Ryan Tyler (ORPC) and Josh Brekken (ADF&G)</u>

- No comments/questions.

<u>2021 Fish Monitoring (slides 16-24): Nathan Johnson (ORPC) with Karl Hill (IVC), Merrick Jackinsky (ORPC), Josh Brekken (ADF&G), and Andy Seitz (UAF)</u>

- IVC is very motivated to protect the salmon run for the next 10,000 years as it has for the past 10,000 years. IVC is the strongest voice to protect the salmon run because the community depends on it for sustenance. IVC intends to integrate western science and academia with indigenous knowledge developed over many generations to protect the salmon.
- While on site, ORPC and ADF&G observed hundreds of smolt above the device from a boat but only a small fraction of these smolt were observed during the same time period on camera. This further confirms the finding that smolt densities tend to be highest near the river surface. ADF&G noted that only a finite section of the river around the device was monitored at that time.
- Three to four UAF biologists were monitoring the downstream cameras for 10 minutes at the top of every hour during the smolt and adult priority periods, resulting in 168 hours of video imagery analyzed. The vast majority of direct interactions with the turbine or "strikes" occurred while the device was in "production mode." No evidence of injury or mortality based on video

monitoring and observations (note that the scope of this UAF project did not capture fish after "strikes" to determine injury or mortality).

- ADF&G – Were any other fish species interactions of note observed?
    - Some sticklebacks were observed on-camera, none of which were disoriented.
- ADF&G – Was the EyeSea software utilized for the UAF fish monitoring effort?
    - No, the analysis of fish interactions was done manually because the EyeSea software was not yet ready for data analysis. The software still needs to be trained extensively. Manual analysis was very time consuming, but likely more accurate.

<u>2022 Monitoring Status (slides 25-29): Nathan Johnson (ORPC) with Garrett Staines (PNNL) and Karl Hill (IVC)</u>

- IVC noted they have been monitoring ice conditions and there may be an opportunity to raise the device in an attempt to establish communications with the on-device cameras. This is not a set plan or guarantee as this is all dependent on environmental conditions, safety and technology, but IVC will try its best to re-establish camera connections. ORPC and IVC will still proceed with planning for backup monitoring options for the upcoming smolt migration.
- ORPC and IVC have supported a TEAMER application with MarineSitu (a University of Washington spin-out) to train automated detection software they have developed using fish monitoring images collected in 2021. MarineSitu is similar to EyeSea but can use both SONAR and video imagery.
- NOAA – How many echosounders will be used for the PNNL hydroacoustic monitoring effort?
    - A single 7° beam SONAR would be placed directly upstream of the device. The foils themselves would not be covered by the echosounders due to data quality issues generated by the foils.
- NOAA – The echosounder would not provide information on direct fish interactions with the turbine's foils, correct?
    - Correct. Though the echosounder can provide insights into avoidance behavior as fish approach the device.
- ADF&G – Please provide more clarity on the bias introduced due to the smolt spatial distribution when using echosounders. If more fish are located on one side of the river, would this result in a bias?
    - Echosounder analysis typically comes with an assumption of even distribution of the objects being captured. PNNL is more concerned about the vertical distribution of smolt.
- ADF&G – We currently know the smolt densities tend to be concentrated closer to the water surface. Therefore, bias would be introduced, correct?
    - Yes. This site-specific knowledge is very helpful and will inform PNNL's adjustments to assumptions and analysis.
- ADF&G – Does the SONAR collect data right at the water surface?
    - SONAR data is collected from just underneath the surface. Wind and debris can reduce quality of SONAR data collected at the surface.
- ADF&G – Will the turbine be operational when this hydroacoustic monitoring occurs?
    - Ideally yes. PNNL would want to represent the most realistic conditions possible, such as an operational turbine, but we understand there may be operational limitations. Echosounder data will be collected 24/7 over the course of its deployment.

- ADF&G – Is there any merit to hydroacoustic monitoring while the device is both on and off?
    - Yes, it may be valuable to compare fish behavior under the two conditions. ADF&G observed evasion behavior when looking at smolt directly above the device. Avoidance behaviors may be observed in the area covered by the SONAR.

<u>Recommendations/Next Steps (slides 30-34): Nathan Johnson (ORPC) with Karl Hill (IVC)</u>

- IVC has been informed that Bristol Bay Science and Research Institute (BBSRI) will not be doing smolt counts on the Kvichak River this year and therefore will not be able to contextualize monitoring data with BBSRI's estimated total outmigration. BBSRI did not do smolt counts in 2021 either.
- IVC is confident in their ability to identify the timing of the smolt outmigration. IVC requests the authority to determine the smolt salmon priority period and to end the priority period for adult salmon.
- There will be no priority period in which two turbines are in-water until 2023. The Adaptive Management Team should regroup earlier in the year in 2023 to discuss how to approach operations and monitoring of 2 devices during priority periods.
- No questions.

<u>Closing Questions and Comments</u>

- ADF&G – Does PNNL need approval from the Adaptive Management Team (AMT) to proceed with the hydroacoustic monitoring effort?
    - ORPC and IVC will not be tying this effort directly to the Fish Monitoring Plan but will take this effort as an opportunity to expand our knowledge base at the site. PNNL's hydroacoustic monitoring effort is primarily for the purpose of collecting empirical data to inform probability of encounter models under the U.S. Department of Energy (DOE) Triton Initiative. Some logistics and permitting still need to be completed before the project can proceed, but ORPC and IVC are supporting PNNL as best they can to get this study accomplished this field season. The intent is to conduct field monitoring in 2022 and 2023.
    - ADF&G supports this as a great way to continue developing knowledge for the project by using a different study methodology.
    - PNNL would eventually like to conduct multiple years of hydroacoustic monitoring during the smolt run.
- ADF&G – Does IVC intend to operate the device 24/7 during the smolt priority period or turn it off from midnight to 4 AM when the peak portions of the run occur?
    - Yes, IVC intends to operate the device 24/7 to continue developing an understanding of smolt-turbine interactions while the turbine is in "production mode." IVC has not seen any evidence of fish mortality. IVC has also voluntarily conducted drone monitoring at the site and would like to do more in the future to complement other monitoring methods. IVC seeks to balance protecting the salmon run with continuing to develop an understanding of fish-turbine interactions.
    - ADF&G agrees that it is beneficial to continue real-time monitoring while the device is operational to get as much information about the project as possible. ADF&G staff are interested in visiting the site again during the 2022 smolt run.

- ADF&G – Since smolt are typically concentrated at the surface, river water height may impact UAF monitoring results. Were water levels during the 2021 monitoring effort compared to other years?
    - No, the water level was not compared. The local gage station has not been operational for many years. High water events typically occur in the fall rather than spring/summer though. The smolt outmigration typically coincides with a low water period.
- ADF&G – Was there any attempt to determine a confidence interval in the strikes reported in the UAF fish monitoring effort?
    - No. Sensitivity analyses and determining confidence intervals would be a next step.
- NOAA – The smolt migration appears to be skewed; there is a peak day early in the migration period, with a long tail. There may be an opportunity to turn off the device until after the peak migration has occurred and the main surge of fish have safely passed.
    - Without BBSRI smolt counts, it may be difficult to determine the cumulative smolt run with just visual tools such as a drone or on-water observation. There does appear to be a defined peak most years but there is some variability year to year.
- NOAA – Could DOE direct funding towards BBSRI for acoustic monitoring if the proposed PNNL monitoring does not end up occurring?
    - In addition to funding, there may be other factors contributing to BBSRI not conducting annual monitoring including equipment status and staff availability. IVC plans on reaching out to BBSRI for more clarity and to see if it can support them in recommencing monitoring.
- IVC is confident in their ability to steward the Kvichak River salmon. Tribal authority to determine smolt salmon priority periods would further IVC's ability to continue practicing effective, locally informed stewardship of Kvichak River salmon.

2022 Operations & Monitoring Proposal:

- IVC authority to determine RivGen operations during salmon priority periods. IVC proposes to operate the RivGen unit continuously, as conditions allow, during the salmon smolt and adult migrations. Operations will be determined based on local indigenous knowledge, observations, and communication with scientific and regulatory agencies. If negative effects are observed during operations, device operations will be curtailed and ADF&G and NOAA will be consulted.
- End priority period monitoring for adult salmon.
- Modifications to the Fish Monitoring Plan will be requested as appropriate.
- PNNL and Aquacoustics to conduct upstream hydroacoustic monitoring during 2022 smolt outmigration period.
- 2022 Monitoring activities will inform planning for operating and monitoring two devices in 2023.
- IVC will meet with the AMT to review 2022 results and consult on an operation plan and study needs for the 2023 field season.