STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINING, LAND AND WATER

PRELIMINARY DECISION
ADL 109053

Proposed Point Bridget 2.0 Land Exchange
AS 38.50

PUBLIC COMMENT PERIOD ENDS 5:00 PM, MONDAY, MARCH 22, 2021

I. Proposed Actions

Preliminary Decision: Point Bridget 2.0 Land Exchange - ADL 109053

Attachment A: Vicinity Map
Attachment B: Vicinity Map
Attachment C: Public Notice
Attachment D: Materials referenced in Alaska Department of Fish and Game Agency Review Comment

Primary Proposed Action, Land Exchange: The State of Alaska (State), acting through the Department of Natural Resources (DNR), Division of Mining, Land and Water (DMLW), Land Conveyance Section (LCS) received a request to enter into an equal value land exchange with the Gospel Missionary Union dba Echo Ranch Bible Camp (ERBC) and Juneau Hydropower Inc. (JHI) in accordance with *AS 38.50 Exchange of State Land*, *AS 41.21.182 Purchase or Exchange Authorized*, and *11 AAC 67.200 Purpose-.280 Execution of Exchange*. The parties are proposing a land exchange between the three parties to exchange a private nonexclusive easement, of approximately 0.55 acres across tide and submerged lands within Point Bridget State Park for fee title of approximately 0.31 acres of land owned by ERBC adjacent to the park. The issuance of the private nonexclusive easement to JHI, serialized as ADL 109059, is dependent upon the approval of the proposed land exchange (ADL 109053). See *Attachments A* and *B* for a depiction of the project area.

Public Notice of Proposal: In accordance with *AS 38.05.945 Notice*, during a period of at least 30 consecutive days, the public will have the opportunity to submit written comment on this proposal.

See **Section XVI. Submittal of Public Comments** at the end of this document and *Attachment C:* Public Notice for details on how to submit a comment for consideration. If, after consideration of timely, written comments, LCS moves forward with the proposal, a Final Finding and Decision (FFD) will be issued.

II. Authority

DNR has the authority under *AS 38.50 Exchange of State Land* to exchange state-owned land if, on preparation and issuance of a written finding, it is determined to be in the best interest of the State, as required by *AS 38.05.035(e) Powers and Duties of the Director*. Article VIII, Section 1, of the Constitution of the State of Alaska states, "It is the policy of the State to encourage the settlement of its land and the development of its resources by making them available for maximum use consistent with the public interest."

Under *AS 41.21.182 Purchase or Exchange Authorized,* the State may enter into an exchange agreement under *AS 38.50 Exchange of State Land* to improve access, consolidate ownership, or otherwise enhance the purposes of Point Bridget State Park.

III. Administrative Record

The project file for Alaska Division of Lands (ADL 109053) constitutes the administrative record for this proposed action. Also incorporated by reference are:

- DNR case files: ADL 109053, ADL 109059;
- Comprehensive Plan of the City and Borough of Juneau, adopted November 2013; and
- City and Borough of Juneau Land Management Plan, 2016 Update.

IV. Scope of the Proposal

The scope of this proposal, under the statutes described in the preceding **Section II. Authority,** is limited and specific to determining if it is in the State's best interest to exchange an easement for fee title to the private parcel.

V. Description

a. Location: Within DNR's Southeast Region, the subject parcels are in and adjacent to Point Bridget State Park, approximately 40 miles north of Juneau. See *Attachments A and B* to see the Vicinity Maps for additional information.

   USGS Map Coverage: Juneau C-3

   Platting Authority: Juneau Borough

   Native Councils and Corporations: Sealaska Corporation is the Native regional corporation, Goldbelt Incorporated is the village corporation, and the local tribal organizations are the Central Council of Tlingit and Haida Indian Tribes of Alaska and Douglas Indian Association.

b. Legal Description:
   Description of parcel to be acquired by the State: Through the exchange process the State will receive fee simple title with mineral estate to ERBC land, which includes a portion of Tract B1 of USS 1154, Plat 2017-18, Juneau Recording District. This parcel is located in Section 13, Township 37 South, Range 63 East, Copper River Meridian. After survey, this parcel will consist of a new tract with a total acreage of 0.31 acres. See *Attachment A:* Vicinity Map.

   *Description of private nonexclusive easement to be granted to JHI:*JHI will receive a 30-foot wide, approximately 795 feet long, private nonexclusive easement (ADL 109059) for a fiber optic and electric transmission line across State land in Section 12, Township 37 South, Range 63 East, Copper River Meridian, Juneau Recording District. This easement will extend offshore and terminate at the northern boundary of Point Bridget State Park. A survey is required after construction of the easement which will establish exact dimensions and location. See *Attachment B:* Vicinity Map.

VI. Title

The State holds fee title to the tide and submerged lands under the Alaska Statehood Act and the Submerged Lands Act of 1953. Title Report 21285 was issued January 5, 2021. No third-party interests were identified.

ERBC holds fee title to Tract B1 of USS 1154, Plat 2017-18, Juneau Recording District. Title Report 21506 was issued on January 4, 2021. No third-party interests were identified. ERBC and JHI will present to the State a Preliminary Commitment of Title with chain of title documents for Tract B1 of USS 1154, Plat 2017-18, Juneau Recording District, and a final title policy after the parcel has been conveyed to the State.

Native Interest: The subject parcels are within the boundaries of the Sealaska regional corporation. There are no Native interests identified with these parcels.

Other Conflicts or Pending Interest: None.

VII. Background and Discussion

Background

DMLW and ERBC completed the first Point Bridget equal value land exchange in 2018 (ADL 106979). The initial exchange included the State exchanging approximately 38 acres of surface lands within Point Bridget State Park for approximately 60 acres of surface and subsurface lands owned by ERBC adjacent to the park. Prior to the first land exchange, there was no State land access to the main portion of the park. The initial exchange created legal overland access to accommodate increased public visits to the park. The initial exchange also helped ERBC to consolidate and manage their land without isolated segments of State park land between. After the initial exchange, a secondary easement was requested by JHI and ERBC to provide electric power.

This secondary land exchange was proposed between JHI, ERBC, and the State. The new Point Bridget 2.0 land exchange included granting an easement across State tidelands to JHI in exchange for a fee title of a private parcel from ERBC. The State, ERBC, and JHI began negotiations for this land exchange in 2019, with a preliminary exchange agreement signed on September 22, 2020. Pursuant to that agreement, appraisal work was completed December 10, 2020. This preliminary decision fulfills requirements of *AS 38.05.035, Powers and Duties of the Director*, which is required under *AS 38.50 Exchange of State Land*.

Discussion

Point Bridget State Park was established by the legislature under *AS 41.21.180 Purpose of AS 41.21.180 - 41.21.183* in 1988 and is a 2,850-acre park located forty miles north of Juneau. Primary purposes for establishing the park included protecting the area's recreational and scenic resources and to preserve and enhance the continued use of the area for hunting and fishing and recreational activities.

Under *AS 38.50 Exchange of State Land,* the State may exchange State-owned land if it is found to be in the State's best interest, as required by *AS 38.05.035(e) Powers and Duties of the Director*. In this instance the land exchange is also authorized under *AS 41.21.180 Purpose of AS 41.21.180 - 41.21.183* if the exchange improves access to the park, consolidates ownership of the land, or otherwise enhances purposes of the park.

The proposed Point Bridget 2.0 land exchange is beneficial to the State and public and fulfills requirements of *AS 41.21.182 Purchase or exchange authorized* as it will improve access to the park and consolidate land ownership. The proposed land exchange will improve public access for fishing to Cowee Creek in Point Bridget State Park and will connect access to isolated parcels of the park. Currently, public access to the popular fishing spot at Cowee Creek is inhibited by the lack of contiguous land access and the public accesses the creek by a trail that traverses/trespasses land owned by ERBC. The proposed land exchange will also support the primary purposes in which the State park was established by preserving and enhancing the use of the area for fishing and recreational activities.

The exchange of an easement across State tide and submerged lands to JHI will allow for clean, renewal electrical power to be provided to users across Berners Bay at Kensington Mine and provide an alternative to use of diesel fuel for power. In exchange for the easement across tide and submerged lands to JHI, ERBC will receive access to electric power from JHI.

VIII. Planning, Classification, and Mineral Orders

1. *Planning:* The subject parcel containing the easement to be granted to JHI is in a Legislatively Designated Area (LDA) and has been withdrawn from the public domain. The proposed land exchange supports the primary purposes of establishing Point Bridget State Park.

2. *Land Classification Order:* Regulation *11 AAC 67.220 State land or interests in state land subject to exchange* requires that a land exchange cannot be inconsistent with a land use plan adopted or amended under *AS 38.04.065 Land use planning and classification* and that exchange lands must be classified Agriculture, Reserved Use or Settlement. Point Bridget State Park is an LDA and withdrawn from the public domain therefore, it is not subject to classification under *AS 38.05.300 Classification of land* or the area land use plan (Juneau State Land Plan) developed under *AS 38.04.065 Land use planning and classification*. Therefore, this land exchange will not require a classification action or an amendment to the Juneau State Land Plan. The lands exchanged to the State will become part of Point Bridget State Park in keeping with *AS 41.21.182 Purchase of exchange authorized*.

3. *Mineral Order:* DNR previously closed the lands to mineral entry and location as a requirement of *11 AAC 67.230(b) Preliminary exchange agreement* and because mining activities are not compatible with surface uses. A mineral order is not necessary for the parcel to be acquired by the State as it will become part of Point Bridget State Park. Mineral location and exploration is not available within an LDA as those lands have been withdrawn from the public domain for the purpose of public use and recreation. Public records do not reflect any known subsurface resources, mineral resources, or mining claims on the ERBC owned parcel.

4. *Local Planning:* The City and Borough of Juneau has zoned the lands involved with this exchange as natural resource and includes designations such as resource development, state park, and stream corridor protection. The area is also designated as a new growth area.

5. *Flood Risk:* According to FEMA's National Flood Hazard map, the parcel containing the easement to be granted to JHI is in flood Zone V. Zone V is coastal flood zone

with velocity hazard (wave action) and no base flood elevations determined. The ERBC owned parcel to be acquired by the State is in Zone A which is subject to inundation by the 1% annual chance flood and has no base flood elevations determined.

IX. Traditional Use Findings

Both the ERBC-owned private parcel and proposed easement are located within the Juneau Borough and a traditional use finding is therefore not required per *AS 38.05.830 Land Disposal in the Unorganized Borough*. There are no anticipated significant changes to traditional uses of the land and resources of this area as a result of the proposed action. Additional information on traditional use is welcome during the public comment period and if this proposal is approved, LCS will address the information received in a subsequent FFD, if one is issued. See the **Section VIII Submittal of Public Comments** at the end of this documents and *Attachment C:* Public Notice for details on how to submit comment.

X. Access, including Access To and Along Public or Navigable Water

Public Access: Access to the ERBC-owned, private parcel that will be acquired by the State will be via a trail in Point Bridget State Park. The easement proposed to be issued to JHI has walk-in access through nearby public trails. There are no public roads to the easement. The easement can also be accessed by boat from the Echo Bay boat ramp.

Access To and Along Public or Navigable Waters: In accordance with *AS 38.05.127 Access To Navigable or Public Water*, DNR will determine if a water body is navigable or public and establish easements or rights-of-way as necessary to ensure unobstructed access to and along the body of water. Regulations dictating the creation of easements or rights-of-way under this statute include *11 AAC 51.035 Determination of Navigable and Public Water*, *11 AAC 51.045 Easements To and Along Navigable and Public Water,* and *11 AAC 53.450, Buffer Strips, Reserved Areas, and Public Easements*.

XI. Hazardous Materials and Potential Contaminants

The Statewide Abatement of Impaired Land (SAIL) Section in DMLW conducted a desktop review of the readily available information to identify contamination or solid waste concerns that could impact this land exchange. No items of concern were identified during SAIL's review.

There is no known contamination of, or hazardous materials on, the parcel containing the easement to be granted to JHI. The State makes no representations and no warranties, express or implied, concerning the existence or absence of any hazardous substances, hazardous wastes, contaminants, or pollutants on the land proposed for the easement. The State does not assume any liability for the removal of hazardous substances, hazardous wastes, contaminants, or pollutants, nor for the remediation of the site should such substances ever be identified.

XII. Survey

Parcel to be acquired by the State: JHI and ERBC will accomplish a professional subdivision survey of the described 0.31-acre parcel, performed by an Alaska Licensed Surveyor, to the standards of the Juneau platting authority, reviewed by DNR, and approved by the Juneau platting authority, prior to issuance of the easement and the State receiving a warranty deed from ERBC.

Private nonexclusive easement to be granted to JHI/Berners Bay Easement Segment: A DMLW-approved as-built survey is required for ADL 109059 to determine the constructed location of installed improvements and location and acreage of the entire easement on State owned, DMLW managed lands. The Applicant must acquire survey instructions and coordinate with the DMLW Survey Section for the as-built process. The Applicant must acquire bonding to cover the cost of the specified survey prior to the issuance of an Early Entry Authorization (EA). A draft copy of the as-built record of survey must be submitted to the DMLW Survey Section prior to the expiration of the EA and a final as-built record of survey must be approved by DMLW before issuance of the final easement document.

XIII. Appraisal

In 2020, Horan and Company, LLC of Sitka, Alaska appraised the value of the State's interest in the proposed tidelands easement and estimated the size of the Echo Ranch Bible Camp parcel in compliance with the rules and regulations set forth by the Uniform Appraisal Standards. The appraisal was titled *Appraisal Report Point Bridget Land Exchange 0.55 Acre Easement in Sec. 12, T37S, R63E, CRM for a Portion of Tract B1, USS 1154 ADL 109053 Juneau, Alaska*. The purpose of the appraisal was to estimate the market value of the State-owned easement proposed to be granted to the private party and to estimate the size of the private parcel to be acquired by the State so that both would be of equal value.

The appraised value of the State owned 0.55 acre, 795 feet long, 30 feet wide easement was determined to be approximately $1,100. The estimated value of State lands was used to determine the size of the private parcel involved in the exchange so that both the private parcel and easement would be of equal value. The appraisal finds 0.31 acres of private land to be conveyed with this exchange would be equal to the 0.55-acre easement to be granted to JHI. DNR reviewed and accepted this appraisal.

Both the easement and private parcel owned by ERBC will need to be surveyed following the issuance of an EA and prior to the State receiving a warranty deed from ERBC. Because this is an equal-value exchange and no State land is being conveyed that has a value of more than $5,000,000, legislative approval is not required (*AS 38.50.010 Authorization and Procedure for Exchange of State Land* and *AS 38.50.140 Legislative Review*).

XIV. DMLW and Agency Review

Information and comments received from multiple sections within DMLW prior to and during agency review have been considered and included in the preparation of this PD. Agency review was conducted between December 28, 2020 through February 11, 2021. Comments pertinent to this proposed action received during agency review have been considered and addressed below. Additional timely comments received during the Public Notice period will be considered and addressed in a subsequent Final Finding and Decision if one is issued.

<u>DNR DMLW LCS received brief comments of non-objection from the following agencies:</u> DNR Division of Forestry and Department of Transportation and Public Facilities.

DNR DMLW LCS Response: LCS appreciates your review of the proposal.

<u>DNR Division of Oil and Gas (DOG)</u>: DOG thanked LCS for sharing information on the proposed Point Bridget 2.0 Land Exchange. DOG has no objection to the proposed

disposal and has not issued any third-party authorizations on the subject land, nor are there any pending applications or activity in the vicinity.

DOG asks to please alert the applicants that the State reserves oil, gas, minerals, fissionable material, geothermal resources, and fossils that may be in or upon the land that it conveys in accordance with Section 6(i) of the Alaska Statehood Act and Alaska Statute 38.05.125. The State also reserves the right to enter the land for the purposes of exploring for, developing, and producing these mineral resources. A mineral order closing the area to locatable mineral entry, if any, does not apply to leasable mineral resource exploration, development, or production.

> *DNR DMLW LCS Response:* LCS appreciates your review of the proposal. The proposed decision does not include conveying any land out of State ownership and the mineral estate will be reserved in accordance with Section 6(i) of the Alaska Statehood Act and *AS 38.05.125 Reservation*.

Alaska Department of Fish and Game (ADF&G): The Alaska Department of Fish and Game (AD&G) has reviewed ADL 109053, a proposed land exchange adjacent to Point Bridget State Park near Juneau to provide electric power to the Kensington Mine across Berners Bay. The Gospel Missionary Union, dba Echo Ranch Bible Camp (ERBC) and Juneau Hydropower Inc (JHI) are requesting a utility easement (30' wide x 795' long) across state owned tidelands within the park in exchange for a 0.31 acre tract of land to be added to the park.

ADF&G does not have any major objections with the current authorization, however, we would like to submit the following comments regarding the proposed utility easement across state owned tidelands at issue here as well as the eventual continuation of a submerged powerline across Berners Bay. Berners Bay is a productive and biologically diverse marine ecosystem supporting a variety of fish and wildlife species as well as associated commercial and sport harvest opportunities as reflected in the co-designations of Habitat, Harvest and Dispersed Public Recreation for much of the surrounding area by the Juneau State Land Plan (Adopted 1993).

While short-term impacts from the installation of a power line across Berners Bay could potentially be mitigated with timing windows, there are many unknowns about the long-term impacts of submarine power cables on marine life, which may include heat and Electro-magnetic field emissions; contamination; and direct loss of benthic habitat (see Taormina et al. 2018, OSPAR 12221, attached [*see Attachment D*]). One of the key components in the literature and included on NOAA's submarine cable, domestic regulation webpage references best practice guidelines (OSPAR 12221 [see *Attachment D*]) including, "protected areas, environmentally sensitive and/or valuable areas with e.g. habitats and species sensitive to physical disturbance or damage where the cable laying activity or operation would result in adverse effects should be avoided." Discussions with the applicant have addressed some of these concerns, however, we will submit additional comments when more detailed plans are provided in subsequent authorization requests. In the meantime, the below comments will address the current authorization as well as provide initial comments regarding the subsequent authorization.

Fish Resources

The proposed utility easement across state owned tidelands is located approximately 2,500 feet east of Cowee Creek. Cowee Creek has been cataloged by ADF&G's Anadromous Waters Catalog as providing important habitat for chum, coho, and pink salmon; cutthroat trout; Dolly Varden; and Steelhead trout. Sport anglers commonly fish near the mouth of Cowee Creek and it is not uncommon for the public to walk across the state-owned tidelands to reach the rocky point east of the proposed utility easement. While, the installation of the utility line here may require temporary public exclusion, effort should be made to avoid installation during peak fishing periods to minimize disruptions to public use. Final installation should be designed in such a way so that public access across the utility line is not impeded. The applicant is advised that while outside the scope of this authorization, any crossing of Cowee Creek or other anadromous streams as this powerline crosses privately owned uplands between the Glacier Highway and the ERBC will require review by ADF&G Habitat Section and may require a Fish Habitat Permit. Additionally, US Army Corp of Engineers Wetland Permits may be required.

Shellfish Resources
Berners Bay and Echo cove have historically been important areas for personal use, subsistence, sport, and commercial shellfish fisheries. The ADF&G Shellfish Program annually conducts aerial surveys preceding the start of the commercial Dungeness fishery on June 15th. Over the last ten years the proposed area has been surveyed five of those. The highest density of commercial crab gear in the greater Berners Bay area has consistently been observed just offshore of the proposed site. The site likely contains Dungeness and juvenile red king crab habitats, yet without depths of the proposed site this would be hard to quantify. Depending on the subsequent easement placement across the bay, avoiding installation during the Dungeness fishery (June 15th-August 15th) and (October 1st – November 30th) may be important. The main conflict with the Dungeness fishery would be in the first 0-25 fathoms.

Marine Mammal Resources
Berners Bay is a productive marine environment providing valuable habitat for 10 marine mammal species, including two species listed under the ESA.

- During the eulachon and herring spawning events, numerous species feed in Berners Bay including hundreds of Steller sea lions and harbor seals, > a dozen humpbacks, and thousands of gulls.
- The multiple river systems that run into Berners Bay (Gilkey, Lace, Berners, Antler) support anadromous fish runs that provide prey resources for marine mammals. There are two key[11] harbor seal haulouts and an anadromous stream within 1 mile of the proposed easement (map A, below). Key haulouts are identified as having >50 seals during the Marine Mammal Lab August surveys and are likely important areas for seal pupping and molting.
- Berners Bay is a biologically important area for humpback whale fall (September – November) and spring (March – May) feeding.
- There are four key[1] harbor seal haulouts and one Steller sea lion haulout in the northern part of Berners Bay (**See overview map, attached** [See *Attachment D*]).

Installation should avoid the above referenced humpback whale feeding windows, avoid approaching the above referenced haulouts, and use a marine mammal observer to halt

[1] Key haulout (>50 seals) is a designation used to implement the ADF&G mariculture guidelines. https://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/research_pdfs/harbor_seal_haulout_data_layer.pdf

installation when marine mammals are present. The applicant is advised that they should consult with NOAA to ensure compliance with the Marine Mammal Protection Act and the Endangered Species Act.

> *DNR DMLW LCS Response:* LCS appreciates the review by ADF&G of the proposal and time and effort in providing initial concerns about the fish, shellfish, and marine mammal resources that could be impacted by this project. The proposed easement in this decision will terminate at the Point Bridget State Park Boundaries. Therefore, any responses for the perceived eventuality of this easement across Berners Bay, are dependent upon an easement application and agency review comments in relation to an easement that proposes to cross Berners Bay and is outside of the scope of this decision.
>
> LCS recognizes that Berners Bay and Echo Cove have historically been important areas for personal use, subsistence, sport, and commercial activities associated with the extraction of fish and marine resources. This easement authorization agreement will contain provisions to mitigate interference with those activities. For example, construction and maintenance of the utility line will be prohibited during seasonal events that would interfere with seasonal fisheries and other marine resource extraction activities in the area. The purpose of these provisions will be to mitigate conflict in the area with user groups and potential degradation to sensitive marine habitat and species that may be affected during construction and/or maintenance activities of the proposed easement, DMLW Southeast Office – Easement Unit will consult with ADF&G habitat section for concurrence on the aforementioned provisions of this easement authorization before an agreement is provided to the applicant.

The following agencies or groups were included in the agency review, but no comment was received:

- Department of Environmental Conservation;
- Department of Natural Resources;
  - Division of Geological and Geophysical Surveys;
  - Division of Agriculture;
  - Division of Parks and Outdoor Recreation; and
  - State Historic Preservation Office.

XV. Submittal of Public Comments

See *Attachment C*: Public Notice for specific dates and conditions.

Pursuant to *AS 38.05.945 Notice*, LCS is issuing public notice inviting comment on this Preliminary Decision.

In accordance with *AS 38.05.946(a) Hearings*, a municipality or corporation entitled to receive notice under *AS 38.05.945(c) Notice* may hold a hearing within 30 days after receipt of the notice. If a hearing is held, the Commissioner (or representative) shall attend the hearing. The Commissioner has discretion on whether or not to hold a public hearing.

LCS will consider all timely, written comments received. If analysis of such comments indicates the need for significant changes to the PD, additional public notice for the affected lands will be given. Reducing the amount of land offered and making minor changes to any of the proposals will not be considered significant changes requiring additional public notice.

If the proposals are approved and no significant change is required, the PD, including any deletions, minor changes, and summary of comments and LCS responses will be issued as a subsequent FFD without further notice.

Only persons from whom LCS receives timely, written comment during the identified comment period will be eligible to file a request for reconsideration of the FFD. Upon approval and issuance of a FFD and these actions, a copy of the decision, orders, and amendment will be made available online at http://landsales.alaska.gov/ and sent with an explanation of the request for reconsideration process to any party who provides timely written comment.

DNR is prepared to accommodate individuals with disabilities by providing auxiliary aids, services, or special modifications in order to participate in this review. Individuals who may need such assistance should contact DNR's Public Information Center. For more information refer to *Attachment C*: Public Notice.

DEADLINE TO SUBMIT WRITTEN COMMENT IS
5:00 PM, MONDAY, MARCH 22, 2021

XVI. Stipulations

The applicant will be required to comply with the following stipulations to complete the proposed land sale:

1. Surveys of both parcels will need to be completed prior to the issuance of the easement to JHI and the State acquiring the private parcel from ERBC. Following the signing of the Final Exchange Agreement, JHI will need to apply for an EA with the DNR Southeast Regional Office for the easement. An as-built survey must be submitted to and approved by DNR to determine proper location and final easement dimensions, which would be approximately 795 feet in length, 30 feet in width, and occupy approximately 0.55 acres. Once the requirements for issuance have been met, the final private nonexclusive easement will be granted by DNR to JHI. A subdivision survey of the ERBC-owned private parcel must also be conducted before conveying to the State and approved by the Juneau platting authority. Prior to JHI and ERBC submitting the survey to the Borough of Juneau for approval, the survey will need to be submitted to the DNR DMLW Survey section for cursory review. Survey costs will be paid for by JHI and ERBC.
2. Preliminary Commitment for Title will be presented to the State for Tract B1 of USS 1154, Plat 2017-18, Juneau Recording District, following a DNR approved subdivision survey of the ERBC-owned private parcel. The cost will be paid for by JHI and ERBC.

If extenuating circumstances delay any of the stipulations listed above, JHI and ERBC are responsible for notifying LCS and receiving approval from LCS for the delay with new timeframes for completion to be given. Failure to do this could result in the closure of the land exchange application. The land exchange cannot be completed until all the above stipulations have been satisfied.

XVII. Discussion and Alternatives

LCS is considering the following alternatives:

<u>Alternative 1:</u> Exchange land
Exchange an easement to JHI in exchange for the ERBC-owned private parcel as proposed in this decision and in accordance with *AS 38.50 Exchange of State Land*, *AS 41.21.182 Purchase or Exchange Authorized*, and *11 AAC 67.200 Purpose-.280 Execution of Exchange.*

<u>Alternative 2:</u> Issue an easement to JHI or purchase private parcel from ERBC
Issue an easement to JHI across State tidelands and submerged lands in Point Bridget State Park for a fee. Purchase private parcel from ERBC.

<u>Alternative 3:</u> Retain
DNR will take no action and decline to exchange land and refuse granting an easement to JHI.

Alternative 1 will provide an easement to JHI and allow for clean, electrical power to be provided to the occupants across Berners Bay. This arrangement will also allow for power to be provided to ERBC. The land to be acquired by the State as part of this exchange will consolidate State land ownership, improve public access to Point Bridget State Park according to *AS 41.21.182 Purchase of Exchange Authorized*, and eliminate trespass across ERBC owned land. Therefore, it is in the best interest of the State to exchange an easement for the ERBC owned parcel, as proposed in this decision. This is the preferred alternative.

Article VIII, Section 1 of the Alaska Constitution states, "it is the policy of the State to encourage the settlement of its land and the development of its resources by making them available for maximum use consistent with the public interest." Alternative 1 provides a method for DNR to meet the obligations laid out in the Constitution and statute and maximizes public interest.

Under Alternative 2, DNR will issue the easement to JHI for a fee or purchase the private parcel from ERBC. Under this option the State earns revenue from the easement but fails to address trespass issues across ERBC owned land and connectivity issues within Point Bridget State Park. ERBC is also unwilling to sell the private parcel to the State. This alternative is partially not viable or in the best interest of the State. This alternative is not preferred.

Under Alternative 3, the State will take no action and land would not be exchanged. This alternative fails to assist JHI in providing clean, electrical energy to occupants across Berners Bay and does not address the connectivity and trespass issues across ERBC owned land adjacent to Point Bridget State Park. This is not in the best interest of the State. This alternative is not preferred.

For the reasons outlined above, Alternative 1 is the preferred alternative.

Recommendation follows.

XVIII. Recommendation and Preliminary Decision

The recommended action is Alternative 1 because it allows for consolidation of land ownership for the State, improves park access by eliminating trespass across ERBC owned land, and addresses the need for clean, electrical power to users across Berners Bay. The PD described above, as represented by the preferred alternative, has been reviewed and considered. I find that the recommended action may be in the best interest of the State and that it is hereby approved to proceed to public notice.

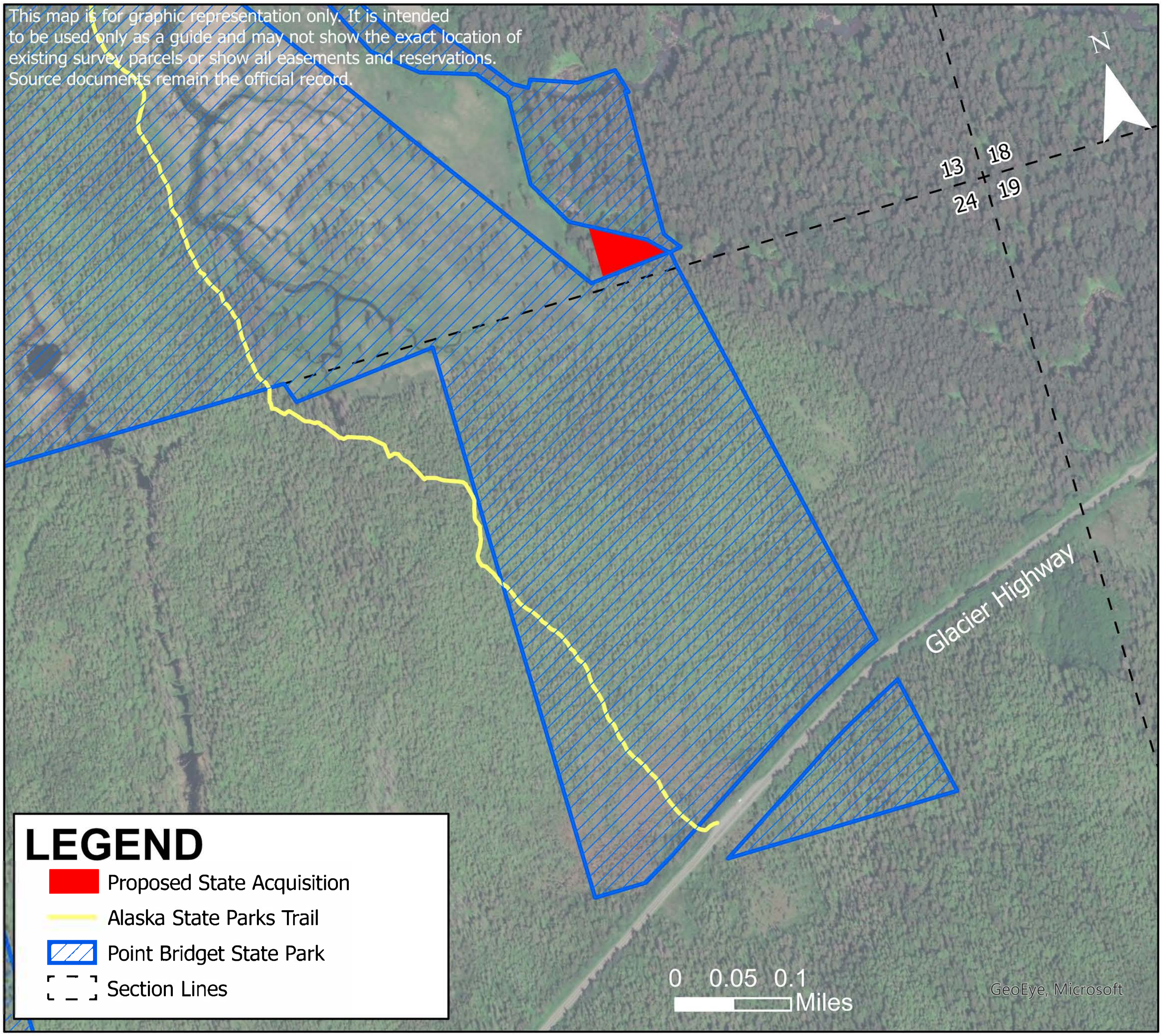
The is a Preliminary Decision, and analysis of subsequent public review may result in changes to the preferred alternative of the proposed land exchange.

____[signature on file]________________ _____[2/18/2021]______
Prepared by: Kelsey M. Anderson Date of Signature
Natural Resource Specialist III
Land Conveyance Section
Division of Mining, Land and Water
Department of Natural Resources
State of Alaska

____[signature on file]________________ _____[2/18/2021]______
Approved by: Rachel Longacre Date of Signature
Section Chief
Land Conveyance Section
Division of Mining, Land and Water
Department of Natural Resources
State of Alaska

Point Bridget 2.0 Land Exchange
ADL 109053

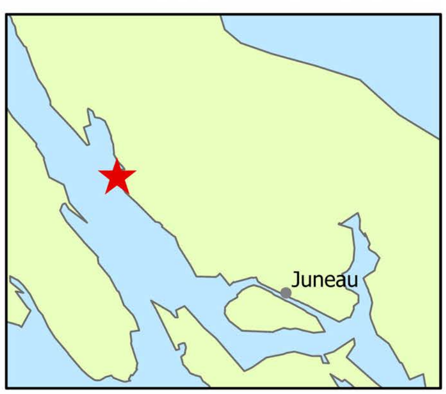
Preliminary Decision: Attachment A
Proposed Land Exchange
Pursuant to AS 38.50

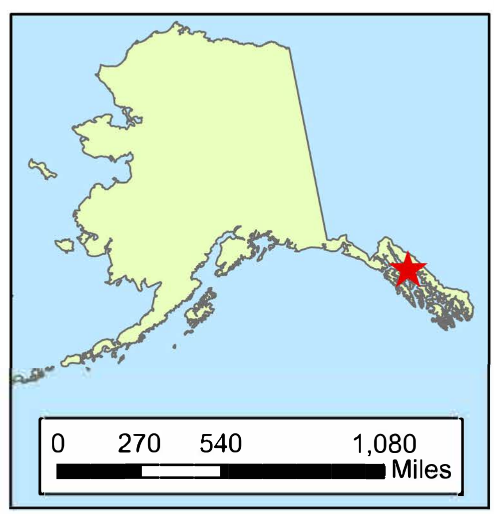


Section 13, Township 37 South, Range 63 East, Copper River Meridian

USGS Quad 1:63,360 Juneau C-3

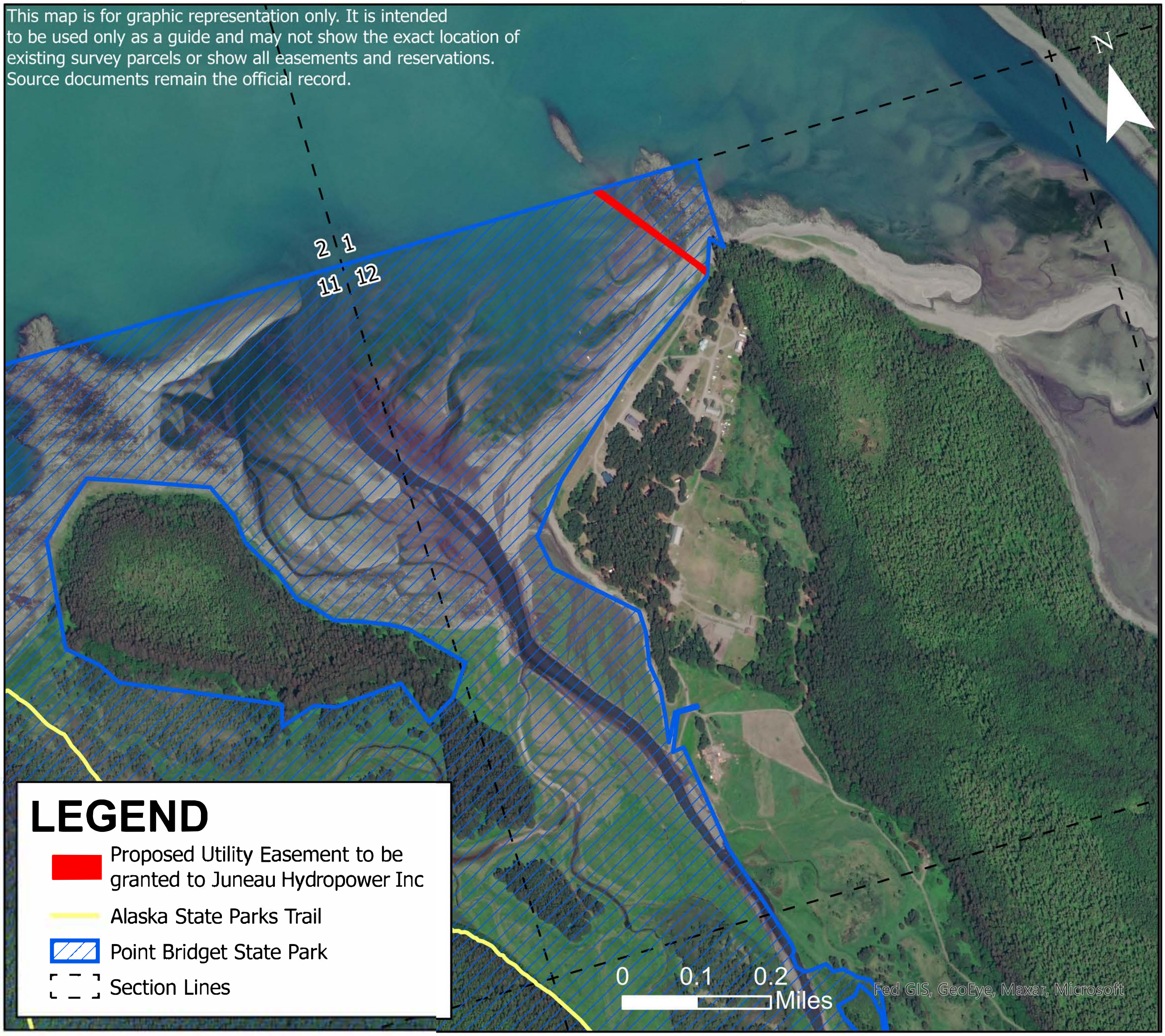
For more information contact:
Kelsey M. Anderson
Department of Natural Resources
Division of Mining, Land and Water
Land Conveyance Section
Phone: 907-269-8851
Fax: 907-269-8916
Email: Kelsey.anderson1@alaska.gov





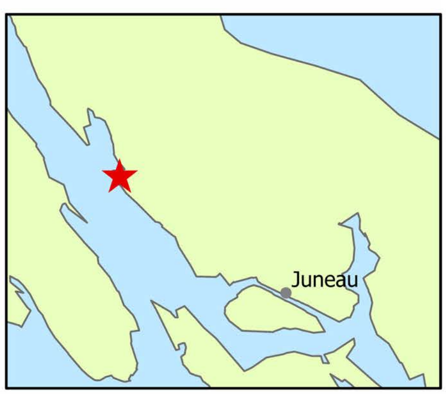
Point Bridget 2.0 Land Exchange
ADL 109053

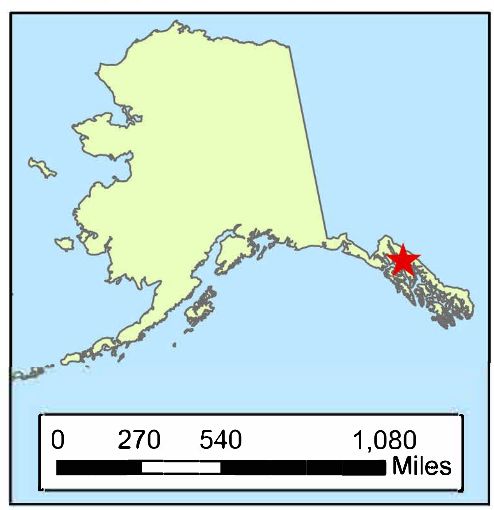
Preliminary Decision: Attachment B
Proposed Land Exchange
Pursuant to AS 38.50



USGS Quad 1:63,360 Juneau C-3

Section 12, Township 38 South, Range 63 East, Copper River Meridian





For more information contact:
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Land Conveyance Section
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STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINING, LAND AND WATER

ATTATCHMENT C: PUBLIC NOTICE

Requesting Input for Proposed
Point Bridget 2.0 Land Exchange
ADL 109053
AS 38.50

PUBLIC COMMENT PERIOD ENDS 5:00 PM, MONDAY, MARCH 22, 2021

The Alaska Department of Natural Resources (DNR), Division of Mining Land and Water (DMLW), Land Conveyance Section (LCS) is conducting a public notice for a proposed land exchange in and adjacent to Point Bridget State Park 40 miles north of the city of Juneau. The legal descriptions for the parcels involved are 0.31 acres in Tract B1 of USS 1154, Plat 2017-18 in Section 13 of Township 37 South, Range 63 East, Copper River Meridian and 0.55 acres in Section 12, Township 37 South, Range 63 East, Copper River Meridian. The legal descriptions of these parcels would change following a final exchange agreement and survey.

To obtain the notice, Preliminary Decision (PD), or instructions on submitting comment, go to http://dnr.alaska.gov/mlw/landsale/ or http://aws.state.ak.us/OnlinePublicNotices/. For assistance in obtaining the documents by an alternative method, to request auxiliary aids, services, or special accommodations, contact DNR's Public Information Centers on State work days, Monday through Friday, between 10:00 AM and 5:00 PM in Anchorage at (907) 269-8400 or Fairbanks at (907) 451-2705 or the Southeast Land Office in Juneau at (907) 465-3400 or TTY: 711 for Alaska Relay or 1-800-770-8973 or go to http://dnr.alaska.gov/commis/pic/ for additional contact information. Individuals who require special assistance must request assistance from the Public Information Center in Anchorage no later than 4:00 PM, Monday, March 15, 2021.

Pursuant to *AS 38.05.945 Notice*, the public is invited to submit comments on the Preliminary Decision for which notice is being conducted concurrently. **The deadline for public comment is 5:00 PM,** Monday, March 22, 2021.Only persons from whom DNR DMLW LCS receives timely, written comment during the identified comment period will be eligible to file an appeal of the Final Finding and Decision (FFD). Written comment may be received by fax, email, or postal mail. To submit comments or for direct inquiries, contact Kelsey M. Anderson by mail at 550 West 7th Ave, Suite 640, Anchorage, AK 99501 or by fax at (907) 269-8916 or by email at kelsey.anderson1@alaska.gov. If you have questions, call Kelsey M. Anderson at (907) 269-8851.

If no significant change is required, the PD, including any minor changes and a summary of comments and responses, will be issued as the FFD without further notice. A copy of the FFD will be sent to any persons who commented timely on the PD.

DNR reserves the right to waive technical defects in this notice.

Guidelines on Best Environmental Practice (BEP) in Cable Laying and Operation

(Agreement 2012-2)

(Source: OSPAR 12/22/1, Annex 14)

Content

1. Background and objectives

In 2008 a background document regarding the influence of laying and operating underwater cables on the marine environment and nature was published in the framework of international cooperation for protection of the marine environment of the North-East Atlantic in line with the OSPAR Convention (OSPAR 2008a). The JAMP assessment (Assessment of the environmental impacts of cables; OSPAR 2009) adopted in 2009 essentially evaluates the environmental impacts of sea cables in terms of their relevance for the area covered by the Convention on the basis of the background document. The assessment served as the technical background document for the 2010 OSPAR quality status report (OSPAR 2010).

Subsequently Germany was requested to submit a proposal for an OSPAR guidance paper on environment and nature compatible construction and operation of underwater cables to EIHA in 2011 (Guidance on Best Environmental Practice on cable laying and operation).

The purpose of this paper is:

- Compilation of possible measures to avoid and mitigate the ecological impacts of construction, operation and removal of underwater cables.

- Differentiation of possible measures regarding various types of sea cables, different burial techniques, burial depths, etc.

- Compilation of possible avoidance and mitigation measures with respect to cumulative effects.

- Identification of remaining gaps in knowledge and the resulting specific research needs. Determining on that basis priorities for future research.

The potential ecological impacts of construction, operation and removal of various types of cable described in current literature and in particular in the above mentioned OSPAR documents as well as the corresponding possible avoidance and mitigation measures form the basis for this guidance paper.

Without any claim to completeness, some proposals are made in the following regarding consideration given to submarine cable laying as a maritime activity. Some of them have already been taken into account in various cable projects, but are not necessarily part of the standard procedures (for telecommunication cables see *e.g*. CARTER et al. 2009).

These aspects should be taken into account both within the framework of the further OSPAR process, and within the development of individual projects.

2. Submarine cable types

As a matter of principle, a distinction should be made between power cables and telecommunication cables on the basis of their different functions, technical characteristics and environmental impacts.

Power transmission cables

Marine power cables are specifically designed to transmit electric currents either as Alternating Current (AC) or Direct Current (DC). Monopolar, bipolar or three-phase systems are different technical solutions in use. Depending on their design the diameter of power cables may be up to 15 cm. Weights vary between 15 to 120 kg/m (OSPAR 2008a).

Alternating Current (AC): There are basically two types of AC sea cable, the **three-conductor cable** and the **single-conductor cable**. The great advantage of the three-conductor cable is that the electromagnetic field of the three conductors is almost neutralised at the surface of the cable, and plastic is used instead of oil as stabilising material to fill the hollow space, preventing broken cables from emitting oil into the sea water. The single-conductor cable is a cable with just one conductor for a single phase, so that three single-conductor cables are required for a three-phase system. The advantage of the latter type of cable is its high transmission capacity, even though the absolute losses rise with increasing transmission capacities.

Direct Current (DC): DC cables have no induced voltages and currents and thus no losses from their metal jackets. To avoid the emission of electromagnetic fields into the environment , the two poles of a DC system, the forward and the return conductor, have to be installed in parallel and as close as possible to each other: such a **bipolar system** again can be designed as a two-conductor cable or as two single-conductor cables. The two conductors thus can be laid either as separate cables, as flat type cables or as coaxial cables. The reduction of the emission of electromagnetic fields ideally reaches 100 % in coaxial cables. **Monopolar systems** consist of only a forward conductor. In such a case the current is fed back via the seawater and the seafloor by means of electrodes in the seawater located at both ends of the forward conductor. In monopolar systems, strong electromagnetic fields are generated along the single cable and electrolysis occurs at the anode and cathode of the return conductor, the seawater. Since monopolar systems with electrodes no longer meet environmental standards of many EU countries (see STEHMEIER 2006) their environmental effects are not addressed in this report.

In general, a DC line can transmit more power than an AC line of the same size. The reactive power flow due to the large cable capacitance will limit the maximum possible AC transmission distance. With DC there is no such limitation, making it the only viable technical alternative for long distance cable links (RAGHEB 2009).

Telecommunication cables

Modern submarine telecommunication systems are fibre optic cables using pulses of light to transport information. However, coaxial cables as the former standard are sporadically still in service (OSPAR 2008a). A fibre optic cable sends information shooting pulses of light through thin transparent fibres usually made of glass or plastics (DREW & HOPPER 2009). The distance over which the optical signal can be transmitted through the fibre without any intermediate undersea signal processing is not unlimited. For that reason fibre optical cables may be equipped with repeaters. DREW & HOPPER (2009) report repeaters to be placed at intervals of 17–34 nautical miles along a fibre optical cable. Repeaters have to be powered via a power cable. The total requirement for a typical 7500 km transatlantic crossing with 100 repeaters would be close to 10 kV (OSPAR 2008a). Outside diameters of fibre optic cables range from 20 to 50 mm (DREW & HOPPER 2009).

Insulation of power cables

The cable industry today offers various types of mass-impregnated (MI) cables and XLPE (cross linked polyethylene) cables, also self-contained fluid filled (SCFF) or gas filled (SCGF) cables are available (OSPAR 2008a).

Mass impregnated (MI) cables contain a fluid impregnated paper insulation that is not pressurized. XLPE cables are equipped with insulations of a solid dielectric material. SCFF cables have conductors with hollow cores which provide a passageway for insulating fluid under static pressure provided by equipment at the cable terminals (pumping plants at the cable ends, feeding into a hollow conductor core). The insulating fluid saturates the cable insulation (being e.g. polypropylene laminated paper or conventional cellulosic kraft paper), maintaining the electrical integrity of the cable, and preventing damaging ingress of water in the event of an underwater leak. Suitable insulating fluids are refined mineral oils or linear alkylbenzene (LAB). Self contained gas filled (SCGF) cables are similar to SCFF cables except the insulation is pressurised with dry nitrogen gas.

Often cables are designed as composite cables with additional components besides the conductors for power transmission (e. g. optical fibres for data transmission). Cable conductors are usually made of copper or aluminium wires, or may be composite conductors with steel strands at their core. The overall assembly of the cable components may be round or flat.

3. Potential environmental impacts associated with submarine cables

3.1 Introduction

Potential environmental impacts associated with subsea cables are disturbance, underwater noise, heat emission, electromagnetic fields, and contamination (OSPAR 2008a, 2009, 2010) including release of nutrients. Environmental impacts of submarine cables may occur during their laying, operation and removal as well as in the case of accidents. The nature, extent and significance of these potential impacts should be determined on a site-specific basis as part of an assessment of environmental impacts. In the following sections these impacts are briefly discussed taking aspects like spatial extent, timescale (duration, frequency, reversibility) and magnitude of impacts as well as their relevance for the different phases in cable life and for the various cable types into consideration. Possible mitigation measures will be presented on this basis.

3.2 Disturbance by the placement of cables

The laying of cables leads to seabed disturbance and associated impacts (damage, displacement or disturbance) on flora and fauna, increased turbidity, remobilisation of contaminants from sediments and alteration of sediments. Along with noise and visual disturbance, these effects are mainly restricted to the installation, repair works and/or removal phase and are generally temporary. In addition, their spatial extent is limited to the cable corridor (in the order of 10 m width if the cable has been ploughed into the seabed; OSPAR 2009). Such impacts relate both to submarine telecommunications and to power cables. Some mobile benthic species (for example, crabs) are able to avoid most disturbance whereas sessile (bivalves, tubeworms etc.) and sensitive species (such as slower growing or fragile species) will be more impacted.

Though modern equipment and installation techniques can reduce the re-suspension of sediment during cable burial or removal, remaining suspended sediment may nonetheless - depending on percentage of silt fraction and background levels - obstruct the filtration mechanisms of some benthic and pelagic organisms at least temporarily (OSPAR 2009). It can also affect the growth of the macrobenthos and may have a lethal effect on some species. Contamination arising from seabed disturbance is only a risk in heavily contaminated locations (OSPAR 2009, COOPER et al. 2007a, 2007b). Particularly in coastal areas concerned the laying of cables can also lead to increased nutrient releases into the water column and consequently may contribute to eutrophication effects locally.

The application of cable protection (often stones) along the cable route in areas characterized by soft sediments will lead to artificial introduction of hard substrates. The submarine cables themselves, if not buried, will also provide a solid substrate for a variety of species. This 'reef effect' has been extensively discussed in literature (see OSPAR 2009) and may lead to the introduction of non-local fauna and thus to an alteration of the natural benthic community. In most cases effects will be localized although long-lasting.

3.3 Underwater noise

There is only little information on potential noise impacts due to the installation (or removal) and operation of sub-sea cables (OSPAR 2008a). Sound emissions associated with the installation, removal or operation of submarine cables are considered as less harmful compared to activities such as seismic surveys, military activities or construction work involving pile driving. Generally, maximum sound pressure levels related to the installation or operation of cables are moderate to low. Only one publication of recordings of noise emissions during cable laying could be found (NEDWELL et al. 2003, North Hoyle). It would be favourable to undertake further field measurements to allow a more profound discussion of potential impacts. Nevertheless, noise associated with the laying of cables adds to the already prevailing acoustical disturbances.Therefore, where appropriate, the timing, duration and method of any cable laying operations should be managed to minimise impacts.

In summary, currently there are no clear indications that noise impacts related to the installation (or removal) and operation of subsea cables pose a high risk for harming marine fauna (OSPAR 2008a). However, it has to be stressed that there are still significant gaps in knowledge in regard to both the characteristics of sound emissions and sound perception by fauna.

3.4 Heat emission of power cables

When electric energy is transported, a certain amount gets lost as heat, leading to an increased temperature of the cable surface and subsequent warming of the surrounding environment. Important factors determining the degree of temperature increase are cable characteristics (type of cable), transmission rate and characteristics of the surrounding environment (ambient temperatures, thermal conductivity, thermal resistance of the sediment etc.). In general, heat dissipation due to transmission losses can be expected to be more significant for AC cables than for HVDC cables at equal transmission rates.

Published theoretical calculations of the temperature effects of operational buried cables are consistent in their predictions of significant temperature rise of the surrounding sediment. The maximum conductor temperature may be 90°C, the maximum cable sheath temperature 70°C. Under specific circumstances a temperature rise of up to 30K directly at the cable is possible while an average temperature rise of 5–15 K cannot be excluded. The corresponding heat gradient then extends over several metres (OSPAR 2008a; BFS 2005).

There is evidence that various marine organisms react sensitively to an even minor increase in the ambient temperature. Nevertheless, field studies on heat related impacts of operational submarine cables appear to be completely lacking. Only one measurement of the temperature increase of the sediment near the cable of the Danish offshore wind farm "Nysted" has been published so far (MEIßNER *et al*. 2007). First laboratory experiments revealed that the polychaete worm *Marenzelleria viridis* shows the tendency to avoid areas of increased sediment temperature whereas the crustacean *Corophium volutator* does not (BORRMANN 2006).

Due to the lack of field data, the effects of artificially increased temperature on benthos are at present difficult to assess. There is the potential that a long-lasting increase of the seabed temperature may lead to changes in physiology, reproduction or mortality of certain benthic species and possibly to subsequent alteration of benthic communities due to emigration or immigration. The temperature increase of the upper layer of the seabed inhabited by the majority of benthos depends, amongst other factors, on the burial depth of the cable.

Other than direct effects on the marine biota, temperature rise of the sediment due to heat emission from the cable may also alter the physico-chemical conditions in the sediment and increase bacterial activity (MEISSNER & SORDYL 2006). Processes set off in deeper sediment layers are likely to finally affect the entire seabed above the cable due to contact with pore water. Alteration of sediment chemistry might possibly exert secondary impacts on the benthic fauna and flora. It should be noted that the content of organic matter in the sediments determines these processes and their ecological relevance. There is still need of further field investigations to assess possible effects of heat dissipation.

3.5 Electromagnetic fields generated by power cables

Electromagnetic fields are generated by operational power cables. Electric fields increase in strength as voltage increases and may be as strong as 1000 µV per m (GILL & TAYLOR 2001). In addition, induced electric fields are generated by the interaction between the magnetic field around a submarine cable and the ambient saltwater (GILL et al. 2005). Magnetic fields are generated by the flow of current and increase in strength as current increases. The strength may reach the multiple of the natural terrestrial magnetic field.

Magnetic fields generated by cables may impair the orientation of fish and marine mammals and affect migratory behaviour. Field studies on fish provided first evidence that operating cables change migration and behaviour of marine animals (KLAUSTRUP 2006, GILL et al. 2009). Marine fish use the earth's magnetic field and field anomalies for orientation especially when migrating (FRICKE 2000). Elasmobranch fish can detect magnetic fields which are weak compared to the earth's magnetic field (POLÉO et al. 2001; GILL et al. 2005).

Marine teleost (bony) fish show physiological reactions to electric fields at minimum field strengths of 7 $mV*m^{-1}$ and behavioural responses at 0.5-7.5 $V*m^{-1}$ (POLÉO et al. 2001). Elasmobranchs (sharks and rays) are more than ten-thousand fold as electrosensitive as the most sensitive teleosts. GILL & TAYLOR (2001) showed that the dogfish *Scyliorhinus canicula* avoided electric fields at 10 $\mu V\ cm^{-1}$ which were the maximum expected to be emitted from 3-core undersea 150kV, 600A AC cables.

3.6 Contamination

Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment (see disturbance) or because of damage to cables with subsequent release of insulation fluids. Contamination may also occur due to accidents and technical faults during construction.

3.7 Cumulative effects

Cumulative effects, the combined effect of more than one activity, may reinforce the impacts of a single activity due to temporal and/or spatial overlaps. At present, there are no sufficient data available to address any cumulative effects.

4. Best environmental practice

Best environmental practice (BEP) is defined as *"the application of the most appropriate combination of environmental control measures and strategies"* (OSPAR Convention, Appendix 1). Measures that represent best environmental practice should be adopted during all phases of project planning. Such measures could be used in conjunction with mitigation measures to minimise the magnitude and significance of effects to the local environment (BERR 2008).

Following BERR (2008) and SCHUCHARDT et al. (2006) best environmental practice contains at least the following measures:

- Sound data base and monitoring

- Reducing environmental impacts and risks (by applying Best Available Techniques and mitigation measures)
- Implementation of ecological compensation measures
- Increasing ecological awareness

Sound data base and monitoring

An environmental impact assessment (EIA)[1] should address both the route selection process and further planning steps and should be elaborated on the basis of sound data. However, data should be appropriate for the respective question since a number of possible environmental impacts can be reduced or even avoided by examining alternative routes or installation methods and subsequently fine tuning the selected route.

Monitoring of possible impacts identified in the environmental impact assessment should be carried out especially if there is a forecasting uncertainty regarding certain impacts (e.g. effects resulting from magnetic fields, heat dissipation) or if sensitive areas, identified in the EIA, are affected (e.g. in connection with NATURA 2000 regions).

Reducing environmental impacts and risks

Best Available Techniques: As defined in Appendix 1 of the OSPAR Convention best available techniques (BAT) "means the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste. [...]"The section on BAT in Appendix 1 of the Convention also specifies: *"Techniques" include both the technology used and the way in which the installation is designed, built, maintained, operated and dismantled."*

Best Available Techniques (BAT) should generally be applied and projects should document their specific choice of BAT.

Since the use of BAT represents a key measure for avoiding environmental impacts, these measures will be described in separate subsections of section 5.

Mitigation measures: see section 5.

Implementation of ecological compensation measures

Where a potential adverse effect is identified and no suitable mitigation measures are available, compensation by means of nature conservation and landscape management measures should be considered. The scale and scope of such compensation measures will be dependent on the site-specific requirements and proportionate to the scale of impact as identified by the environmental impact assessment (see OSPAR 2008b).

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1 Even though cables are not covered by the EIA Directive, it is recommended that the Contracting Party responsible should assess the environmental impacts of newly planned submarine cables, especially power cables within the OSPAR maritime area through the EIA process (OSPAR 2009).

Increasing ecological awareness

The mitigation of adverse environmental impacts should be a major goal of project management in all project phases. To achieve this, it is necessary to set up an appropriate management structure and a system should be established within the organisation of each project as well as in all companies involved in a project with the aim of supporting ecological awareness at all levels by means of suitable training programmes and at the same time ensuring compliance with environmental standards through checks.

5. Mitigation measures

5.1 Introduction

As already described in section 4, application of best environmental practice (BEP) is a requirement for effective avoidance and minimization of environmental impacts by means of mitigation measures.

Mitigation may be defined as 'measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects' (European EIA Directive 85/337/EEC). Article 5 (3) requires that Environmental Impact Statements (EISs) include details of proposed mitigation measures. Mitigation should occur as an iterative part of the EIA process, developing and refining measures to address the significant impacts identified during the other stages of EIA (GLASSON et al. 1999). Therefore mitigation measures should be developed within the planning process. This requires early and close cooperation between technical and environmental experts.

Since there is sufficient evidence that the placement and operation of submarine cables may affect the marine environment, the precautionary principle should be applied and appropriate mitigation measures should be taken (OSPAR 2009). In this context any possible impacts should be avoided, reduced or mitigated as far as possible. Impacts that cannot be avoided, reduced or mitigated should be compensated for by means of suitable measures (section 4). Available measures to minimise or even avoid most of the anticipated environmental impacts are shown in the following table:

Table 1: Possible mitigation measures to minimise or avoid environmental impacts of various anthropogenic pressures due to cable laying and operation

	Mitigation Measures					
Environmental impacts	Route selection	Construction times	Burial technique	Burial depth	Cable type	Removal
Disturbance	x	x	x	(x)	(x)	see text
Noise	(x)	(x)	(x)			
Heat emission	(x)			x	x	
Electromagnetic fields				x	x	
Contamination	x		(x)	(x)	x	x
Cumulative effects*	x	x	x	x	x	
x: important measure; (x) less important measure; * knowledge insufficient						

5.2 Mitigating impacts of the placement of cables

5.2.1 Disturbance

Following BERR (2008) the main planning steps where mitigation measures can be applied to reduce sediment disturbance are the selection of the cable route and the cable burial method. The former serves the purpose of avoiding e.g. sensitive habitats, the latter is aimed at reducing impairments occurring during the real cable laying.

Route selection

Selecting the route (including landfall) with the lowest environmental impact and highest resource efficiency by comparing different alternative routes on the basis of sound and comparable data (avoiding sensitive areas, etc) is one of the most important steps towards realising best environmental practice of a cable project. Route selection should be carried out within a formal approval procedure (or several if necessary) with integrated environmental impact assessment EIA.

When selecting a route corridor, it is necessary to give consideration to engineering issues as well as environmental concerns, such as existing protected areas and other ecologically important and sensitive areas, and other uses, such as existing cables, offshore wind farms, shipping, dumping sites, natural resources (e. g. sand and gravel extraction sites) and fishery. While taking these aspects into account, the route corridor selected should meet in the most optimal way possible the following conditions in order to minimise or avoid environmental impacts:

- protected areas, environmentally sensitive and/or valuable areas with e.g. habitats and species sensitive to physical disturbance or damage where the cable laying activity or operation would result in adverse effects should be avoided;

- shortest possible length;

- bundling with existing cables and pipelines, where it is safe to do so;

- minimal number of crossings with other cables or pipelines to reduce the number of crossing structures.

After a route corridor has been selected, an appropriate level of site investigation is essential to ensure that the optimum route and burial methods are selected for the cable (see section 4). After analyzing the site investigation data, additional mitigation measures may be necessary and should be considered (e.g. re-routing/micro-siting, see BERR 2008).

Baseline information on the distribution of protected and sensitive habitats and species within the construction area should be used also to plan the positioning of the anchor arrays for the cable-laying ship (BERR 2008). In this way, exclusion zones for anchoring should be established if necessary. (Disturbance due to anchors of the cable-laying ship can be further reduced by using tenders to lift the anchors rather than dragging them across the seabed.)

Burial technique / Burial depth

The burial technique and burial depth are closely related to each other. Two points play an important role in the selection of the burial technique and/or burial depth from an ecological point of view: 1. Reduction of sediment displacement and 2. Avoidance of sediment and morphology changes.

1. Reduction of sediment displacement: Where there are species that are sensitive to increases in suspended sediment occurring close to positions of cable burial, it is recommended that the technique that would result in the lowest release of sediment is utilized whenever this is possible (BERR 2008).

As far as the burial technique is concerned, installation via jetting by means of sledge or ROV or use of a plough involves the lowest environmental impacts. Jetting fluidises the seabed using high power jets, and material may suspend to the water column for prolonged periods (a number of hours), and have the capacity to be transported over longer distances, increasing the number of potential receptors. Ploughing usually entails lifting a wedge of seabed and the seabed backfills over the laid cable. The level of sediment disturbance is, therefore, lower using ploughing compared to jetting techniques. The cable can be laid and buried in one or two separate working steps to achieve the required burial depth. Burying the cable in one step may further minimize the environmental impacts. Another option is to dredge a trench in which the cable is laid and which is subsequently refilled. However, the latter burial method leads to significantly greater sediment displacement.

Horizontal directional drilling may be an appropriate form of mitigation to avoid damage, particularly in the intertidal and landfall areas where habitats may be more sensitive (e.g. chalk cliffs, saltmarsh, etc.; BERR 2008). This method has been proposed for the German "Norderney-Corridor" again because of the presence of saltmarsh habitat and the existing dike (PGU 2006). In tidal flats where large laying vessels cannot operate, laying barges and (self propulsion) vibration ploughs may be used for a "post lay burial". *E. g.,* for the "Norderney-Corridor" the cable laying took place during high tide and the subsequent burial was done at low tides with the barge lying on belly serving as "holding point" for the trenching plough.

2. Avoidance of sediment and morphology changes: Morphological changes of the sediment may under certain circumstances occur when cables are laid in soft substrates. Whenever possible, cable should be buried, also to reduce the impacts of heat dissipation and magnetic fields (see below). At the same time the burial techniques applied should resuspend as little sediment as possible so that the trench closes naturally shortly after burial. Otherwise the trench should be backfilled with on-site or comparable material.

In areas with natural hard substrates and at greater water depths, it is often not possible to bury cables. Because the surface structure is changed to a considerably lesser extent than in the case of soft substrates, however, burial is not absolutely necessary. Should, nevertheless, the cable be buried in a trench that does not naturally refill following cable burial, it is important that, when possible, techniques are used that ensure that no berm is left (BERR 2008). Backfilling the trench will ensure that species recovery occurs quicker and that no obstacles are left on the seabed surface.

If cable protection such as rock-mattress cover is required (e.g. in the case of crossings with other cables or pipelines), inert natural stone material should be used to minimise the degree of impact.

Where sensitive habitats (e.g. vegetated shingle, saltmarsh, etc.) are present along a cable route and horizontal directional drilling is not possible it may be necessary to remove vegetation prior to installation and replant/enhance following installation (BERR 2008).[2]

Construction times

Once the cable route and burial technique have been selected there are limited further measures that can be adopted to reduce sediment disturbance. The precise timing of the works (e.g. over a spring or neap tide) is crucial for tidal flats, where limited time windows and shallow waters require good synchronisation of laying and burial operations. In these cases burial should take place at low tide with e. g. vibration ploughs whenever possible. Further offshore the speed at which the burial proceeds may have some influence on the sediment disturbance.

Particularly near the coast, including landfall, it is necessary to specify times of the year during which work should not be carried out since many areas are at certain times of the year habitats of species that react sensitively to disturbances. These include resting grounds during bird migration, wintering and moulting areas of e.g. sea ducks, feeding and coastal breeding habitats, spawning grounds of fish and sandbanks where seals give birth to their young.

Visual and other construction related disturbance, in relation to hauling-out of seals, can be effectively mitigated by avoiding cable installation operations in the vicinity of known haul out sites during sensitive periods. Further offshore construction times should consider resting and wintering areas of ducks and seabirds as well as areas known for marine mammals, especially calving sites of harbour porpoise. The definition of time windows for cable laying can thus be a very effective measure for reducing environmental impact where necessary.

5.2.2 Underwater noise

There are no clear indications that underwater noise caused by the installation of sub-sea cables poses a high risk of harming marine fauna. There is a potential for disturbance of fish and marine mammals. However, knowledge gaps still exist (see section 7). The following mitigation measures should be considered and – where necessary - applied as a precaution in sensitive areas.

Route selection and Construction times

If the route selected is crossing areas especially relevant for species sensitive to underwater noise (e.g. harbour porpoise) appropriate scheduling of cable-laying activities to avoid feeding, spawning and/or nursery areas at sensitive times of the year will minimise the potential for noise-related impacts on these species (OSPAR 2008a, 2009, see also section 5.2.1).

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[2] Guidance is available relating to translocation and enhancement for saltmarsh habitat in the Environment Agency/Defra publication 'The Saltmarsh Management Manual' and the Chartered Institute of Water and Environmental Management (CIWEM)/Royal Society for the Protection of Birds (RSPB) document 'The saltmarsh creation handbook: a project managers guide to the creation of saltmarsh and intertidal mudflat' (see BERR 2008).

Information on *e.g.* spawning and/or nursery habitats should be available from published sources or previous surveys. If this is not available then a series of dedicated surveys should be commissioned (BERR 2008).

Burial technique

Burial techniques involving substantial noise generation should not be employed. In particular blasting in rocky subsoil should be avoided. Information on burial technique with the lowest noise emissions is currently not available (see knowledge gaps, section 7).

5.2.3 Contamination

Route selection

Contamination arising from seabed disturbance is only a risk in heavily contaminated locations. Again, avoidance of such areas would be an appropriate mitigation measure (OSPAR 2009). The application of burial techniques with minimized sediment resuspension in areas where sediment is found to have elevated levels of pollutants will minimise pollution risk (BERR 2008).

5.3 Mitigating impacts of operational cables

5.3.1 Heat emission

The reduction of generated heat is by far more important regarding power cables than telecommunications cables. Heat dissipation from fibre-optic cables is supposedly negligible even though modern cables are equipped with electrical power supplies (OSPAR 2008a, 2009). The focus should therefore be laid on heat emission from high and medium voltage power transmission cables. As power losses are higher for HVAC (high voltage AC) cables than for HVDC (high voltage DC) cables during cable operation, heat dissipation can be expected to be minor for DC cables than for AC cables at equal transmission rates.

Route selection

In general a bundled system of comparable capacities or a coherent marine transmission grid will reduce the number of individual power cables (e.g. linking different offshore wind farms together by using sub-sea cables with a high transmission capacity). In this way the overall space used as well as the total area affected by temperature increase and by other possible physical and chemical impacts will be reduced.

Burial depth

The cable-induced temperature increase of the upper layer of the seabed depends, amongst other factors, on the burial depth of the cable. To reduce temperature rise an appropriate burial depth should be applied. There is evidence that various marine organisms react sensitively to an even minor increase in the ambient temperature. On the basis of current knowledge, however, it is not yet possible to specify at what temperature increase in the sediment significant consequences can be expected for the marine environment (BFS 2005). In Germany, therefore, the Wadden Sea National Park Administrations of Lower Saxony and Schleswig-Holstein have defined the maximum permissible temperature rise in the Wadden Sea as 2 K at a depth of 30 cm below the seafloor (BFS 2005). For German offshore waters the respective Federal Agency for Nature Conservation agreed on a threshold of a maximum tolerable temperature increase of 2 K in 20 cm depth in the sediment. This value was originally established as a precautionary approach in order to protect bottom organisms from harm and benthic communities from change caused by anthropogenic temperature rise. The so called 2 K criterion can be met by an appropriate burial depth of power cables (OSPAR 2008a, BFS 2005). In general an appropriate trenching depth of 1-3 m can limit the rise in sediment surface temperature to prevent macrozoobenthic fauna from harm and benthic communities and processes from changes.

In addition to ecological aspects and technical options regarding cable laying, it is necessary to take into account the thermal properties of the sediment, the type of cable and the transmission capacity when defining the burial depth.

In German waters cable burial depths are proposed to be not less than 1 m in the EEZ and at least 3 m in areas with heavy ship traffic (e.g. shipping channels). Within offshore wind farms, cable burial depth is at least 0.6 m. In tidal channels of the Wadden Sea cables are buried at least 2 m below the seabed. In North America and Southeast Asia typical burial depths for all sorts of cable are between 0.9 and 3.5 m (see OSPAR 2008a). Other sources report about preferred burial depths of 0.6 to 0.9 m in many coastal areas of the U.K. (OSPAR 2008a).

Cable Type

To reduce the environmental impact of thermal radiation, suitable mitigation measures on the choice of cable type can include the use of HVDC transmission systems instead of AC-cables for interconnectors and wind farm-connectors. In addition, the use of a bipolar transmission system instead of two separate monopolar cables will lead to a reduction of the heated area.

5.3.2 Electromagnetic fields

Electromagnetic fields are generated by operational power cables. This effect is much more relevant to power transmission cables than to telecommunications cables, even though modern fibre-optic cables are equipped with electrical power supplies (OSPAR 2009). Although there are specific studies according to which coaxial telecommunication cables also induce electric current in the surrounding area, such current is very low. These aspects are therefore not examined in further detail here.

Cable type

Directly generated electric fields are regarded to be controllable by adequate shielding, e.g. steel plates, sheaths within the cable insulating the conductor etc. However, an induced electric field generated by the magnetic field may occur. In case of high current flows during power transmission the electric fields near the cable significantly exceed values typical under natural conditions.

Occurrence of magnetic fields associated with power transmission is best limited by field compensation to be achieved by using appropriate conductor / cable placement patterns and/or configuration geometry. When using two separate single-conductor cables for a DC transmission, they should be buried in the seabed parallel to and at the shortest distance possible from each other (‘close lying’), so that the magnetic fields would neutralise each other as far as possible. In a two-conductor cable this neutralisation reaches ideally 100 % when using a coaxial-design and no electric field will be induced and should therefore be considered and where suitable applied as avoidance measures.

In case of AC transmission systems the magnetic field is best limited by using three conductor-cables leading to an almost complete field neutralisation at the surface of the cable, since the sum of the voltages and currents of the three phases is zero at any one time. If three single conductor cables are used, again they have to be installed as close as possible and parallel to each other to achieve sufficient field compensation. Nevertheless, due to the phased character of the magnetic field, an electric field will be induced in surrounding conductive materials such as salt water.

Burial depth

Because the strength of both magnetic and (induced) electric fields declines as a function of the distance from the cable, an additional reduction of the exposure of marine species to electromagnetic fields can be achieved by cable burial. The sediment does not have any screening effect, but burial of the cables reduces the exposure of sensitive species to electromagnetic fields by increasing the distance of the animals to the cable.

5.3.3 Contamination

Cable Type

Release of contaminants into the environment from the cable itself can only occur if cables are not removed after decommissioning or if operational cables are damaged, in particular if fluid-filled cables are damaged. Removal of the cable at the end of the operating period and use of cables without fluid components would therefore represent suitable avoidance measures.

Removal

Cables that use oil as an insulating medium may release oil in the event of damage or due to ageing. To avoid this release, the cables can be removed after decommissioning. Removal after decommissioning should be stipulated in the approval, as has already been implemented for cables in the German exclusive economic zone (EEZ) and the territorial waters. However, cable removal involves additional environmental impacts that roughly correspond to those during construction. Removal may not take place, or should be restricted, if it generates greater adverse environmental impacts than would be the case if the cable were left in the seafloor.

5.4 Cumulative effects

Generally all mitigation measures applied for individual cables also contribute to reduction of cumulative impacts. They will thus not be repeated here. Above and beyond the measures for individual cables, coordinated route selection and the coordination of the construction times are suitable measures to reduce cumulative impacts.

Strategic planning and route selection

In general a bundled system of comparable capacities or a coherent marine transmission grid will reduce the number of individual power cables (e.g. linking different offshore wind farms together by using sub-sea cables with a high transmission capacity). As a result, cumulative impacts are reduced (SCHREIBER et al. 2004). Overlapping of electromagnetic fields is already avoided by virtue of the necessary safe distances between the cables.

Construction times

By coordinating construction times, it is possible to avoid reinforcement of impairments due to the burial of several cables either simultaneously or immediately after each other.

Other measures

Avoidance of impacts in specific projects will also mitigate or entirely eliminate possible cumulative impacts. This applies to the burial technique, the burial depth as well as the type of cable.

6. Environmental Impact Assessment EIA

In general the installation and operation of submarine cables should follow a formal approval procedure that includes the elaboration of an environmental impact assessment EIA. *Inter alia*, the EIA should provide sufficient information about the technical design of the project as well as the occurrence of species and habitats within possible cable corridors. The environmental impacts expected and the choice of suitable mitigation measures should be based on this information.

6.1 Data Base

As a minimum, the following data should be available for the EIA as well as for the selection of appropriate mitigation measures:

- sediment and habitat structure;
- benthic communities;
- habitat structure relevant for fish fauna;
- occurrence of breeding and resting birds in the landfall areas;
- occurrence of marine birds and mammals in coastal areas as well as offshore;
- occurrence of hazardous waste (e.g. munitions) and cultural heritage sites;
- other activities e.g. dumping at sea, aggregate extraction, fishing, archaeological features – wrecks.

This can essentially be based on existing data but collection of new field data will be necessary in many cases.

6.2 Monitoring and assessment phase

Monitoring to evaluate the predicted environmental impacts of the construction and operation of a cable should be carried out especially if the pressure-impact relationship is not known sufficiently.

For example, there is still need of further investigation and research regarding various aspects for a comprehensive evaluation of the impacts of cables, for further developing "best available techniques", for derivation of new mitigation measures and the evaluation of their effectiveness. This includes (without any claim to completeness):

- distribution and effects of temperature rise due to heat dissipation;
- distribution and effects of electromagnetic fields;
- distribution and effects of noise during installation.

6.3 Access to Data

If possible and not infringing the confidentiality of commercial information, environmental data regarding individual marine regions and collected in connection with the cable project as well as the respective monitoring reports should be made publicly accessible.

As already proposed in section 4, the data collected in connection with the project should be fed into a database which is accessible to the public as far as possible and in which all data relevant to the environment for individual marine regions are compiled and updated.

7. Knowledge gaps

Gaps in knowledge essentially exist in four areas:

- The impacts of the **temperature increase** of the sediment on benthic species and communities are known only to a basic degree at present. Relevant field studies are almost completely lacking.

- Considerable forecast uncertainty still exists with regard to the impacts of weak **electromagnetic fields** on fish and marine mammals. Studies on this topic are rare and resulted in contradictory results in some cases. For this reason, extensive investigations are still necessary. Apart from field studies it appears expedient to conduct experimental investigations. Experimental mesocosm studies (GILL et al. 2009) are an example of this. Laboratory tests may also furnish important supplementary information.

- Gaps in knowledge also exist with respect to the **regeneration** period and regeneration capacity of sensitive habitats like *Posidonia* meadows, mudflats and reefs.

- Further study is required to assess the **noise levels** produced by the range of available cable burial devices and tools in the various types of seabed sediments encountered in the OSPAR region. This can be achieved through real time monitoring during cable installation.

The gaps in knowledge mentioned can be closed only in part by means of customary monitoring of individual projects. In some areas further basic research is necessary.

8. Conclusion

Since there is sufficient evidence that the placement and operation of submarine cables may affect the marine environment, the precautionary principle should be applied. Appropriate mitigation measures are available and should be taken:

- Choice of appropriate cable routes to reduce or avoid impairment of protected or sensitive areas (e.g. areas of sensitive species and habitats, areas with contaminated sediments);

- Selection of suitable conductor / cable placement patterns and/or configuration geometry (cable type) to limit the emission of electromagnetic fields;

- Burial of the cables to an adequate depth in order to reduce the cable induced temperature rise of the upper layer of the sea bottom and to avoid impairment of marine species by electromagnetic fields;

- Selection of suitable burial techniques to minimise disturbance effects of benthic species and habitats and the release of contaminants;

- Scheduling of the cable laying to reduce disturbances in sensitive areas (*e. g.* feeding, resting, moulting, spawning or nursery areas) at sensitive phases of the year (*e. g.* moulting times of seals, breeding times of harbour porpoises as well as resting, moulting and wintering times of ducks and seabirds).

Cable laying and operation therefore requires a comprehensive and sound planning phase and approval procedure taking account of the mitigation measures presented in this Guidance document.

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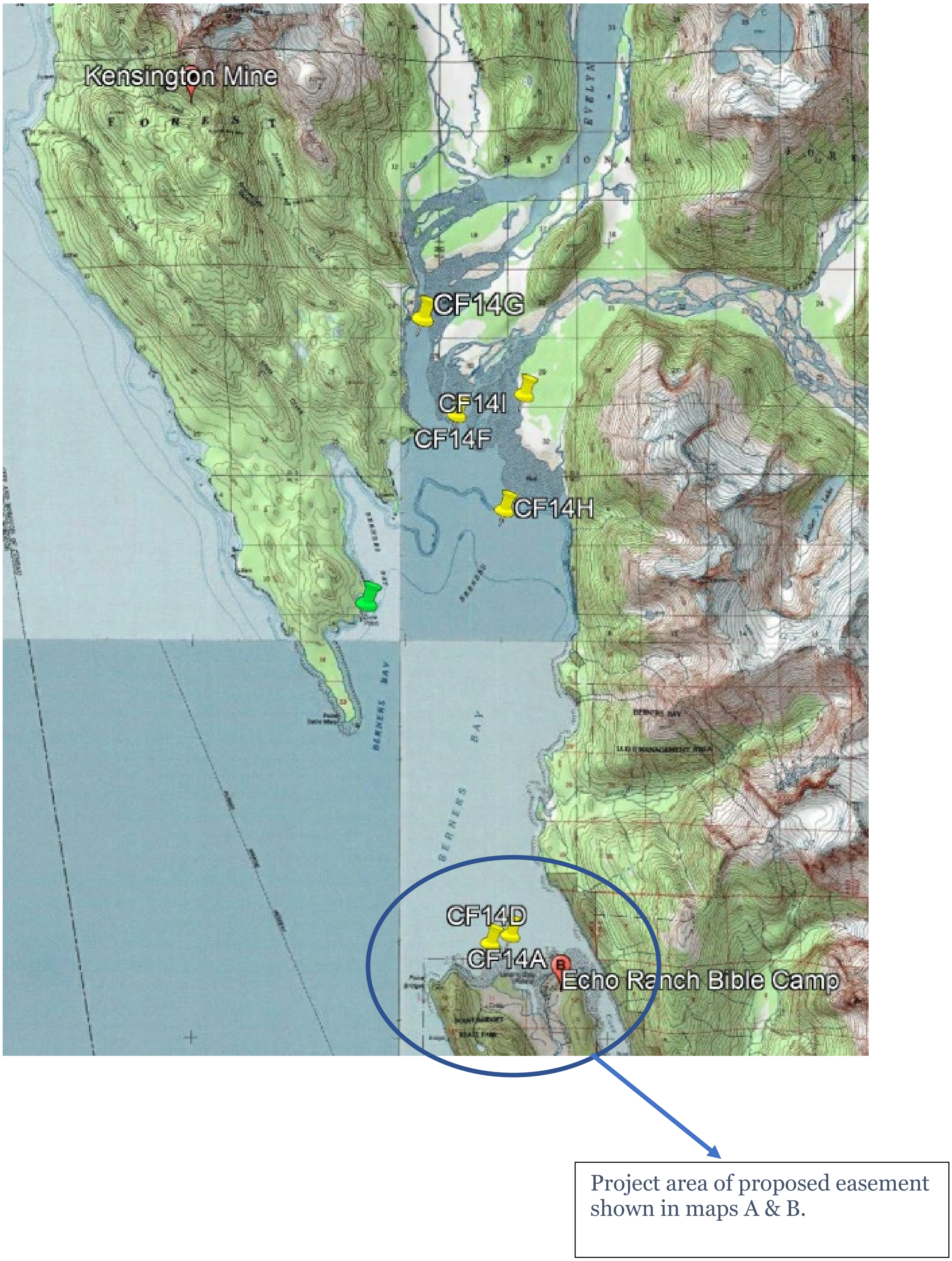
Overview map Berners Bay, Kensington Mine, Echo Ranch Bible Camp, pinniped haulouts

Green placemark=Steller sea lion haulout
Yellow placemarks=Key harbor seal haulouts



Renewable and Sustainable Energy Reviews 96 (2018) 380–391

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions

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ARTICLE INFO

Keywords:
Submarine power cables
Marine renewable energy
Environmental impacts
Ecosystem functioning
Benthic habitats

ABSTRACT

Submarine power cables (SPC) have been in use since the mid-19th century, but environmental concerns about them are much more recent. With the development of marine renewable energy technologies, it is vital to understand their potential impacts. The commissioning of SPC may temporarily or permanently impact the marine environment through habitat damage or loss, noise, chemical pollution, heat and electromagnetic field emissions, risk of entanglement, introduction of artificial substrates, and the creation of reserve effects. While growing numbers of scientific publications focus on impacts of the marine energy harnessing devices, data on impacts of associated power connections such as SPC are scarce and knowledge gaps persist. The present study (1) examines the different categories of potential ecological effects of SPC during installation, operation and decommissioning phases and hierarchizes these types of interactions according to their ecological relevance and existing scientific knowledge, (2) identifies the main knowledge gaps and needs for research, and (3) sets recommendations for better monitoring and mitigation of the most significant impacts. Overall, ecological impacts associated with SPC can be considered weak or moderate, although many uncertainties remain, particularly concerning electromagnetic effects.

1. Introduction

In 1811, a powered cable was laid down across the Isar River in Germany. This is considered to be the first underwater power cable in the world. More than a century later, the first commercial High Voltage Direct Current (HVDC) cable, installed in 1954 in the Baltic Sea, linking Sweden and Gotland Island. Since then, submarine power cables (SPC), using direct current (DC) or alternating current (AC), have continued to spread across the globe. Technologies have improved with respect to materials, cable length and width, and installation techniques. Applications of SPC are numerous: they can be used to connect autonomous grids, to supply power to islands, marine platforms or subsea observatories, and to convey power generated by marine renewable energy (MRE) installations to electrical sub-stations. While most SPC are on top of or buried within the seafloor, some (known as dynamic cables) are deployed through the water column between the surface and the seafloor. This last category of cables is used for offshore oil platforms and, recently, to export energy produced by floating MRE devices (like wind turbines), a technology still under development. In 2015, almost 8000 km of HVDC were present on the seabed worldwide, 70% of which were in European waters. In comparison, the total length of all submarine cables deployed (including AC and DC power cables and telecommunication cables) is of the order of 10^6 km [1].

SPC, like any other man-made installation or human activity at sea, may cause disturbances to marine life and habitats. When talking about anthropogenic disturbances, it is important to distinguish 'effects' from 'impacts'. According to the framework proposed by Boehlert and Gill [2], effects are modifications of environmental parameters (or

Abbreviations: HVDC, High-Voltage Direct Current; SPC, Submarine Power Cable; DC, Direct Current; AC, Alternating Current; MRE, Marine Renewable Energy; SPL, Sound Pressure Level; HVAC, High Voltage Alternating Current; EMF, Electromagnetic Field

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https://doi.org/10.1016/j.rser.2018.07.026
Received in revised form 3 July 2018; Accepted 13 July 2018
Available online 17 August 2018

"stressors"), such as the substrate type, hydrodynamics, water temperature, noise, or electromagnetic fields beyond the range of natural variability. Impacts correspond to changes observed at "receptor" level, *i.e.*, the different ecosystem compartments (biotopes, biocenosis), or levels (community, populations) or some ecological processes within marine ecosystems (trophic interactions). Impacts may be positive or negative, although this distinction remains subjective.

Scientific interest in interactions between marine life and submarine cables started with the first records of cable damage caused by whale entanglements (16 events between 1877 and 1955; [3]) or by fish and shark bites (at least 39 events from 1907 to 2006; [4]). Although such events have decreased significantly with technological improvements (cable burial and advances in design or protection; [5]), ecological concerns remain. Nowadays, ecological issues refer not only to direct physical interactions between large animals and cables but also to less obvious impacts of cables on marine communities and habitats.

Numbers of SPC will increase drastically in coming decades with increasing grid connections of islands and archipelagos and the development of MRE projects (offshore wind farms, tidal and wave turbines). Several inter-governmental organisations have set objectives for the next decades. For example, in 2014, the European Council set 27% as a target for the minimum proportion of total electricity consumption produced by renewable energies in the EU by 2030 (EUCO 169/14). In 2008, the global electric energy supply produced by all grid-connected renewable energy installations taken together was estimated at 12.9%, and several predictions estimate an increase to 17% by 2030 and 27% by 2050 [6].

Despite more than 10 years of scientific work on potential environmental impacts of MRE projects [7,8], SPC have received much less attention than MRE devices themselves. Indeed, only nine published papers focusing on *in situ* effects or impacts of SPC were found during the literature research. These studies addressed the impacts of SPC on benthic communities, considering both installation or operation phases [9–13], examined communities colonising unburied structures [12,14], and/or reported species-specific changes of behaviour [15–17]. Considering the current exponential increase in SPC worldwide, a robust and accurate assessment of their potential environmental impacts has become a priority.

In this context, the aims of the present study are (1) to review the existing knowledge concerning potential ecological impacts from SPC during installation, operation and decommissioning phases, (2) to attempt to hierarchize these impacts according to their significance and (3) to point out knowledge gaps and recommendations for monitoring and mitigation of these impacts.

2. Methods

A literature search was conducted using online databases and internet search tools (Web of Science, Science Direct, Google Scholar, ResearchGate) to create a bibliographic database including peer-reviewed scientific publications, books, theses and non-peer-reviewed consultancy and technical reports. Owing to a general lack of published studies, a large proportion of current knowledge comes from industrial or governmental reports and environmental impact assessments that may have associated confidentiality issues. The literature search first focused on publications about SPC generalities and their global environmental impacts before targeting specific literature for each of the different identified impacts. Documents focussing on anthropogenic disturbances other than SPC, but potentially inducing comparable impacts (*e.g.*, artificial reefs or sediment reworking for example) were also considered. Based on the main conclusions of the reviewed literature, the relative importance of the different potential impacts and the associated scientific uncertainty was compiled.

3. Features of submarine power cables

3.1. Technical characteristics

SPC are specifically designed to relay electric currents either as Alternating Current (AC) or Direct Current (DC), the transmission type being determined by the capacity and length of the transmission line, as well as commercial issues. For example, a DC line can transmit more power than an AC line of the same size, but is more expensive. AC transmission presents some limitations since the reactive power flow due to the large cable capacitance causes power loss, which then limits the maximum transmission distance (< 100 km). DC is therefore the only viable technical option for long distance cable links. AC is more frequently used within grids of marine renewable energy devices [8]. Cables in use today include monopolar, bipolar and three-phase systems. SPC diameters are between 5 and 30 cm and weigh between 15 and 120 kg m^{-1} (including stabilisation devices such as articulated steel shell). Different methods exist to insulate electric cables in order to contain the emitted electric fields. Specific designs have been addressed for dynamic cables, with specific armouring layers and internal components. Indeed, their high position in the water column makes them more susceptible to fatiguing pressure and twist caused by hydrodynamics (particularly swell). Table 1 describes most types of recently installed SPC.

3.2. Cable installation

Before any deployment, the cable route must be chosen, depending on the bathymetry, seabed characteristics and economic activities of an area. The route must first be prepared, sometimes with adjustment of the slope and depth, or removal of obstacles before the passage of the cable-laying device. An example of an established method is the pre-lay grapnel run, consisting of dragging a hooking device at low speed along the planned route to remove any material, such as abandoned ropes or fishing nets.

Cable deployment is a complex process requiring highly specialised equipment. Cables are usually buried within the seafloor by different techniques including trenching with a cutting wheel in rocky sediments and ploughing or water jetting in soft sediments (Fig. 1; [18]). Ploughing generally allows trenching, laying the cable and burying it with the extracted sediment in a single operation. Special backfill materials for burial can be required when burial is technically complicated. In the case of hard or deep bottoms, the cable can simply be laid on the seafloor and stabilised with suitable cover. The duration of the cable installation process determines the magnitude of some environmental effects, such as increased turbidity or anthropogenic noise. The duration of installation can be highly variable according to methods and seafloor characteristics, as cable laying is much more difficult for a route with obstacles such as boulders, rocks or outcrops, compared with a featureless seafloor [18]. The rate of cable-laying may vary from 0.13–0.21 km h^{-1} for a cable buried using water jetting to 1.85 km h^{-1} for a cable that is simply laid down [19]. For cable burial in the upper

Table 1
Description of five generic submarine power cable types (Photos: 1 = General Cable; 2, 3, 4 = Ningbo Orient Wires and Cables Co. Ltd; 5 = ABB Sweden), XLPE: Cross-Linked Polyethylene; EPR: Ethylene Propylene Rubber (reproduced from [17]).

					
Type	1	2	3	4	5
Rated voltage	33 kV AC	150 kV AC	420 kV AC	320 kV DC	450 kV DC
Insulation	XLPE, EPR	XLPE	Oil/paper or XLPE	Extruded	Mass-impregnated
Typical application	Supplying small islands, connection of offshore wind turbines	Connecting islands with large populations, offshore wind parks export cables	Crossing rivers/straights with large transmission capacity	Long distance connections of offshore platforms or wind farms	Long distance connection of autonomous power grids
Maximum length	20—30 km	70—150 km	<50 km	>500 km	>500 km
Typical rating	30 MW	180 MW	700 MW/three cables	1000 MW/cable pair	600 MW/cable

intertidal zone, the trench is often dug with more common devices such as mechanical excavators, and directional drilling is sometimes employed.

3.3. Cable protection

Depending on anthropogenic and natural perturbations in the route area, the cables may need to be protected from damage caused by fishing gear or anchors [19], strong hydrodynamic forces or storms. When trenching is not possible, other methods exist for unburied cables, such as rock-mattress covering, cable anchoring, ducting, cast-iron shells, concrete slabs, steel plates or dumped rocks [19]. On uneven seafloors, the cable may form "free spans" along its route where it will hang without touching the seafloor. This may promote vibration, chafing, fatigue and, ultimately, cable failure [18]. One solution is to fill the empty space between the cable and the seafloor with rock dumping or concrete bags. As an example of protection methods employed, the cable connecting the French tidal turbine test site of Paimpol-Bréhat to the land was installed on a highly hydrodynamic and hard seafloor (rock and pebbles). The cable is unburied over a large portion of its route but is protected with cast-iron shells and concrete mattresses (Fig. 2); the free spans are filled with concrete bags. In addition to these different protection methods, authorities typically create a protected area encompassing the cable route, with prohibition of other human activities (fishing, anchoring, dredging, *etc.)* in order to protect the cable from damage.

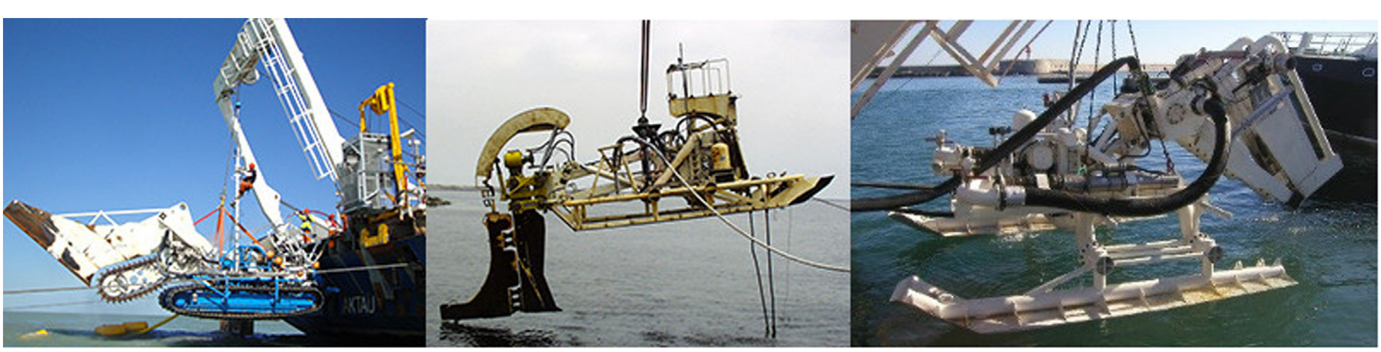

Fig. 1. Wheel cutter (left); Plough (centre) and Towed Jetting Vehicle (right) (courtesy: www.ldtravocean.com).

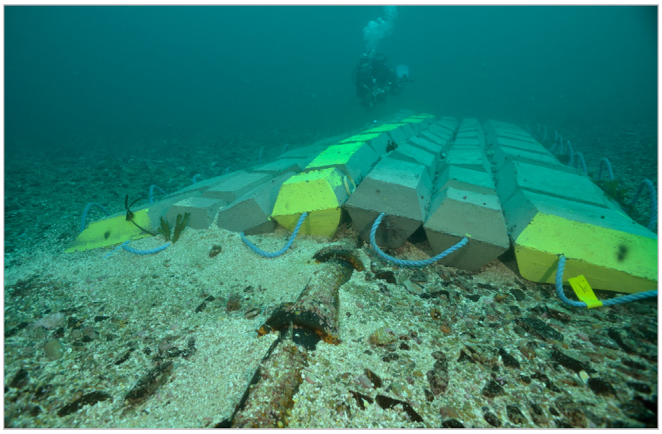

Fig. 2. Photograph of iron shells and concrete mattresses used to protect an unburied cable at the Paimpol-Bréhat tidal turbine test site, France (courtesy: Olivier Dugornay – IFREMER).

4. Environmental effects and impacts

Potential environmental effects associated with SPC are summarised in Fig. 3. During installation, maintenance and decommissioning phases, these effects may include physical habitat disturbances, sediment resuspension, chemical pollution and underwater noise emission. More long-term effects may occur during the operational phase, with changes in electromagnetic fields, heat emission, risk of entanglement, chemical pollution, and creation of artificial reef and reserve effects.

4.1. Habitat reworking

4.1.1. Physical changes

Substratum alterations are mainly created by equipment used for cable route preparation (grapnels such as in the aforementioned Pre-Lay Grapnel Run) and installation of the cable (ploughing, jetting and cutting-wheels). The surface area of disturbance can be enlarged when installation techniques require large ships with several anchoring stabilizers [18].

These methods of reworking the seabed may lead to direct destruction of benthic habitats, flora and fauna. However, such effects are usually restricted to a limited area, the width and intensity of disturbance, depending on the installation method. For example, the footprint of a trenching plough may vary from 2 to 8 m depending on device size [5]. According to Vize et al. [20], ploughing methods seem to cause less seabed disturbance than other methods. These disturbances are usually limited in time, as installation works only require a few hours or days per km of cable [21]. Ploughing and jetting methods favour a quicker recovery of bottom topography, as the trench is filled with displaced and re-suspended material immediately after digging and cable laying. In intertidal areas, physical impacts on the substrate usually occur over a larger surface area, of the order of tens of metres, due to the utilisation of vehicles such as mechanical excavators (Fig. 4). Alternatively, underground horizontal directional drilling (10 m below the sediment surface) may be used in intertidal areas up to distances of 700–1000 m, and occasionally up to 1800 m [18]. This installation technique only disturbs the substrate and biota locally over a few m^2 at the land and sea entrance points.

Unburied cables may also cause habitat loss, but to a lesser extent than buried cables. Disturbance is limited to the cable width itself, or to the dimensions of the materials used to stabilise and protect [22]. In shallow areas, some sections of unstabilised, unburied cables may act as dragging elements that disturb the sediments due to their strumming movement induced by the swell during the operation phase [23]. Wave action may shift the cable, and direct interaction with the hard seafloor can result in surface scraping and incisions in rock outcrops [13]. Maintenance (to a lesser extent) and/or decommissioning phases may generate similar effects to those of installation, but their magnitude will depend on the duration and scale (repairs *vs.* inspections) of the works.

With respect to other human activities at sea, physical disturbance to the seabed caused by cables is spatially limited. For example, the footprint of submarine cables in the UK coastal area is about 0.3 km^2, representing less than 0.01% of the coastal seabed [24], whilst in the Basque Country coastal zone (Northern Spain), the footprint of cables and pipelines is about 2.3 km^2, or 0.02% of the area between the coastline and the exclusive economic zone [25].

4.1.2. Biological changes

Substratum alterations may affect related benthic communities by direct impacts such as displacement, damage or crushing of organisms. Andrulewicz et al. [10] examined the environmental impact of the installation of a buried submarine power cable on soft bottoms of the Baltic Sea. They concluded that there were no significant changes in benthic diversity, abundance or biomass on the cable route or in its close proximity one year after the installation.

The magnitude and significance of biological changes depend on several factors linked to the sensitivity and resilience capability of the species or communities affected. Habitat or community resilience is characterised by the capacity to return to its initial ecological state after a perturbation (cabling in this case), and the duration of this response. The weaker the resilience is, the more sensitive the habitat or the community. Thus resilience depends on several factors, including: the nature and stability of the substratum [26–28], habitat depth [24,29] and life cycle of disturbed species (for example, seagrass meadows, which grow very slowly, may take several years to recolonise a disturbed area [30]).

The magnitude of biological changes is also dependent on the composition of the community itself, *i.e.*, the relative occurrence of benthic species (abundance and biomass) and assemblages (richness) along the cable route, compared with their occurrence at the regional scale. Due to the small spatial footprint of cabling, the overall impact on benthic communities is negligible if its spatial distribution is significantly homogeneous.

Benthic community resilience after commissioning of submarine cables remains poorly understood owing to the lack of long-term studies (*i.e.* occurring several years). Despite the relatively small spatial footprint affected by SPC operations, future studies should focus on the resilience of habitats and communities of particular ecological or economic interest (*e.g.* sea grass, maerl beds and nursery areas).

4.2. Sediment resuspension

Depending on the nature of the seafloor, sediment reworking by installation, maintenance or decommissioning can lead to turbid plumes that can reach several tens of hectares, with suspended particulate matter concentrations that can reach several dozen $mg\,l^{-1}$ [31]. Apart from sediment type, the extent and properties of plumes will depend on factors such as installation technique, hydrodynamic conditions and the scale of cable-laying. For instance, in the Nysted offshore wind farm (Denmark) where the substrate is dominated by medium sand sediment, cable installation in water depths between 6 and 9.5 m, generated mean particle concentrations of 14 $mg\,l^{-1}$ (up to 75 $mg\,l^{-1}$) at 200 m from the operation site during trenching with a backhoe dredger, and 2 $mg\,l^{-1}$ (up to 18 $mg\,l^{-1}$) during jetting (Seacon, 2005 in [20]). Turbidity can persist for several days depending on the duration of the whole cable-laying process. At the Nysted offshore wind farm, one month was necessary to excavate 17,000 m^3 of sediment for a 10.3-km long, 1.3-m wide and 1.3-m deep cable trench [32]. However, at any given location on a cable route, disturbance will typically persist from a few hours to a few days.

Decrease in water transparency and deposition of the resuspended material may limit light for primary producers and impact feeding

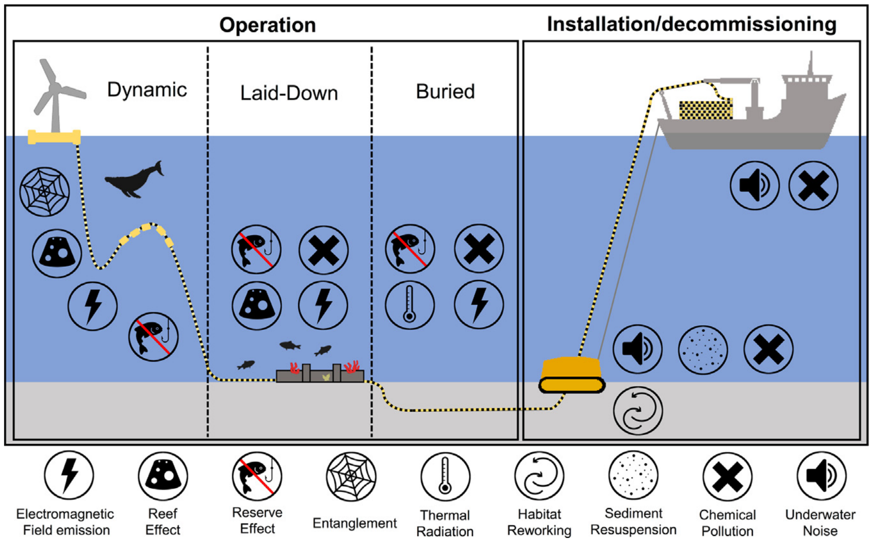

Fig. 3. Diagram of the potential impacts caused by different types of SPC immersion (Dynamic, Laid-Down and Buried) during their operation and installation/decommissioning phases.

Fig. 4. Installation works of the 2000 FLAG Atlantic 1 in the intertidal area, Brittany, France (courtesy: www.ldtravocean.fr).

ability of fish that detect their prey visually [33]. The efficiency of invertebrate filter-feeding could also be temporarily modified [34,35]. Resuspension/deposition processes through the plume may bury the eggs of bottom laying species. The presence of mineral particles in the water column may also lead to gill damage in young fish larvae [36,37]. For example, early survival of cod recruits (whose eggs are pelagic) may be affected by the sediment plume created by cable trenching [38].

Nevertheless, turbidity increases resulting from cable installation and decommissioning constitute localised and short-term effects. Although no study has focused on the impact of particle resuspension induced by cable installation and decommissioning on marine communities, it should generally have negligible impacts on marine ecosystems.

4.3. Chemical pollution

The main chemical risk is the potential release of sediment-buried pollutants (*e.g.*, heavy metals and hydrocarbons) during sediment resuspension caused by cable burial, decommissioning or repair works. The highest contaminant concentrations are generally located in coastal areas due to human activities. A preliminary analysis to assess the level of sediment toxicity should be performed in potentially polluted areas to select a cable route which avoids the remobilisation and dispersion of pollutants [39].

Pollution can also occur during the operation phase, especially for monopolar DC cables using sea electrodes for the return current path (which represent around 30% of HVDC in service use [40]). Indeed, the cathode and the anode of sea electrodes release toxic electrolysis products like chlorine and bromine which can impact the immediate water quality [10,40]. To a lesser extent, some older cables have hydrocarbon fluid insulation and may leak contaminants into the marine environment when damaged. The amount of fluid released will vary according to the time needed to detect and repair the leakage, its location and the extent of the damage, but in worst cases several tens of litres can be released per hour (Schreiber et al. 2004, in [41]). It should be noted that installation of oil-insulated cables ceased in the 1990s [42]. Furthermore, ships and hydraulic equipment pose a higher potential risk of accidental oil leakage during operations [23,43]. Cables also include copper, lead and other heavy metals that are potential sources of contamination. For example, a cable consisting of a 3.5-mm lead sheath contains 12 kg lead m^{-1} (Schreiber et al., 2004 in [41]). Heavy metals can potentially dissolve and spread into the sediment from damaged and abandoned cables, but the quantities released are considered insufficient to have significant impacts. Furthermore, such pollution is rare as cables are usually removed when no longer in operation. Although no studies focus specifically on SPC-related contaminants, this source of disturbance is considered to be rare, spatially localised and unlikely to have significant impacts on benthic communities.

4.4. Underwater noise

Anthropogenic noise can be produced during route clearance, trenching and backfilling, cable and cable protection introduction by the vessels and tools used during these operations. Intensity and propagation of underwater noise will vary according to bathymetry, seafloor characteristics (*e.g.*, sediment type and topography), vessels and machines used, and water column properties. *In-situ* data on such noise is scarce, and modelling approaches have been used to estimate the sound pressure levels (SPL) expected during installation. Nedwell and Howell [44] examined the noise produced by plough trenching in a sandy gravel area for the installation of an electric cable within a Welsh offshore wind farm. Results showed a maximal noise emission of 178 dB re 1μPa (on a frequency range from 0.7 to 50 kHz) at 1 m from the trenching area. A similar study by Bald et al. [45] focused on noises from trenching and cable installation of a wind-farm platform in a sandy area in the Bay of Biscay. During the installation phase, average sound level was 188.5 dB re 1 μPa (at 11 kHz) at 1 m from the source. Modelling using these *in situ* data estimated that the underwater noise would remain above 120 dB re 1μPa in an area of 400 km^2 around the source.

Another, albeit lesser, noise emission caused by submarine cables comes from vibrations during operation of several kinds of HVAC (High Voltage Alternating Current) cables because of the Coulomb force occurring between conductors [46]. For example, a 138 kV transmission cable situated in Canada emits a SPL, for the 120 Hz tonal vibration, of approximately 100 dB re 1 μPa at 1 m [47]. Compared to cable installation, such SPL is low, but continuous because it occurs during the whole operation phase.

There is no clear evidence that underwater noises emitted during cable installation affect marine mammals or any other marine animal, although it is accepted that many marine animals (notably mammals and fishes) detect and emit sounds for different purposes such as communication, orientation or feeding. Marine mammals have high frequency functional hearing ranges from 10 Hz to 200 kHz [48], while fish typically hear at much lower frequencies, often from 15 Hz to 1 kHz [49]. Other taxa, organisms including sea turtles [50,51] and many invertebrates such as decapods [52], cephalopods [53,54] or cnidarians [55] have also been shown to be sound-sensitive. Many studies highlight the reaction of cetaceans to anthropogenic sounds of different intensities [56,57]. Sounds generated by ship activity can impact the behaviour of different fish species [58,59]. Anthropogenic underwater noise can affect marine life in different ways, by inducing species to avoid areas, disrupting feeding, breeding or migratory behaviour, masking communication and even causing animal death [60]. So far, characterisation of acoustic thresholds causing temporary or permanent physical damage are much better described for marine mammals [61,62], than for fish [63], and remain unknown for marine invertebrates and sea turtles [64].

Compared with other anthropogenic sources of noise, such as sonar, piling or explosions, underwater noise linked to undersea cables remain low. Cable installation is a spatially localised temporary event, so the impact of noise on marine communities is expected to be minor and brief. HVAC cable vibration, although significantly lower than potential SPL during the installation phase, requires special attention though because its long-term impacts remain unknown.

4.5. Reef effect

Like other immersed objects (*e.g.* shipwrecks, oil/gas platforms, and MRE devices) unburied submarine cables and associated protection/stabilisation can create artificial reefs, inducing the so-called 'reef' effect [65]. Artificial reefs have been commonly used for centuries to enhance fisheries, and more recently for habitat rehabilitation or coastal protection [66]. These structures are colonised by hard-substrate benthic species including epifauna and mobile macrofauna, and may also attract mobile megafauna, such as decapods or fishes.

The extent of the reef effect depends on the size and nature of the cable protection structure, but also the characteristics of the surrounding area and native populations [65]. Such artificial structures are expected to have limited reef effects when located within a naturally hard substratum environment. For example, Sherwood et al. [14], looking at the effects of laying and operating the BassLink HVDC cable, found that, 3.5-years after the cable installation, the benthic sessile community present on the half-shell cover was similar to the surrounding basalt reef area (Fig. 5A). Similar investigations showed no significant differences between communities on powered cables and hard bottom control areas [9,12,67]. By contrast, on soft sediments, unburied cables generate a stronger reef effect and host a new community, as illustrated by the unburied sections of the ATOC/Pioneer cable (Half Moon Bay, California) colonised by actinarians [13]. In this case, sea anemones became more abundant on the cable than on the surrounding soft bottom 8 years after cable installation (Fig. 5B) and fish species were more abundant close to the cable, probably in response to increased habitat complexity compared with the surrounding environment.

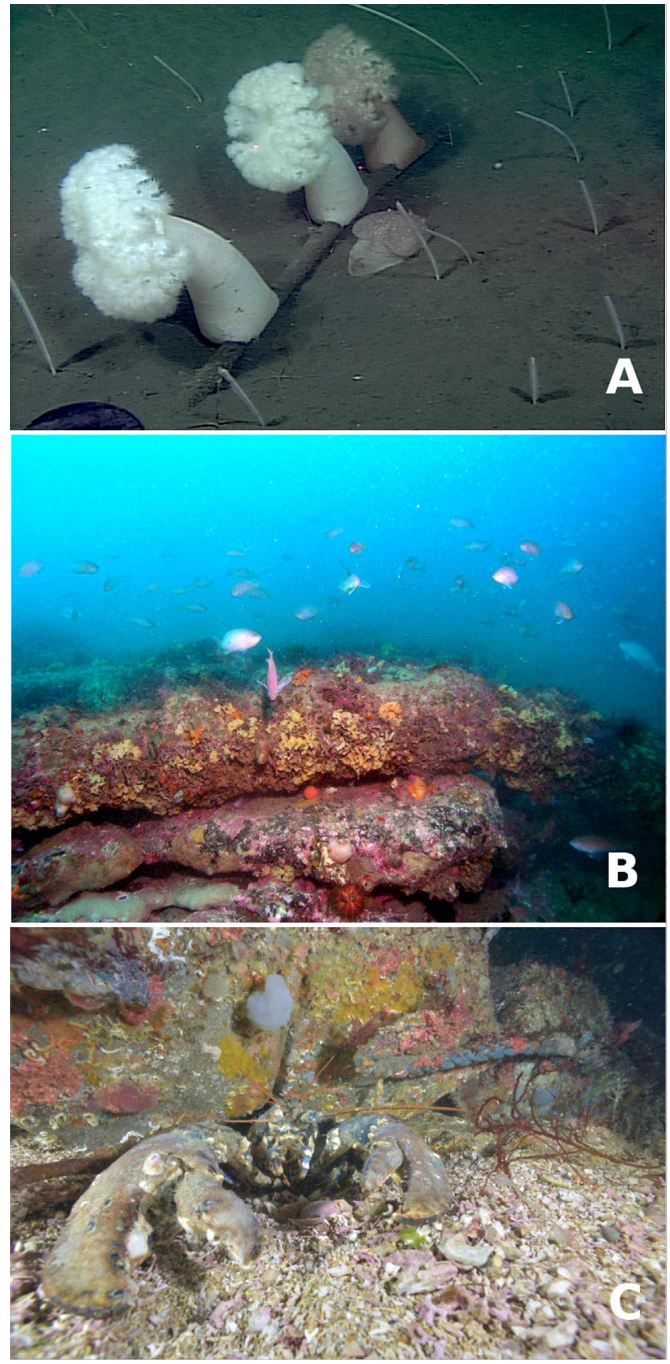

Fig. 5. Photographs of laid-down cables: A) the ATOC/Pioneer Seamount cable (California, USA) in an unconsolidated sandy silt area showing three *Metridium farcimen* settled on the cable (courtesy: [13]); B) the BassLink cable (Tasmania, Australia), protected by a cast-iron half-shell, showing a heavy encrustation of algal and invertebrate species on the underlying basalt reef (courtesy: [14]); and C) the rock mattresses used to stabilise the cable connecting the Paimpol-Bréhat tidal turbine test site, France, to the land, showing heavy colonisation by megafauna species like the European lobster (*Homarus gammarus*) (courtesy: Olivier Dugornay – IFREMER).

'Reef effect' is usually considered to be a positive anthropogenic impact, as artificial reefs generally have higher densities and biomass of fish and decapod crustaceans than surrounding soft bottoms. Also, when associated with a fisheries exclusion area (as described in Section

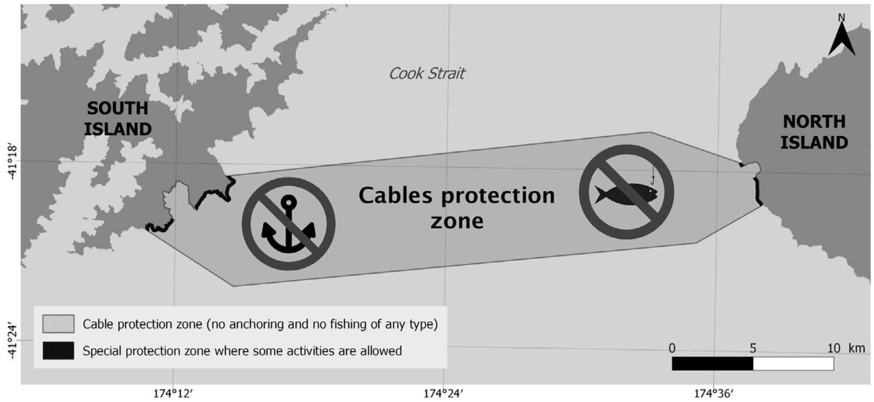

Fig. 6. Protection zone of three SPC and one fibre-optic cable situated across Cook Strait, New Zealand. The total protected area covers approximately 236 km^2 (reproduced from [73]).

4.6), artificial reefs may function as refuges for these populations, with potential spill-over benefits for adjacent stocks and fisheries [68]. This is particularly true for commercial species, like the European lobster (*Homarus gammarus*) or edible crab (*Cancer pagurus*) observed on offshore wind-farm foundations [69,70]. In some cases, the cable reef effect is considered a compensatory measure for habitat destroyed during cable installation [65]. Concerning dynamic cables used to connect offshore floating MRE projects, in addition to the processes of colonisation and concentration, biofouling can significantly increase cable weight and wear at least on the first tens of metres, creating technical problems [71].

On the other hand, reef effect may potentially result in long-term negative effects if the structures facilitate the introduction of non-indigenous sessile species. Indeed, the number of non-native species present on new hard artificial substrate can be 2.5 times higher than on natural substratum [72]. Thus, the presence of a new hard substratum, such as a cable or its protection structures, on soft sediment can potentially open a corridor to a new area for some hard-bottom sessile species. Such processes can potentially lead to the spread of new introduced species by a stepping stone process across biogeographical boundaries [73]. Although cable routes are narrow and often buried in areas of soft sediment, and no spread of invasive species caused by SPC has been documented, this question needs to be considered in light of the exponential growth of offshore wind farms.

4.6. Reserve effect

The potential reserve effect of SPC is linked to the limitation/interdiction by local authorities of environmentally damaging human activities (trawl fishing, anchoring, dredging, *etc.)* around the cable route during the operation phase and is considered as a positive effect for ecosystems. In some cases, the use of passive fishing equipment (nets, lines, and traps) is permitted, reducing the protection of targeted species. The size of the protected zone and the level of restriction depend on the cable installation method (buried or unburied), the number of cables present in the area, and the size of the electrical connections. For example, the Cook Strait cables have an extensive protected area to prevent damage to three submarine HVDC cables and one fibre-optic cable which link the North and South Islands of New Zealand over 40 km. An area seven kilometres wide around these cables, where anchoring and fishing of any type are prohibited, was created by New Zealand authorities, corresponding to a marine protected area of approximately 236 km^2 (Fig. 6; [74]).

With fishing access restricted, economically exploited sedentary species (such as scallops or clams) will be protected throughout their lives, but protection of mobile species (such as fish) will only be effective during the time they live in/pass through the cable area. A study focusing on fish found no significant differences in species richness inside and outside a protection zone [75]. The reserve effect has been clearly demonstrated for some commercial offshore wind farms, including their associated electric cable grids. Within the Dutch offshore wind farm Egmond aan Zee, where all nautical activities are prohibited, the habitat heterogeneity [76], benthic biodiversity and possibly the use of the area by the benthos, fishes, marine mammals and some bird species have increased (although counterbalanced by a decreasing use of several other bird species). These changes occurred during the first two years of wind-farm operation, in response to the establishment of the marine protected area but also other factors, such as the reef effect of the wind turbine foundations, rockfill and cables. Nenadovic [77] studied a protected area associated with a fibre-optic cable route on the coast of the Gulf of Maine (USA) and showed a significant difference in epifaunal community structure between protected and unprotected areas. In particular, engineer species were more frequent near the cable route. The maintenance of such species with a complex biological structure highlights the structuring effect of marine protected areas.

4.7. Electromagnetic fields

The potential ecological impacts of electromagnetic fields (EMF) are of particular concern. EMF are generated by current flow passing through power cables during operation and can be divided into electric fields (called E-fields, measured in volts per metre, $V\,m^{-1}$) and magnetic fields (called B-fields, measured in μT). Electric fields increase in strength as voltage increases and may reach 1000 $\mu V\,m^{-1}$ for an electric cable [78], but are generally effectively confined inside cables by armouring. EMF characteristics depend on the type of cable (distance between conductors, load balance between the three phases in the cable, *etc.)*, power and type of current (direct *vs.* alternating current – AC generates an alternating magnetic field which creates a weak induced electric field of a few $\mu V\,m^{-1}$, called an iE-field, near the cable), and whether it is buried or not [8,79]. When the cable is buried, the sediment layer does not entirely eliminate the EMF, but reduces exposure to the strongest EMF existing in direct contact with the cable [80]. The strength of both magnetic and induced electric fields increases with current flow and rapidly declines with distance from the cable [81].

Electric currents with intensities of 1600 A are common in submarine cables. In response, magnetic fields of approximately 3200 μT are generated, decreasing to 320 μT at 1 m distance, 110 μT at 4 m and values similar to the terrestrial magnetic field (50 μT) beyond 6 m [82]. By contrast, according to AWATEA [83], a standard submarine cable carrying 132 kV AC (350 A) generates a magnetic field of 1.6 μT on the "skin" of the cable (*i.e.*, within millimetres), while cables carrying 10–15 kV DC do not generate a significant magnetic field beyond a few centimetres from the cable surface. The magnetic field varies greatly as a function of the cable type, and modelling of the magnetic field

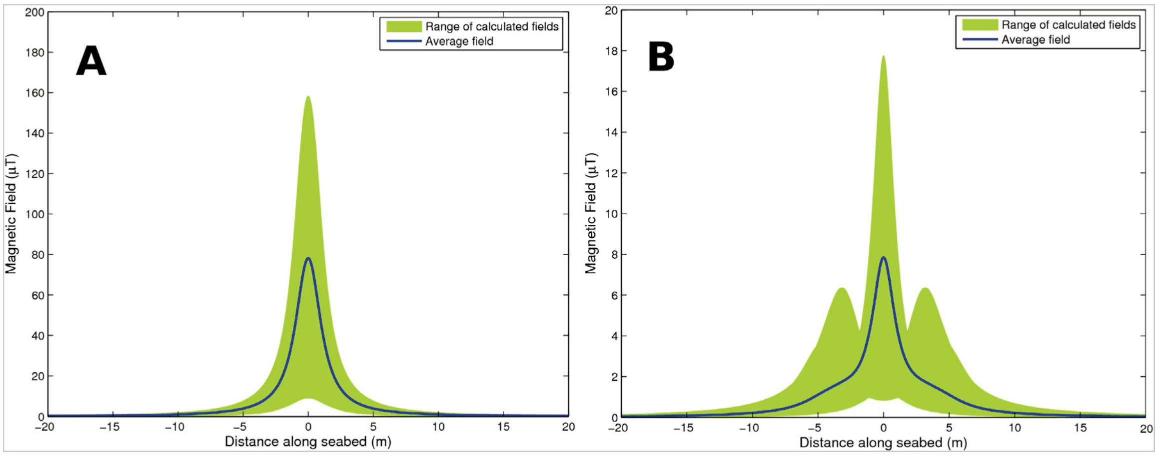

Fig. 7. Modelled magnetic fields at the sediment-water interface originating from different types of buried submarine cables in operation; **A:** Calculated data based on 9 DC cables. **B:** Calculated data based on 10 AC cables (courtesy: [80]).

induced by either DC (Fig. 7A) or AC cables (Fig. 7B) reveals this heterogeneity (1–160 µT at the cable surface; [81]). Particular attention must be paid to monopolar DC cables using sea electrodes for the return current path, the design of which leads to higher magnetic and electric fields [40,81]. Although modelling presents serious limitations in the understanding of ecosystem-scale responses to such disturbances, the rare *in-situ* EMF studies available for review yielded values of measured EMF comparable to those calculated by modelling [10,14].

Many marine species around the world are known to be sensitive to electromagnetic fields, including elasmobranchs (rays and sharks), fishes, mammals, turtles, molluscs and crustaceans. Indeed, the majority of these taxa detect and utilize Earth's geomagnetic field for orientation and migration [84–88]. Some are electrosensitive, like elasmobranchs, which are able to detect E-fields and iE-fields through specific organs called ampullae of Lorenzini [89,90]. This electrosense can be used to detect electric fields emitted by prey, conspecifics or potential predators, as well as for orientation [90]. A few incidents of bites observed on unburied SPC may also be linked to the electric field emitted by cables.

Thus, SPC can possibly interact in a negative way with sensitive marine species, especially benthic and demersal organisms through:

- effects on predator/prey interactions,
- avoidance/attraction and other behavioural effects,
- effects on species navigation/orientation capabilities,
- and physiological and developmental effects.

Elasmobranchs can detect very low electric fields (starting from 0.005 µV cm^{-1} [81]), and magnetic (20–75 µT [82,86]). Power cables inducing a strong electric field can repel many elasmobranch species, preventing some movement between important areas (such as feeding, mating and nursery areas). As part of the COWRIE (Collaborative Offshore Wind energy Research Into the Environment) project, Gill et al. [91] reported that elasmobranchs are attracted by electric fields generated by DC between 0.005 and 1 µV cm^{-1}, and repelled by electric fields of approximately 10 µV cm^{-1} and higher. Mesocosm studies (COWRIE project) on impacts of EMF emitted by submarine cables on several elasmobranch species showed that the response was not predictable and seemed to be species specific, maybe even specific to individuals [92]. Teleosts, especially diadromous fish, also use natural EMF to migrate. Westerberg and Lagenfelt [16] showed that the swimming velocity of European eel (*Anguilla anguilla*) slightly decreased when crossing the electromagnetic field of a non-buried 130 kV cable, but did not report evidence of population-scale impact. Furthermore, no substantial impacts have been shown on physiology or survival of these taxa [93,94].

Concerning invertebrates, data are scarce except for a few studies relating to minor or non-significant impacts of anthropogenic electromagnetic fields on benthic invertebrates [15,17,93,95,96]. However, a recent experimental study performed by Hutchison et al. [97], highlights a subtle change in the behavioural activity of the American lobster (*Homarus americanus*) when exposed to EMF from a HVDC cable.

Another noteworthy issue is that substantial data gaps exist between the interaction of pelagic species (like pelagic shark, marine mammals or fishes) and dynamic cables. These gaps remain partly owing to difficulties in evaluating impacts at population scale around these deployments.

4.8. Heat emission

When electric energy is transported, a certain amount is lost as heat by the Joule effect, leading to an increase in temperature at the cable surface and a subsequent warming of the immediate surrounding environment [98]. Constant water flow around a laid-down or a dynamic cable tends to dissipate thermal energy and confines it to the cable surface [18]. However, for buried cables, thermal radiation can significantly warm the surrounding sediment in direct contact with the cable, even at several tens of centimetres away from it, and especially in the case of cohesive sediments [99]. Heat emission is higher in AC than DC cables at equal transmission rates. Heat emission can be modulated by physical characteristics and electrical tension of the cable, burial depth, bottom type (thermal conductivity, thermal resistance, *etc.)* and physical characteristics of the environment [19,98,99].

Despite the evidence for thermal radiation from subsea cables, very few studies exist on the subject and most consist of numerical modelling [18,100]. One of the rare field measurement studies concerned the offshore wind array of Nysted (maximal production capacity of about 166 MW), in the proximity of two AC cables of 33 and 132 kV buried in a medium sand area, approximately 1 m deep. Results showed a maximal temperature increase of about 2.5 ºC at 50 cm directly below the cable [41]. Transposition of these results to other locations is difficult, considering the large number of factors impacting thermal radiation, and other field studies are necessary to gain a better understanding of thermal radiation effects.

Temperature increases near the cable can modify chemical and physical properties of the substratum, such as oxygen concentration profile (redox interface depth) and, indirectly, the development of microorganism communities and/or bacterial activity. Physiological changes in benthic organisms living at the water-sediment interface and in the top sediment layers can also potentially occur [19,101]. Temperature radiation can potentially cause small spatial changes in benthic community structure by way of migratory behaviour modification with cryophilic species being excluded from the cable route in favour of other, more tolerant species.

To our knowledge, the impacts of local temperature increase caused by electric cables on benthic communities (macrofauna diversity or microbial structure and functioning) have rarely been examined, and *in-situ* investigations are lacking. Furthermore, studies using controlled temperature increases are often unrealistic regarding the extent of suspected warming. This considerable knowledge gap prevents drawing conclusions about ecological impacts of long-lasting thermal radiation on ecosystems, but considering the narrowness of the corridor and the expected weakness of thermal radiation, impacts are not considered to be significant. Nevertheless, new field measurements and experiments are required to fully understand this phenomenon under operational conditions and to assess its impacts on potentially exposed organisms.

4.9. Entanglement risks

Before the 1960s, entanglement of mobile megafauna with cables occurred during the operation phase leading, in the worst cases, to lacerations, infections, starvations and drowning of the trapped marine mammals [102]. Technical improvements made since the 1960s for installation of laid-down cables have reduced this risk [3]. Currently, entanglement risks only concern dynamic SPC. Although this risk is considered to be non-significant, concerning a single dynamic SPC (such as pilot scale projects still under development), it may require more attention in the future owing to the growth in commercial farms of floating devices and associated webs of dynamic SPC and mooring lines hanging in the water column. According to Kropp [103], arrays of dozens of dynamic cables and mooring lines per km^2 can potentially affect large marine animals, *i.e.* whales.

According to existing reports, entanglements caused by dynamic SPC will remain a low risk [103,104]. The large diameters of SPC (> 5 cm) make them relatively inflexible [105], and mooring lines and dynamic SPC should be tight enough to reduce entanglement [103]. However, indirect entanglement resulting from discarded fishing gear wrapped around dynamic SPC [102] may significantly impact a larger set of species, including marine mammals, sharks or fishes. Quantifying such risks will only be possible when floating MRE installations are operational. Consequently, entanglement risk remains highly speculative at this stage, relying on modelling data.

5. Recommendations

5.1. Mitigation and compensation measures

Potential environmental impacts of cables should be anticipated prior to the installation phase by applying avoidance and reduction measures. In order to mitigate potential environmental disturbances caused by cabling activity, measures exist and should be applied, including the choice of an appropriate cable route and installation technique, answering the following:

- Planning the cable route to avoid impacts on habitats and benthic species that are most sensitive to disturbance or are of special ecological interest (with special attention to slow-growing long-lived species). Particularly important and sensitive habitats in the North Atlantic include biogenic reefs comprising *Modiolus modiolus* (Horse mussel beds), *Sabellaria spinulosa* (honeycomb worm), maerl beds and *Zostera* seagrass meadows.
- Selecting landing zones and cable routes in order to prevent the remobilisation of contaminants present in sediments and contamination of the trophic food web.
- Using cable technology suitable for reducing the emission of magnetic fields, such as three-phase AC cables and bipolar HVDC transmission systems [39], and minimising the emission of directly generated electric fields through adequate shielding [44].
- Avoiding the use of monopolar DC cables using sea electrodes, which produce toxic compounds, generate higher EMF and accelerate corrosion of manmade structures, in favour of cable systems with other return path options causing less disturbance [40].
- Deploying dynamic SPC with the lowest risks of entanglement for marine megafauna where relevant. Appropriate configurations, as for mooring lines [104], and appropriate cable type, with diameters and colours allowing visual tracking of affected species [103].
- Managing installations with respect to life cycles of mobile species (winter dormancy, migration, mating and/or spawning, *etc.)*, and to avoid disturbance of sensitive species (*e.g.*, fish, crustaceans, marine mammals, marine turtles or resting/feeding birds).
- Prioritizing burial depth appropriate to the substratum type. To reduce exposure of sensitive species to electromagnetic fields and heat emission, the physical distance between animals and the cable can be increased. According to models proposed by Normandeau et al. ([81], Fig. 7), the EMF level at the water-sediment interface with a 2 m burial depth would be approximately 25% of its initial value- *versus* 60% for a 1 m burial depth.
- Prioritizing the laid-down option rather than burying in the presence of unavoidable fragile benthic soft bottom habitats (*e.g.*, seagrass beds; [11]).
- Installing devices with a strategy to reduce electrical connections and limiting the number of export cables (*i.e.*, when several MRE projects are present in close proximity).

To complement reduction and avoidance strategies, compensation measures should be considered if residual impacts persist. In this event, and only after having addressed mitigation options, compensation measures may be applied directly to the implantation site, or in close proximity. Discussions between stakeholders are recommended to establish parameters for scale and responsibilities for compensation measures.

A possible form of compensation measures can consist of improving future engineering strategies through experimental studies of ecosystem functioning and resilience following disturbance. For example, on the Paimpol-Bréhat French tidal turbine test site, the cable route connecting turbines to the land crosses important seagrass meadows containing *Zostera noltei* and *Z. marina*. In response, the prime contractor (EDF, Electricité De France) developed an experimental protocol aiming to transplant some seagrass plants located on the route area to another barren place before cable burial. Such measures aimed to test transplantation techniques and acquire knowledge about the mechanism of recolonisation by seagrass after installation of a cable [106]. Similar transplantation experiments are currently being tested in the context of SPC installation (*e.g.*, ongoing project by Red Eléctrica de España in Majorca and Ibiza).

Environmental monitoring strategies performed in parallel with cable installation should: (i) verify the impact predictions made in the environmental impact study and detect unforeseen alterations, (ii) ensure the fulfilment of mitigating measures proposed, and (iii) provide data to improve future environmental impact assessments and installation plans [107].

5.2. Future research priorities

A hierarchical model of potential impacts based on the expected levels of ecological effects and the associated levels of scientific knowledge (or uncertainty) is presented in Table 2. This synthetic output corresponds to a concerted expert judgement of the authors, and takes into account the main conclusions of the literature cited in this paper. The main priorities concern benthic habitat disturbance, reef and reserve effects and potential impacts of EMF. A substantial data gap remains concerning the impacts of EMF because data on sensitivity thresholds or tolerance are only available for a small number of taxa. Major uncertainties therefore remain for several large groups

Table 2
Synthesis of the importance of potential impacts caused by Submarine Power Cables (SPC) on different marine compartments during installation, operation, maintenance and decommissioning, based on the author's interpretation of the reviewed literature. For each interaction, the extent of the impact and associated uncertainty are quantified as 'Negligible', 'Low', 'Medium' or 'High'. Bur = Buried SPC; LD = Laid-Down SPC; Dyn = Dynamic SPC. Black fill = no impact.

	Physical habitat			Invertebrates			Fish			Elasmobranch and Diadromous Fish			Marine mammals		
	Bur	LD	Dyn	Bur	LD	Dyn	Bur	LD	Dyn	Bur	LD	Dyn	Bur	LD	Dyn
Installation / Decomissioning / Maintenance															
Seabed disturbance	Medium (1)	Low (1)	No impact	Medium (1)	Low (1)	No impact	Low (2)	Negligible (1)	No impact	No impact	No impact	No impact	No impact	No impact	No impact
Sediment resuspension	Negligible (1)	No impact	No impact	Low (1)	Negligible (1)	No impact	Low (1)	Negligible (1)	No impact	Low (1)	Negligible (1)	No impact	No impact	No impact	No impact
Chemical pollution	No impact	No impact	No impact	Low (1)	Negligible (1)	Negligible (1)	Low (1)	Negligible (1)	Negligible (1)	Low (1)	Negligible (1)	Negligible (1)	Low (1)	Negligible (1)	Negligible (1)
Underwater noise	No impact	No impact	No impact	Low (2)	Low (2)	Low (2)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)
Operation															
Reef effect	No impact	Medium (1)	Low (2)	No impact	Medium (1)	Low (2)	No impact	Low (1)	Low (2)	No impact	Low (1)	Low (2)	No impact	No impact	No impact
Reserve effect	Medium (1)	Medium (1)	Medium (1)	Medium (1)	Medium (1)	Medium (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)
Chemical pollution	No impact	No impact	No impact	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)	Negligible (1)
Electromagnetic fields	No impact	No impact	No impact	Low (3)	Low (3)	Low (3)	Low (2)	Low (2)	Low (3)	Low (2)	Medium (2)	Medium (3)	No impact	No impact	Low (2)
Heat emission	No impact	No impact	No impact	Negligible (2)	Negligible (1)	Negligible (1)	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact
Entanglement	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact	Negligible (2)	No impact	No impact	Negligible (2)	No impact	No impact	Low (2)

Extent of impact: Negligible | Low | Medium | High

Uncertainty: ① Low ② Medium ③ High

(cetaceans, pinnipeds, fishes, crustaceans, and many pelagic species) [81]. Better knowledge of the different sensitivity thresholds is needed to fill these data gaps, especially for several key species at different stages of their development. Additionally, environmental issues may arise following industrial-scale deployment of MRE devices using multiple submarine electric cables installed in close proximity and creating a network impacting a large area. The cumulative effects of more than one activity or perturbation factor, which may act in synergy, must be considered [108]. For example, recovery of benthic communities after cable installation may be slower and less efficient if the benthic ecosystem is already threatened by other anthropogenic disturbances such as chemical pollution, eutrophication, or invasive species (especially in enclosed and shallow areas). The assessment of impacts due to interactions between different kinds of disturbances remains highly speculative, partly since environmental impacts of single cables are still poorly understood.

6. Conclusions

Although SPC have been used since the mid-19th century, environmental concerns associated with their installation and operation are much more recent. This is due to an increased awareness of anthropogenic impacts, the rapid expansion of SPC deployments, and the growing demand for electric interconnections between countries that have adopted a common energy strategy.

The main potential environmental impacts associated with SPC during their operational phase are those related to the production of electromagnetic fields, the creation of artificial reefs and "reserve effects" caused by the interdiction of certain human activities. Cable installation, maintenance and decommissioning also impact the environment, causing direct benthic habitat modification, which can be especially problematic in the case of sensitive bioconstructed habitats. These phases of SPC may also induce significant particle and pollutant resuspension events in very confined and modified shallow coastal areas. Mitigation measures are possible before, during or after projects to limit the ecological impacts of SPC and associated maritime operations.

While potential environmental impacts generated by SPC are recognised, better knowledge of amplitude and duration is essential. Generally these disturbances occur over short times scales, creating relatively minor impacts on ecosystem structure and functioning. Nevertheless, the nature and amplitude of certain impacts remain poorly studied, particularly the EMF impacts on elasmobranchs, diadromous fishes and invertebrates, and assessment of cumulative impacts. Despite these knowledge gaps, the present review provides a quantification and ordering of the different impacts of SPC on marine environments and offers updated practical recommendations for developer mitigation strategies.

Acknowledgements

This work is the result of a collaborative effort between authors of the paper sponsored under EERA (European Energy Research Alliance), UKCMER (UK Centre for Marine Energy Research), Région Bretagne and the National Research Agency under the Investments for the Future program bearing the reference ANR-10-IED-0006-17. The authors would like to thank Normandeau Associates Inc., Louis Dreyfus Travocean, the Monterey Bay Aquarium Research Institute, John Sherwood and collaborators as well as Olivier Dugornay for their kind assistance in supplying the different photography and figures. We also thank three anonymous reviewers for constructive criticism and valuable suggestions. Finally, the authors would also like to thank Nolwenn Quillien, Julie Lossent, Guillaume Damblans and Kelly Cayocca for their help.

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