Fisheries and Oceans Canada | Pêches et Océans Canada
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National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2021/053

SCIENCE ADVICE ON REVISITING PATHWAYS OF EFFECTS (PoE) DIAGRAMS IN SUPPORT OF FFHPP RISK ASSESSMENT

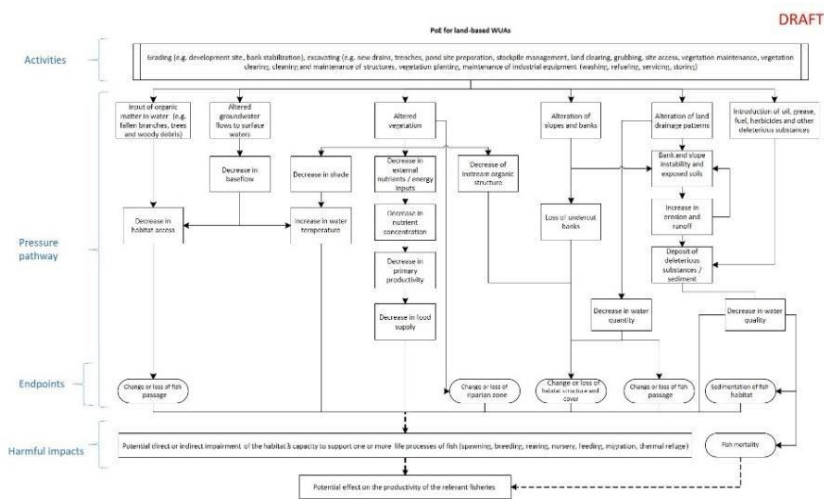

Figure 1. Draft consolidated Pathway of Effects (PoE) diagram demonstrating potential impacts to fish and fish habitat from Works, Undertakings, and Activities (WUAs) conducted in or near water (Land-based WUAs).

Figure 2. Riparian shoreline works during construction (top), and after completion (bottom). Photo credit: DFO.

Context:

The Fisheries and Oceans Canada (DFO) Fish and Fish Habitat Protection Program (FFHPP) has requested science advice on four consolidated draft Pathways of Effects (PoE) diagrams, including consideration of their redesign, validation of existing linkages, and assessment of completeness of the linkages. To facilitate the consistent assessment of projects under the Fisheries Act, FFHPP reworked the Program's 20 existing PoE diagrams and consolidated them into four draft diagrams that align with FFHPP's categories of Works, Undertakings, and Activities (WUAs) referred to in this document as the 'consolidated PoE diagrams': 1) Land-based WUAs, 2) Noise and Energy producing WUAs, 3) In-water WUAs, 4) WUAs affecting Flow. Revised and validated PoE diagrams will allow the FFHPP to consider impacts of project types in a consistent manner, and to understand the impacts of a project at the site and ecosystem level.

The objectives of this science advice process were to: 1) review and validate the pathways included in the consolidated PoE diagrams to ensure they are accurate and valid; 2) assess whether the linkages between the WUAs, pressures and endpoints on fish and fish habitat are comprehensive and complete; and, 3) determine if the process of using these consolidated PoE diagrams allows FFHPP to identify which endpoints require avoidance and/or mitigation measures to reduce and manage the risk that the proposed WUA will impair the habitat's capacity to support the life processes of fish (or result in death of fish), and to identify residual impacts to be evaluated for authorization and offset, thus, ensuring that fish and fish habitats are conserved and protected.

This Science Advisory Report is from the February 23-26, 2021, National Advisory Meeting on Science advice on revisiting Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

SUMMARY

- Pathways of Effects are used to link classes of activities in or near water to effects on fish or fish habitat they are likely to cause. This Science Advisory Report (SAR) provides recommendations for changes to draft consolidated Pathways of Effects (PoE) diagrams produced for use in the assessment of projects in or near water.
- These PoE diagrams are intended to focus on the aspects of Works/Undertakings/Activities (WUAs) - pressures - endpoints that DFO manages. They are tools used to communicate potential impacts to proponents, Indigenous Peoples (i.e., First Nation, Metis, and Inuit communities and rights holders), and the general public. While it is recognized that there are likely many more pressures and endpoints that would be included in a fully comprehensive ecosystem effects diagram (e.g., land-use beyond the riparian zone), that is not their intent.
- While PoE diagrams may be useful in wider applications (e.g., restoration projects), the main purpose of these PoE diagrams is to apply to WUAs that may have a negative impact on fish and fish habitat. Therefore, the focus is to identify the most common impacts that could result in negative effects.
- These PoE diagrams are intended to be used nationally in both marine and freshwater systems, to identify the most common pressures that can be managed by applying avoidance and/or mitigation measures. The spatial and temporal scale of the impacts that cannot be mitigated are assessed in a subsequent phase of FFHPP's decision-making process. Science advice on the broader risk management framework may be requested at a later date once further developed.
- The applicability of pressures and linkages could vary across system types (i.e., stream, river, lakes, marine coastal) and regions, and it is recognized that this context-dependency is to be considered by users of the PoE diagrams.
- For each of the PoE diagrams more changes were discussed than were accepted. All accepted changes are identified in the body of this SAR and highlighted in a corresponding figure as follows:
    - Land-based: 35 changes discussed and 26 accepted changes (Figure 4).
    - Noise and Energy: 31 changes discussed and 23 accepted changes (Figure 5).
    - In-water: 31 changes discussed and 25 accepted changes (Figure 6).
    - Flow: 30 changes discussed and 25 accepted changes (Figure 7).
- Recommended changes to all four consolidated PoE diagrams are more fully documented in Brownscombe and Smokorowski (2021).
- As a result of the review and after the recommended changes are taken into account, it was agreed that the resulting PoE diagrams are accurate and valid and are recommended for inclusion in the revised consolidated PoE diagrams.
- It is recognized that there are limitations with the current structure and presentation of these PoE diagrams in that there is necessarily a trade-off between comprehensiveness and

tractability. Decisions were made to limit the connections to those that most commonly require consideration, or to ensure that they are considered when relevant.

- It was agreed that the revised diagrams are sufficiently comprehensive and complete, encompassing the core components of WUA impacts on fish and fish habitat with the purpose of being tractable for FFHPP decision-making and communication. Exceptions were noted related to marine or large system coastal processes, aquatic invasive species, and other development-specific PoE diagrams (e.g., shipping) that are not part of the four core diagrams reviewed here.
- The process of using these revised PoE diagrams, if used in a manner that ensures all possible linkages and all applicable PoE diagrams are consulted, will facilitate the application of avoidance and mitigation measures to identify residual impacts.
- There are a number of uncertainties regarding the use of PoE diagrams for regulatory decision making. These include: their generalized nature and variable applicability across system types, regions, and WUAs; variable levels of scientific support for the linkages presented; and the nature of the pathway (i.e., linear vs non-linear) that will influence endpoints in different ways.
- Other considerations should also be kept in mind when using these PoE diagrams to facilitate decisions, including the need to consider cumulative effects and multiple stressors, potential alternatives to the most common direction of a pressure identified in the diagrams, and the need for users to have a relevant science background and training in their standardized use.

BACKGROUND

DFO's Fish and Fish Habitat Protection Program (FFHPP) has a regulatory regime in place to avoid, mitigate, and offset the negative effects of projects occurring in or near water (DFO 2021) on fish and fish habitat. In order to understand these negative effects, linkages need to be made between the works, undertakings, and activities (WUAs), the 'pressure' by which WUAs affect the ecosystem, and the resulting 'endpoints' affecting fish and fish habitat (Figure 3).

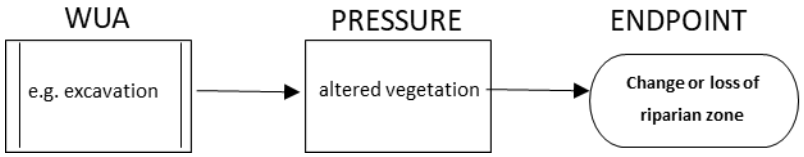

Figure 3. Example of an individual linkage within a Pathways of Effects diagram including the work, undertaking, and activity (WUA), pressure, and endpoint affecting fish and fish habitat. Definitions of key terms are included in Appendix 1.

The FFHPP has formally used Pathways of Effects (PoE) diagrams since 2005 to support regional practitioners in identifying and communicating the effects of proposed WUAs on fish and fish habitat (DFO 2018). Through changes to the modernized *Fisheries Act (FA)* in 2019, the FFHPP now has a higher regulatory standard through which proposed works, undertakings, and activities will be reviewed. However, there are concerns that existing PoE diagrams cannot be applied in a consistent manner in support of the regulatory review of projects, and in the assessment of their risks to fish and fish habitat.

To facilitate the consistent assessment of projects under the *FA*, FFHPP reworked the Program's 20 existing PoE diagrams (see Appendix 1 in Brownscombe and Smokorowski 2021) and consolidated them into four draft diagrams that align with FFHPP's categories of WUAs (referred to in this document as the 'draft consolidated PoE diagrams'): 1) Land-based WUAs, 2) Noise and Energy producing WUAs, 3) In-water WUAs, and 4) WUAs affecting Flow. It is thus important to ensure that the pathways and linkages to resulting endpoints on fish and fish habitat are accurate, valid, comprehensive, and complete.

The FFHPP has requested DFO's Canadian Science Advisory Secretariat (CSAS) to conduct a peer review of these four draft consolidated PoE diagrams, including consideration of their redesign, validation of existing linkages, and assessment of completeness of the linkages. Revised and validated PoE diagrams will allow the FFHPP to consider impacts of project types in a consistent manner, and to understand the impacts of a project at the site and ecosystem level. The restructured and validated PoE diagrams, and the standardization of their use, will help determine where a project fits in the FFHPP Risk Management Framework, and ultimately determine which program instrument (e.g., letter of advice or *FA* authorization) is best suited to manage the risk associated with the project. . This will help ensure that fish and fish habitat are conserved and protected consistently across the country.

The objectives of this science advice process were to: 1) review and validate the pathways included in the draft consolidated PoE diagrams to ensure they are accurate and valid; 2) assess whether the linkages between the WUAs, pressures, and endpoints on fish and fish habitat are comprehensive and complete; and, 3) determine if the process of using these consolidated PoE diagrams allows FFHPP to identify which endpoints require avoidance and/or mitigation measures to reduce and manage the risk that the proposed WUA will impair the habitat's capacity to support the life processes of fish (or result in death of fish), and to identify residual impacts to be evaluated for authorization and offset, thus, ensuring that fish and fish habitats are conserved and protected.

The science advisory process used one working paper (Brownscombe and Smokorowski 2021), which assessed the accuracy and completeness of the four draft consolidated PoE diagrams through a literature search, and provided evidence to facilitate the discussions and support the decisions made during the CSAS process. Furthermore, each of the four draft consolidated PoE diagrams were formally peer reviewed by individual expert participants, and the collective expert opinions of participants rounded out the basis of the final recommended changes. This SAR provides recommendations for changes to revise the draft consolidated Pathways of Effects (PoE) diagrams produced for the use in the assessment of projects in or near water.

ANALYSIS

The following considerations formed the basis of the science advice, which are to be taken into account when using this advice and the PoE diagrams:

- These PoE diagrams are intended to focus on the aspects of WUAs, pressures, and endpoints that DFO manages to ensure compliance with relevant provisions under the FA and the Species at Risk Act. They are tools that are used by FFHPP to communicate potential impacts of WUAs on fish and fish habitat to proponents, Indigenous Peoples, and the general public. While it is recognized that there are many more pressures and endpoints that could be included in a fully comprehensive ecosystem effects diagram, that is not their intent.

- The main purpose of the current PoE diagrams used by FFHPP is to identify the most common impacts of WUAs in or near water that could result in negative effects, with the goal of managing those impacts through the relevant management (i.e., avoidance and mitigation) measures. While it is acknowledged that in future it may be useful to apply PoE diagrams in a wider context (e.g., to identify potential impacts that could result from restoration projects), it is important to note that this is not their current intent.
- These PoE diagrams are intended to be used nationally in both marine and freshwater systems, to identify the most common pressures that can be managed by applying avoidance and/or mitigation measures. The spatial and temporal scale of the impacts that cannot be mitigated are assessed in a subsequent phase of FFHPP's decision-making process. Science advice on the broader risk management framework may be requested at a later date once further developed.

The meeting participants acknowledged that the four draft consolidated PoE diagrams provided an excellent starting point for this CSAS review. Combining 20 diagrams into four was a complex task, but the bulk of the WUAs, pressures, and endpoints that DFO manages, as determined by the legislative responsibilities, was covered. Brownscombe and Smokorowski (2021) provided the necessary evidence for a sound review of the draft amalgamated diagrams, and as a result, linkages that were considered well supported and valid were accepted as presented and not discussed further. There is an important but delicate balance between tractability and comprehensiveness, and this balance was debated throughout this CSAS process. A number of new linkages and/or pressure nodes were suggested, but since they were not considered common or 'core', they were not included in the final recommended changes.

Efforts were made to ensure consistency in formatting and level of detail across diagrams. Linkages that appear in more than one diagram, particularly those with multiple pressure node connections following to the endpoints, were instead changed to refer to the more applicable diagram. The four PoE diagrams reviewed do not work in isolation of each other, and it is rare that only one would be consulted. Similarly, there were some inconsistencies in wording identified related to the same pressure nodes and endpoints among the four PoE diagrams and suggestions were made to adjust these accordingly when noted. If some were missed during this exercise, potentially because the pressure nodes and linkages were not discussed, it was agreed that wording should still be adjusted to ensure consistency among diagrams, without having to obtain consensus from the group on every individual change designed to achieve consistency.

The applicability of pressures and linkages could vary across system types (i.e., stream, river, lakes, marine coastal) and ecozones as well as DFO regions across Canada. For example, the impact of riparian WUAs on shoreline vegetation, and the resulting effect on water temperature, is likely much greater on a small stream with small water volumes than a large river or marine coastal environment. It is important that users of these PoE diagrams consider the applicability of each pressure node and endpoint to the particular system affected by the WUA. Some of these differences were highlighted in Brownscombe and Smokorowski (2021), but not in a comprehensive manner.

Regarding the directionality of some of the pressure nodes, in many cases where either direction (increase or decrease) is equally plausible, the pressure node was worded as 'change in' or 'altered'. But in cases where one direction was more likely, then that direction was used (e.g., decrease in water quality from the addition of deleterious substances or an increase in nutrients). However, in some cases the directionality is not 100% consistent and this should be kept in mind by users of these PoEs. Caveats to the most common direction, when they exist,

are noted in Brownscombe and Smokorowski (2021), as they are important to identify as a possibility. For example, an increase in nutrients most often leads to a decrease in water quality, except in cases where that increase is to a formerly ultra-oligotrophic receiving system, which can then increase productivity in the ecosystem and therefore could potentially have a positive effect on fish and fish habitat. However, in the case of nutrient addition that accompanies wastewater input, the accompanying deleterious substances would reduce water quality regardless. It thus remains critically important that the users of PoE diagrams have the relevant science background, have an understanding of the full impact of the proposed WUA, and knowledge of the ecology of the affected riparian zones, watercourses and/or waterbodies to be able to apply them correctly.

The rationale for all changes identified below is briefly described, but much more detail on the justification, the literature available to support the change, and the strength of the connection is available in Brownscombe and Smokorowski (2021). For all pathway changes identified below, when the final connection from a pressure node or an endpoint leads to the 'Potential direct or indirect impairment of the habitat's capacity to support one or more life processes of fish (spawning, breeding, rearing, nursery, feeding, migration, thermal refuge)', this wording has been shortened to 'Potential direct or indirect impairment…' for brevity. Note that in the context of the PoEs, wherever fish is mentioned it is understood to mean the definition in the *FA*, which includes marine mammals (see Appendix 1).

In all cases there were more pressures and pathways discussed than were suggested as changes to the diagrams. These discussions can be found in the Proceedings of this meeting, and the accompanying spreadsheet that documented all the discussed changes and decisions. The following four sections identify the accepted changes recommended specifically for each of the PoE diagrams to achieve Objectives 1 and 2 as outlined above.

Pathway of Effects Diagram 1: Land-based WUAs

For the Land-based PoE diagram, 35 suggested changes were discussed; 26 were accepted as recommendations for alteration in the final version of the Land-based PoE diagram. These 26 changes are identified here, highlighted in Figure 4, and more thoroughly supported in Brownscombe and Smokorowski (2021).

1. Wording change: Change wording in pressure node from 'Input of organic matter in water (e.g., fallen branches, trees, and woody debris)' to 'Increased input of woody material'
    - Input of organic material is a natural process, therefore this wording change is to clarify two aspects: 1. 'Increased input' is to distinguish that this is referring to the 'dumping' or the falling of larger organic matter into the water as a result of WUAs in the riparian zone, and excludes input caused by natural events such as natural mortality, or wind throw. 2. The wording change to 'woody material' is to clarify that it is larger riparian-derived woody material (i.e., fallen branches, trees, and woody debris) that is the concern here. The word 'large' was not included because it implies a defined threshold size and the exact size and amount of woody debris that may cause a passage issue is not well studied or known. For the definition of 'woody material' see Appendix 1.
2. New connection: 'Increased input of woody material'-> see 'In-water PoE diagram'
    - Add a new link from increased input of woody material to refer to the In-water PoE diagram, which covers all the consecutive pressure nodes following that activity, including barrier (passage and constriction or expansion of flow impacts) and smothering effects. It

is important to highlight smothering could be particularly relevant for log dumping activities.

3. Remove linkage: 'Increased input of woody material' -> 'Decrease in habitat access' -> 'Change or loss of fish passage'
    - With the connection to the In-water PoE diagram, the link between 'Increased input of woody material' and 'Decrease in habitat access', and 'change or loss in fish passage' is not necessary since the In-water diagram more comprehensively covers those effects. However, the nodes will remain on the diagram because they are still relevant to the 'Decrease in baseflow' pathway.
4. Wording change: Change wording in pressure node from 'Increase in water temperature' to 'Altered water temperature'
    - The link between groundwater and temperature does not always lead to an increase in temperature. For example, during winter, relatively warm groundwater flows can be essential to maintaining overwintering pools, and if the input of this baseflow decreased when surface waters were cooler than groundwater, water temperature would decrease. There is also a less common but still relevant indirect mechanism to decrease water temperature via input of structure and more complex channel morphometry. There is potential for this mechanism to result in the increased lateral movement of water and/or channel migration, which can increase exchange between surface and groundwater, buffering against water temperature increases.
5. New pressure node and connection: 'Altered groundwater flows to surface waters' -> 'Decrease in baseflow -> (NEW) 'Change or loss of wetted area'
    - Altered water quantity and wetted area are two different mechanisms of change to fish habitat, although wetted area has been used to imply more broad impacts in the past. A decrease in wetted area directly reduces the habitat available to fish, and fish population productivity generally tends to decrease proportionally with declines in habitat area and quantity.
6. Add * to note potential for alternate direction: Add * to 'Decrease in baseflow*'
    - It was agreed that land-based WUAs would most often result in a decrease in baseflow, and therefore the directionality should be maintained. However, the potential exists that some major land-use changes can result in a redirection of groundwater flows, which can at times increase baseflow to a system. Including the * ensures that users of the diagrams consider this potential during their project reviews.
7. New connection: 'Altered groundwater flows to surface waters' -> 'Altered water quantity'-> 'Potential direct or indirect impairment…'
    - This new connection links groundwater to water quantity, which in turn captures the more complex habitat suitability aspects of altered volumes of water, beyond the change in wetted area.
8. New connection: 'Altered groundwater flows to surface waters' -> 'Decrease in baseflow' -> 'Decrease in food supply'
    - Water flow plays a very important role in providing fish food, and decreases in baseflow can result in reduced fish feeding opportunities and growth, warranting this direct connection.

9. Wording change: Change wording in pressure node from 'Decrease in external nutrients/energy inputs' to 'Altered external nutrients/energy inputs'.
    - Depending on the context, altered vegetation could decrease or increase the amount of nutrients entering an aquatic habitat. Either way, such changes in nutrient levels may be undesirable because of a potential for complex ecosystem responses that could be detrimental to fish communities, depending on system characteristics.
10. Pressure node removal: Remove ‘Decrease in nutrient concentration’.
    - This pressure node reflects an added level of mechanistic detail to the diagram that is not consistent with the other pathways, and therefore it was recommended for removal.
11. Wording change: Change wording in pressure node from 'Decrease in primary productivity' to 'Altered primary productivity’.
    - Logically following the recommended Land-based change #9 above, if nutrient inputs can increase or decrease, the resulting primary productivity of a system could increase or decrease as well.
12. New connection: ‘Altered vegetation’ -> ‘Decrease in food supply’
    - Riparian vegetation is a source of not only nutrients supporting the base of the food web, but also a direct source of fish food through terrestrial inputs, thus a direct connection is warranted.
13. Wording change from ‘Decrease of instream organic structure' to 'Decrease of aquatic organic structure'
    - Organic structure plays a role in fish habitat in nearly all aquatic ecosystems, not just ‘instream’, therefore it was agreed for the wording to be changed to ‘aquatic’.
14. New connection: 'Altered vegetation -> ‘Bank and slope instability and exposed soils’
    - Riparian vegetation plays an essential role in river geomorphology including bank stability and maintenance of undercut banks.
15. New connection: ‘Altered vegetation’ -> ‘Change of loss of habitat structure and cover’
    - Similar to Land-based change #14 above, riparian vegetation plays an essential role in river geomorphology, and thus on available habitat structure and cover.
16. Pressure node removal: 'Alteration of slopes and banks -> ‘Loss of undercut banks’ (REMOVE)->' Change of loss of habitat structure and cover’
    - It is suggested to remove the pressure node ‘Loss of undercut banks’ since it represents a level of specificity not seen in the balance of the pathways. But since undercut banks are a very important habitat feature for fish, this mechanism of change to habitat structure and cover is highlighted in Brownscombe and Smokorowski (2021).
17. Wording change: Change endpoint wording from ‘Fish mortality’ to ‘Sublethal effects and/or mortality’.
    - Altering the ‘Fish mortality’ endpoint to ‘Sublethal effects and/or mortality’ is an important change to make on this and the other PoE diagrams. Essentially, this endpoint would incorporate all of the *direct* impacts of pressure pathways on individual fish, e.g., from sublethal effects on growth and behaviour to mortality. Impairment of fish population

productivity can occur from sublethal impacts as well (e.g., the energetic costs of environmental stressors resulting in reduced growth and reproductive output).

18. New connection: ‘Sedimentation of fish habitat’ -> 'Sublethal effects and/or mortality'
    - The sedimentation of fish habitat may cause direct fish mortality by depriving eggs or larvae of oxygen. Therefore, a direct connection between sedimentation and sublethal effects and/or mortality is recommended.
19. Wording change from ‘Decrease in water quantity’ to ‘Altered water quantity’
    - Water quantity may decrease and/or increase resulting from an alteration of land drainage patterns (e.g., increased flashiness of flows and decreased baseflow resulting from increasing imperviousness of the riparian zone), both of which can be problematic.
20. New connection: ‘Altered water quantity’ -> ‘Change or loss of wetted area’
    - Wetted area and water quantity are different (see rationale under ‘Land-based change #5) and should be kept separate, but since water quantity directly influences wetted area, the connection is warranted.
21. New connection: ‘Alteration in water quantity’ -> - see ‘Flow PoE diagram’
    - Since a change in the quantity of water in an aquatic system could change a number of habitat features related to flow and levels, the linkage to the Flow PoE is warranted.
22. New connection: 'WUA' -> (‘Altered vegetation’ and ‘Altered slopes and banks’ and ‘Altered land drainage patterns’)-> see ‘Aquatic Invasive Species pathway (TBD)’
    - A combination of the land-based pressures (i.e., altered vegetation, altered slopes, and banks, altered land drainage patterns) may also contribute to additional pressure pathways/endpoints including facilitating invasive species pathways. An Aquatic Invasive Species PoE diagram does not yet exist, but is in development, and thus the connection should be made to capture the linkage.
23. New pressure node: 'WUA' -> ’Increased human access’ (NEW) -> Consult with relevant management agency(ies).
    - A WUA may also contribute to additional pressures through increased human access (e.g., additional vehicles, angling). In freshwater, angling is managed at the provincial level.
24. New connection: 'Alteration of land drainage patterns’ -> ‘Altered water temperature’
    - Alteration of land use that includes impervious surfaces such as asphalt can cause thermal loading in aquatic ecosystems as well, which warrants a connection from alteration of land drainage patterns to altered water temperature.
25. Wording change: Change wording in pressure node from 'Introduction of oil, grease, fuel, herbicides and other deleterious substances’ to 'Introduction of oil, grease, fuel, pesticides, and other deleterious substances’
    - ‘Herbicide’ should be changed to ‘pesticide’ to be more encompassing. For the definition of both terms see Appendix 1.
26. New connection: 'Introduction of oil, grease, fuel, pesticides and other deleterious substances’ -> ‘Decrease in water quality’

- The introduction of deleterious substances directly impacts water quality, which is a separate mechanism from the deposition of deleterious substances to the substrate, and thus a direct connection is warranted.

Pathway of Effects Diagram 2: Noise and energy producing WUAs

For the Noise and Energy PoE diagram, 31 suggested changes were discussed; 23 were accepted as recommendations for alteration in the final version of the Noise and Energy PoE diagram. These 23 changes are identified here, highlighted in Figure 5, and more thoroughly supported in Brownscombe and Smokorowski (2021).

1. Remove connection: Remove ‘Change or loss of wetted area’ endpoint, as there is no support for this connection
   - There is little evidence available to support that pressure changes associated with detonation activities in or near water result in significant losses of wetted area.
2. Wording change: Change wording from ‘Sublethal effects on fish’ to combine this pressure node with the endpoint ‘Fish mortality’ to ‘Sublethal effects and/or mortality’ as a common endpoint across PoE diagrams.
   - Both sublethal and lethal impacts are possible depending on the level of exposure and tolerance of the species. For this draft pathway, this wording change involves the combination of the pressure node (sublethal effects on fish) with the endpoint (fish mortality). See further rationale under ‘Land-based change #17’.
3. Wording change: Change wording in pressure node from 'Physical injury to fish' to 'Physical injury and/or stress to fish’
   - In addition to physical injuries, fish may also experience physiological stress in response to detonation effects. Furthermore, in mammals detonation can lead to injury of the hearing structures, which will not regenerate.
4. New connection: ‘Detonation in or near water-> ‘Instantaneous change in pressure’-> (NEW) ‘Altered migration patterns (avoidance behaviour) access to habitat -> ‘Potential direct or indirect impairment…’
   - The effect of an instantaneous change in pressure is that fish will avoid the area and/or change their behavior, which could reduce their access to habitat.
5. Change wording: Change ‘High velocity particle release’ to ‘High velocity water and solid particle movement’
   - The detonation of an explosive under water produces a shock wave that not only creates the instantaneous change in pressure (already captured on the diagram and described in Brownscombe and Smokorowski 2021), but also produces a sound energy wave, causing brief compression of water followed by a decompression. This sound wave travels longitudinally through the water and substrate, but not as a continuous pressure but by an alternation of compression and decompression. Thus, both water particles and solids transfer the sound energy away from the detonation sources at a very high speed, but the water particle movement is experienced at a greater distance than the solid particle movement before both dissipate. This can result in intense substrate vibrations that can cause fish injury and mortality, especially to fish eggs located in the substrate. Movement of the sound pressure wave caused by the energy transfer between moving water molecules causes both physical and auditory injury to the hearing structures and risk is

correlated with the distance of the receiver from the source. Auditory injury to mammals causes temporary and permanent noise frequency specific hearing loss.

6. New connection: ‘High velocity water and solid particle movement’ -> ‘Change or loss of habitat structure and cover’ (NEW ENDPOINT)
    - The movement of solids including the substrate can alter the structure and cover available to fish, therefore a direct connection is warranted.
7. ’New connection: ‘Detonation in or near water’-> ‘Substrate disturbance’-> ‘Resuspension of sediment’ -> (NEW) 'Deposit of deleterious substances’
    - Blasting often disturbs sediments, which can release deleterious substances contained within, such as heavy metals. Thus, this mechanism would not add new deleterious substances, but instead disturb existing sediments that reside within the substrate. Hence, a connection from resuspension of sediment to ‘deposit of deleterious substances’ should be added.
8. New connection: ‘Detonation in or near water’ -> ‘Substrate disturbance’ -> 'Resuspension of sediments -> ‘Sedimentation of fish habitat’ -> (NEW) 'Sublethal effects and/or mortality'
    - The sedimentation of fish habitat may cause direct fish mortality by depriving eggs or larvae of oxygen and may also have sublethal effects on fish. This connection should be added.
9. New connection: ‘Substrate disturbance ’ -> ‘Change or loss of habitat structure and cover’
    - A change of physical structure and cover may be caused by ground vibration and substrate disturbance, warranting a direct connection.
10. Wording change: Change wording from ‘Sound energy pulse’ to ‘Impulsive sound’
    - The WUA needs to be tied to the impact it has, which is associated with the produced sound type and the received dose and duration. It is important to differentiate between ‘impulsive sound’ and ‘continuous sound’ (see Appendix 1 for definitions and more detail below).
11. New connection: Connect ‘Detonation in or near water’ -> ‘Impulsive Sound’
    - There are two different effects to consider, the physical shockwave with the initial blast, and then sound pressure waves as the sound moves through the water, both of which can cause physical and auditory damage. Risk is dependent on distance (sound waves travel further than shock waves) and co-modulation of the different waves. The sound produced as a result of the detonation is an impulse and therefore a connection should be added to impulsive sound.
12. Remove endpoint: 'Change or loss of fish passage' as node, making a direct connection between ‘Alteration of migration patterns (avoidance behavior) access to habitat’ -> ‘Potential direct or indirect impairment…’
    - This connection is not only linked to passage, but is rather the use of the habitat itself that is important. Noise can have substantial effects on mammal behavior, such as altered directional heading and surfacing frequency, alterations of migration routes and exclusion from important habitat. It is suggested to remove 'Change or loss of fish passage' and to connect ‘Alteration of migration patterns (avoidance behavior)’ directly to ‘Potential direct or indirect impairment…’.

13. Wording change: Change wording from ‘Introduction of underwater noise’ to ‘Release of acoustic energy in water (sound)’
    - The new wording is more technically correct relative to the use of the subjective word ‘noise’. This pressure node would then lead to two types of sound (impulsive and continuous) because of the different mitigations required for each (new connections outlined specifically below).
14. New pressure node and new connection: ‘Release of acoustic energy (sound)’-> ‘Continuous sound’ (NEW) -> ‘Behavioural changes’ ->
    - Continuous sound sources (e.g., vibro-piling, dredging, drilling, vibro-densification of soils, and shipping) do not show abrupt changes in sound pressure levels, and can be both stationary and non-stationary sources that produce moderate sound pressure/amplitude levels typically of a longer duration. Continuous sounds can have impacts on communication and foraging efficiency, can alter habitat that is characterized by its acoustic quality, can displace organisms from important habitats, and can interfere with group behaviours.
15. New pressure node: ‘Release of acoustic energy in water (sound)’ -> ‘Continuous sound’ -> ‘Physical injury and/or stress to fish’ ->
    - Continuous sounds have the ability to cause auditory injury at close ranges (especially dredging, vibro-piling and drilling) but generally have lower source sound pressures and are less likely to cause physical harm than impulsive sounds. Continuous sound can have physiological impacts such as stress, auditory and signal masking.
16. New connection: ‘Release of acoustic energy in water (sound)’ -> ‘Impulsive sound’ -> ‘Physical injury and/or stress to fish’ -> 'Sublethal effects and/or mortality’
    - Impulsive sounds have the ability to cause physical (e.g. membrane ruptures) and auditory injury to the middle and inner ears of mammals causing temporary and permanent noise frequency specific hearing loss. Both effects can increase mortality due to loss of foraging ability or increased predation risk and loss of orientation capabilities. The potential for continuous sound to cause injury is low, however the potential for impulsive sound to cause injury is high.
17. New connection: ‘Behavioural changes’ -> 'Sublethal effects and/or mortality’
    - The behavioral effects of noise are relevant to a wide variety of contexts, including: fish migration irrespective of whether fish passage is involved, navigation in movement contexts outside of traditional definitions of migration, as well as other fitness related processes, such as feeding, predator avoidance, or larval development.
18. Wording change from : ‘Change in mammal communication’ to ‘Impaired communication and ability to navigate’
    - Underwater noise can affect the communication and navigation of a wide variety of marine life, including fish and invertebrates.
19. New pressure nodes and new connections: ‘Release of acoustic energy in water (sound)’ -> ‘Continuous sound’ -> ‘Acoustic Masking’ (NEW) -> ‘Impaired communication and ability to navigate’ (NEW) -> ‘Behavioural changes’
    - When an animal’s ability to perceive a sound (i.e. a signal) is affected by the presence of another sound (e.g. anthropogenic noise), communication and navigation can be

impaired which may cause behavioural changes (e.g. less effective foraging or predator avoidance). For the definition of ‘Acoustic masking’ see Appendix 1.

20. New connection: ‘Release of acoustic energy in water (sound)’ -> ‘Impulsive sound’ -> ‘Acoustic Masking’ -> ‘Impaired communication and ability to navigate’ -> ‘Behavioural changes’
    - Both continuous sound and impulsive sound can interfere with an animal’s ability to perceive sound, and alter their ability to communicate and navigate which can lead to changes in behaviour (e.g. forage and/or predator avoidance).
21. Remove pressure node: ‘Change or loss of wetted area’
    - There is little scientific evidence available to support that underwater noise results in a change or loss of wetted area. The effect of sound is on access to habitat (avoidance behaviour), which is already a pressure node on this diagram.
22. Remove pressure node: ‘Release of compressed air’ (REMOVE)
    - This pressure node 'release of compressed air' is recommended to be removed, because it is a particular type of impulsive (intermittent) sound.
23. New node and connections: ‘Placement of materials/structures in water’ -> (NEW) ’Electromagnetic field production’ -> Alteration of migration patterns/access to habitat’ -> ‘Sublethal effects and/or mortality’. Also add a direct connection from (NEW) ’Electromagnetic field production’ -> ‘Sublethal effects and/or mortality’
    - Electromagnetic Fields (EMF) are a pressure that has growing relevance, especially in marine systems with increased development of offshore wind energy projects and associated power cables. The effects of these cables are diverse, but most impacts are addressed in existing pathways (see Brownscombe & Smokorowski 2021 for details). Despite the fact that the impacts of EMF are not well studied, there is sufficient evidence to support including this pressure node, with connections to migration patterns/access to habitat, as well as sublethal effects and/or mortality.

Pathway of Effects Diagram 3: In-water WUAs

For the In-water PoE diagram, 31 suggested changes were discussed; 25 were accepted as recommendations for alteration in the final version of the In-water PoE diagram. These 25 changes are identified here, highlighted in Figure 6, and more thoroughly supported in Brownscombe and Smokorowski (2021).

1. Wording change: Change wording in pressure node from ‘Trampling of non-motile species’ to 'Trampling of less motile species and life stages'
    - Although there is no direct evidence of this in regard to using machinery in water, less-mobile species are likely more vulnerable to this impact in general. This may include species that fail to avoid trampling for a variety of reasons. For example, species such as those in the Gobiidae (gobies) and Cottidae (sculpins) families have behavioral tendencies to hide in interstitial spaces, which may increase their vulnerability to mortality from trampling. Although there is a general dearth of evidence on this issue, it would be logical to alter ‘non-motile’ to ‘less motile’ species and life stages.
2. New connection: ‘Use of machinery in water’ -> ‘Substrate disturbance’

- The use of machinery in water overall has a high likelihood of disturbing sediments, which should be added as a connection.

3. New connection: ‘Use of machinery in water’ -> ‘see Noise and Energy PoE diagram’
   - Since the operation of machinery can cause behavioural avoidance of the area by fish due to noise, this pathway is covered in the Noise and Energy PoE diagram.
4. Remove connection: Remove WUA -> see ‘Noise and Energy PoE diagram’
   - The linkage to the Noise and Energy PoE diagram is now covered in the more direct ‘use of machinery in water’ pressure node, so the higher level connection is no longer necessary.
5. New connection: ‘Loss of interstitial spaces’ -> ‘Decrease in food supply’.
   - Interstitial spaces provide a diversity of habitat for a wide range of biota from biofilms (i.e., attached bacteria, plankton, etc.), to invertebrates, to fishes, thus it was agreed that this connection was core enough to be included as a pathway on the diagram.
6. Wording change: Remove the word 'herbicide' so the pathway reads: 'Use of machinery in water -> 'Introduction of oil, grease, fuel, and other deleterious substances'
   - In this instance the introduction of deleterious substances is from the use of machinery in water, and therefore the inclusion of ‘herbicides’ here is not appropriate.
7. New connection: ‘Decrease in water quality’ -> ‘Decrease in food supply’.
   - Since a decrease in water quality can lead directly to an important decrease in food supply, it was felt that this connection was core enough to include as a pathway on the diagram.
8. New connection: ‘Change in channel morphology or shoreline morphometry’ -> ‘Constriction or expansion of flow/coastal currents’ -> (NEW) ‘Change or loss of wetted area’.
   - Removal of materials from lotic systems (streams and rivers) has been shown to reduce the overall wetted area, producing more narrow channel morphology and higher flows and water levels. Therefore, a direct connection from constriction or expansion of flow should be added to change or loss of wetted area.
9. New connection: ‘Change in channel morphology or shoreline morphometry’ -> ‘Change or loss of habitat structure and cover’ -> 'Potential direct or indirect...'
   - Changing the channel morphology or shoreline morphometry will directly impact habitat structure and cover available to fish, and therefore a direct link is warranted.
10. New connection: ‘Removal of materials (including organics)/structures’ -> ‘Stranding’ -> ‘Sublethal effects and/or mortality’.
    - Removal of structures such as dams and weirs can result in stranding of fish and invertebrates from the upstream side of the removal. Therefore, stranding should be added as a pressure node in this pathway connecting to sublethal effects and/or mortality.
11. New connection: ‘Removal of materials (including organics)/structures’ -> ‘Entrainment of fish’ -> ‘Sublethal effects and/or mortality’
    - Activities such as dredging have been documented to cause fish entrainment, warranting a connection from removal of materials -> entrainment of fish.

12. New connection: ‘Removal of materials (including organics)/structures’ -> ‘see Aquatic Invasive Species pathway (TBD)'
    - Structure removal can enable access for invasive species. For example, following the removal of the Oak Street Dam in Wisconsin, invasive canary grass (*Phalaris arundinaceae*) quickly overwhelmed native plants in the newly available terrestrial sediments. Researchers are modelling invasive species spread in anticipation of increased access to upstream habitat. It follows that the pathway for removals includes a node to recognize the potential for invasive species range expansion. Since the creation of a new Aquatic Invasive Species PoE diagram is in progress, the recommendation is to refer to the new diagram to capture the potential risk from structure removal.
13. Changes 13-16 all refer to re-drawing the connections related to substrate disturbance leading to resuspension of contaminants and sediment, because a ‘Decrease in water quality’ occurs upon resuspension, and prior to the deposit of said substances. Specifically, as follows:

    Rearrange connections: ‘Resuspension of contaminants’ -> ‘Decrease in water quality’ -> ‘Deposit of deleterious substances’ -> ‘Contamination of fish habitat (NEW PRESSURE NODE)’ -> ‘Potential direct or indirect…’
14. Rearrange connections: ‘Resuspension of sediment’ -> ‘Decrease in water quality’ -> ‘Deposit of deleterious substances’ -> ‘Contamination of fish habitat’ (NEW PRESSURE NODE) -> ‘Potential direct or indirect…’
15. Rearrange connections: ‘Resuspension of sediment’ -> ‘Sedimentation of fish habitat’.
16. Rearrange connections: ‘Introduction of oil, grease, fuel, and other deleterious substances’ -> ‘Decrease in water quality’ -> ‘Deposit of deleterious substances’ -> ‘Contamination of fish habitat’ (NEW PRESSURE NODE) -> ‘Potential direct or indirect...’
17. Wording change: Change pressure node wording from ‘Fish mortality’ to ‘Sublethal effects and/or mortality’.
    - See rationale under ‘Land-based change #17’.
18. New connection: ‘Placement of materials/structures in water’ -> ‘Decrease in water quality’
    - Decreases in water quality can occur from leaching of deleterious substances directly from the material placed in water (e.g., uncured concrete).
19. New connection: ‘Placement of materials/structures in water’ -> ‘Sedimentation of fish habitat’.
    - Placement of a wide variety of materials may result in the sedimentation of fish habitat through mechanisms beyond alterations in flow patterns, hence, a high-level connection from placement of materials to sedimentation of fish habitat is warranted.
20. New connection: ‘Placement of materials/structures in water’ -> 'See Flow PoE diagram'
    - Fish stranding and other impacts may occur due to the changes in channel morphology, wetted area, and/or flow (particularly below hydropeaking dams), but the connection is more related to dam operation as opposed to the addition of the dam structure per se, warranting a higher level connection to cover various types of ‘materials and structures’ placed in water.

21. New connection: ‘Removal of aquatic vegetation’ -> ‘Change or loss of habitat structure and cover’.
    - Aquatic vegetation serves directly as a source of structure and cover for many fishes, and therefore the direct link is warranted.
22. Pressure node removal: remove ‘Loss of aquatic vegetation’ (REMOVE) -> ‘Decrease in nutrient input’ (REMOVE) -> ‘Decrease in nutrient concentrations’ (REMOVE) -> ‘Decrease in primary productivity’ in this pathway. Instead connect ‘Removal of aquatic vegetation’ -> ‘Decrease in primary productivity’ -> ‘Potential direct or indirect…’
    - The extra pressure nodes identified in this chain represent increased detail of mechanisms that is inconsistent with the level of detail included in the other pathways.
23. New connection: ‘Removal of aquatic vegetation’ -> ‘Decrease in food supply’.
    - Aquatic vegetation is a direct food source for some fish species and for secondary producers (e.g., invertebrates) that are consumed by fishes, and therefore a direct connection is warranted.
24. New connection: ‘Removal of aquatic vegetation’ -> ‘see Aquatic Invasive Species pathway (TBD)'
    - Some aquatic invasive species have difficulty becoming established if native vegetation or species are abundant, but once the natives are removed, it can provide the opportunity (empty niche) for invasive species to establish and thrive.
25. New connection: ‘Placement of materials/structures in water’ -> ‘Smothering of bed/seafloor’
    - Currently ‘Smothering of bed/seafloor’ is included at the start of an independent pressure pathway, yet it occurs predominantly due to placement of materials/structures in water, and hence, should be included as a component of this pressure pathway.

Pathway of Effects Diagram 4: WUAs affecting flow

For the Flow PoE diagram, 30 suggested changes were discussed; 25 were accepted as recommendations for alteration in the final version of the Flow PoE diagram. These 25 changes are identified here, highlighted in Figure 7, and more thoroughly supported in Brownscombe and Smokorowski (2021).

1. Wording change: Change pressure node wording from ‘Interbasin transfer of species’ to ‘Increased species interbasin transfer/risk of invasives’ -> See ‘Aquatic Invasive Species Pathway (TBD)’.
    - The diversion of water can form connections between previously disparate aquatic ecosystems, which has been documented to enable species (including animal, plant, pathogen) invasions. Further, the diversion of water often results in altered conditions within both affected systems, which creates opportunities for introduced or invasive species to become established. This is a well-supported pathway, but because it involves more than the transfer of species across basins, the wording change is recommended.
2. Wording change: Change pressure node wording from ‘Fish mortality’ to ‘Sublethal effects and/or mortality’.
    - See rationale under Land-based change #17.
3. New connection: ‘Water diversion' -> ‘Altered water temperature’

- Water diversions may change the temperature of both the diversion reach and the receiving water body, and the direction of the change is dependent on the temperature differences between the two, and the volume of transfer relative to the two affected systems.

4. New connection: ‘Water diversion’ -> ‘Water level/flow modification (change in hydraulics) including impoundments’
   - Since water diversions directly affect the discharge or level of both the diverted and receiving water bodies, this direct connection is warranted.
5. Remove connection: ‘Water diversion’ -> ‘Displacement or stranding of fish’ -> ‘Fish mortality’.
   - With the explicit connection now between ‘Water diversion’ -> ‘Water level/flow modification’, and the subsequent connections to stranding and mortality on the right-hand-side of the diagram, this connection is no longer required a 2nd time on the left-hand side of the diagram.
6. Wording change: Change pressure node wording from ‘Increase in water temperature’ to ‘Altered water temperature’.
   - See rationale under ‘Land-based change #4’ regarding baseflow effects. For the new connection (Flow change #3), water diversions can involve the mixing of diverted/receiving water with a range of temperature differences, and therefore the term ‘altered water temperature’ is more appropriate.
7. New connection: ‘Decrease in baseflow’ -> ‘Altered food supply’
   - See rationale under ‘Land-based change #8’.
8. New connection: ‘Altered water temperature' -> ‘Sublethal effects and/or mortality’
   - Water temperature is a primary driver of fish energetics and thus affects metabolism, growth, and reproduction; any change in water temperature can lead to sublethal effects on fishes. Changes in ambient water temperature can lead directly to fish mortality when resulting temperatures are outside of the bounds of a fish's thermal tolerance.
9. New connection: ‘Sedimentation of fish habitat’ -> ‘Sublethal effects and/or mortality’
   - See rationale under ‘Land-based change #18’.
10. Remove connection: ‘Change in food supply’ -> ‘Change or loss of habitat structure and cover’.
    - While alteration of substrate composition can lead to a change in food supply and to a change or loss of habitat structure and cover, there is no evidence to suggest a cause-and-effect relationship between a change in food supply and a change or loss of habitat structure and cover.
11. Wording change: From 'Scouring of channel bed/bank erosion' to ‘Scouring of the channel bed and bank/shoreline erosion’
    - The original wording was more suitable to lotic systems, however, scouring and erosion can occur on lake and coastal marine shorelines as well, warranting a change in wording.
12. New connection: ‘Scouring of the channel bed and bank/shoreline erosion’-> 'Sedimentation of fish habitat'

- Scouring of the channel bed or erosion of the bank mobilizes fine sediment, which could therefore deposit downstream leading to the sedimentation of fish habitat.

13. New pressure node and new connections: ‘Water level/flow modification’ -> (NEW) ‘Altered sediment supply’ -> ‘Change in channel morphology or shoreline morphometry’
    - Sediment itself is not always detrimental to aquatic systems, given that there needs to be a supply of sediment to maintain channel equilibrium, maintain habitat, and avoid sediment ‘starved’ reaches of rivers. Therefore, changes to the rate of sediment input in either direction could become a problem.
14. New connection: 'Change in channel morphology or shoreline morphometry' -> 'Change or loss of habitat structure and cover'
    - Changes in channel or shoreline shape and form directly modifies the habitat structure and cover available to fishes, so this connection is warranted.
15. Remove connection: Remove ‘Alteration of attraction flows/flow barriers’ so that the resulting pathway is as follows: ‘Water level/flow modification (change in hydraulics) including impoundments’ -> ‘Alteration of migration patterns/access to habitat’ -> ‘Change or loss of fish passage’.
    - ‘Attraction’ is one mechanism driving the impact of water level/flow modification on fish passage, and therefore the pressure node was considered redundant. Attraction flow is an important component of passage (e.g., migration motivation), therefore this mechanism is highlighted in Brownscombe and Smokorowski (2021).
16. New connection: ‘Alteration of migration patterns/access to habitat’ -> ‘Sublethal effects and/or mortality’.
    - Currently this connection is made through ‘Change or loss of fish passage’, which is accurate. However, there are a variety of ways independent of fish passage by which altering migration success and/or access to habitats can impede essential life processes such as spawning or foraging, which can cause reduced biological fitness through direct mortality, or reduced growth, reproductive output or success.
17. Remove ‘Change in thermal cues or temperature barriers’, directly connecting 'Displacement or stranding of fish' -> 'Sublethal effects and/or fish mortality'
    - The connection from displacement of fish to changes in temperature-related impacts on habitat access is not well supported in the literature. There are a variety of reasons why fish become displaced or stranded when water levels or flows change (e.g., rate of flow change, fish species or life stage, channel morphology, time of day, season, etc.). The result of fish being trapped in isolated pools or on dry substrate can be sublethal (e.g., thermal stress) or lethal (e.g., bird predation or desiccation). Therefore, a direct connection from displacement or standing of fish to sublethal effects and/or mortality is more accurate and encompassing.
18. New connection: ‘Altered water temperature’ -> ‘Sublethal effects and/or mortality’.
    - As with Flows/Levels change #8 above, this direct linkage should be made on the right-hand side of the diagram.
19. Pressure node removal: Remove ‘Thermal loading’
    - Redundant to ‘Change in water temperature’.

20. Pressure node removal: Remove ‘Decrease in dissolved oxygen’
    - This is the one place in all the PoE diagrams that dissolved oxygen is included as separate from water quality, however, water quality necessarily includes dissolved oxygen. Therefore, this pressure node is redundant knowing that dissolved oxygen is included with the water quality pressure node.
21. Pressure node removal: Remove ‘Nutrient loading’
    - Redundant to ‘Increase in nutrients’.
22. New connection: 'Decrease in water quality' -> 'Sublethal effects and/or mortality'
    - In addition to nutrients, wastewater also commonly contains a wide variety of substances that can be harmful to fish health. These chemicals can have a diversity of impacts, including reduced reproductive success. There is a strong basis of support for connecting decreases in water quality to fish mortality and sublethal effects.
23. New connection: ‘Introduction of wastewater’ -> ‘Water level/flow modification (change in hydraulics) including impoundments’.
    - The introduction of wastewater can affect water quantity, particularly in some systems with municipal sewage treatment plant outflows and/or municipal storm water drains, and at particular times of year when instream flows are low.
24. Wording change: Change title of this pathway from ‘WUAs affecting flows’ to ‘WUAs affecting water levels and flows’.
    - Including the word ‘levels’ in the diagram title better describes changes that happen in lentic and marine coastal environments, some of which are captured in this PoE diagram. However, not all large lake/coastal processes are captured (e.g., wave attenuation and tidal currents), therefore consideration should be given to the development of a separate coastal PoE diagram more streamlined to dealing with coastal marine and large lake impacts from WUAs.
25. Wording change: Change wording from ‘Dewatering/pumping’ to ‘Dewatering’.
    - ‘Pumping’ is included in the ‘dewatering/pumping’ pressure node, but pumping is a WUA. Hence, ‘pumping’ may be moved to the broader description of WUAs, altering the pressure node to ‘dewatering’

All Four Reviewed Pathways of Effects Diagrams

Objective 3 involved examining if the use of the PoE diagrams in general would aid FFHPP in achieving their program objectives. Specifically, Objective 3 was focused on determining if the process of using these revised PoE diagrams allows FFHPP to identify which endpoints require avoidance and mitigation measures to reduce and manage the risk that the proposed WUA will impair the habitat’s capacity to support the life processes of fish (or result in death of fish), and to identify residual impacts to be evaluated for authorization and offset, thus ensuring that fish and fish habitat are conserved and protected.

Discussions were held around whether the four diagrams will help FFHPP determine endpoints that require avoidance and mitigation measures. During the consolidation of the PoEs, FFHPP minimized the endpoints to the six that FFHPP manages through mitigation measures: 1. Change or loss of riparian zone; 2. Change or loss of fish passage; 3. Change to or loss of wetted area; 4. Sedimentation of fish habitat, 5. Change or loss of habitat structure and cover;

and 6. Sublethal effects and/or mortality. The question was discussed whether there are enough endpoints to capture the components of fish habitat that are affected by the pressures (and incorporating language used during a science review process held by DFO (2014)) that characterized the productivity-response curves to WUA effects on the state of fish habitat. Endpoints that were examined using the literature to derive productivity-state response curves (in DFO 2014) that are not specifically identified as endpoints in the consolidated PoE diagrams include: change in nutrient concentration, change in food supply, change in temperature, change in noise and vibration, change in electromagnetic field, change in access to habitat, change in dissolved oxygen, baseflow, and hydrodynamics. However, these are still included in the consolidated diagrams as pressure nodes, or in the case of noise and vibration, have formed the basis of an entire PoE diagram. Thus, they would still be considered during project reviews.

It was determined that the process of using these revised consolidated PoE diagrams will facilitate the application of avoidance and mitigation measures to identify residual impacts, and thus Objective 3 was achieved, with a few caveats. Specifically, these PoEs do need to be used in a manner that ensures all possible linkages and all applicable PoE diagrams are consulted, potentially including others that were not revised during this review, if applicable. There are also some relevant pathways that have not been developed (or fully developed), yet are applicable to DFO project reviews (e.g., aquatic invasive species, marine or large system coastal processes). While it is recognized that the focus should be on pressures and endpoints that DFO can manage, it is important that attention is still given to those that are not managed as part of the DFO review process. Training in their consistent application and the posting of supporting documentation on the public-facing website would also help ensure that FFHPP program objectives are met via the use of PoE diagrams.

Sources of Uncertainty

There are a number of sources of uncertainty that need to be considered when using any PoE diagram. For instance, these diagrams are highly generalized for the identified WUAs, and therefore may not be applicable at all times or in all locations. Differences in ecosystem type (e.g., small stream vs. large river vs. small lake vs. large lake) or location (e.g., montane vs. prairie vs. shield) will influence which pressures are more or less applicable. Similarly, differences in WUA location, scale and specifics would influence which PoE diagrams are applicable, and how they are applied. To avoid repetition and increase tractability, references are made across diagrams; thus, more than one PoE diagram will often be required. While it is expected that users of these diagrams will have a relevant science background and understanding of their correct application, uncertainty would increase if they are not used appropriately.

The strength of the evidence supporting the included pressures, pathways, and endpoints varies greatly, and each was classified according to evidence available in Brownscombe and Smokorowski (2021). While all pathways included have some support, the importance of each lies in its ultimate impact on productivity, and these final linkages were not reviewed as part of this process.

The operational gains made by simplifying multiple PoE diagrams into fewer generalizable diagrams may result in uncertainty as to which parts of the diagram(s) are relevant to a specific project. Sub-activities (included in all but the Land-based PoE diagrams) are intended to facilitate identification of relevant parts of the diagrams, thus reducing duplication that was originally included in the 20 activity-specific PoE diagrams without losing existing linkages. However, by adopting a simpler set of frameworks it may change how practitioners view an

activity, and may result in the loss of some knowledge context when interpreting WUA impacts. The provision of supporting tools, resources, and training would reduce this uncertainty.

While all connections among WUAs - pressures - endpoints are depicted linearly in the diagrams, it should be kept in mind that the nature of the connections may not be linear (e.g., exponential, sigmoidal, polynomial), and this could influence endpoints and potential residual effects in different ways. Similarly, the interactions between pressures and the environment are not always known and/or captured in pathways.

CONCLUSION

This review of the consolidated PoE diagrams suggested numerous changes are needed to fully capture the impacts to be considered by DFO during a review of a WUA in or near water. All suggested changes are identified in the analysis section, highlighted in Figures 4-7, and supported with greater detail in Brownscombe and Smokorowski (2021). Incorporating the suggested changes will produce PoE diagrams that are sufficiently comprehensive and complete, encompassing the core components of WUA impacts on fish and fish habitat with the purpose of being tractable for FFHPP decision-making and communication. Thus, Objectives 1 and 2 were achieved.

Under Objective 3 it was concluded that the process of using these revised PoE diagrams, if used in a manner that ensures all possible linkages and all applicable PoE diagrams are consulted, will facilitate the application of avoidance and mitigation measures and will help identify residual impacts. Exceptions were noted related to marine or large system coastal processes, aquatic invasive species, and other development-specific PoE diagrams (e.g., shipping) that are not part of the four core diagrams reviewed here.

OTHER CONSIDERATIONS

The intent of this review was to capture the most common or main PoE pressures and endpoints that are managed by FFHPP, and therefore it is recognized that there are potential pressures and endpoints that are not considered in these diagrams. For example, there is ample evidence that WUAs in the watershed upland of the riparian zone (e.g., land-use, forestry), can have major impacts on lowland or downstream waterbodies and watercourses. But, since these activities are not managed by DFO, they are not included in any of these diagrams. In addition, final linkages between the individual pathways and the impact on fish productivity were not reviewed as part of this process. Wherever possible, effort should be made to document the impacts of pressures on fish productivity via standardized monitoring of the impacts of WUAs (and employed mitigations) to ultimately improve the support base for each pathway.

The use of these PoE diagrams will often result in the use of more than one diagram at a time, and multiple endpoints may be affected by one WUA. Consideration also needs to be given to how these four general PoE diagrams relate to other specific PoE diagrams (e.g., shipping, aquaculture), when relevant. However, considering multiple endpoints across one or multiple PoE diagrams does not mean that the true impacts of multiple stressors and cumulative effects are captured. Cumulative effects considerations are now required by the *FA* (34.1(1)) under factors to be considered in project reviews. Specific methods for considering cumulative effects are in development by DFO, and these should be incorporated when available.

PoEs, as presented, imply linear connections, non-interactive and/or equal effects, and a general lack of feedback loops. Changing or adding non-linearity, weak/strong connections, and

loops have the potential to enhance or subdue the impacts of these pathways. This is not to minimize the value of the PoE diagrams, but to caution about what is not considered that could affect outcomes, and especially unexpected cumulative effects.

Finally, it is important to note that the ultimate version of these PoE diagrams that will be formally adopted for use in FFHPP decision-making may not include all changes suggested here. Decisions as to the final version of the PoE diagrams to be posted and used by decision-makers and proponents will be made by FFHPP in consideration of this science advice along with other regulatory and practical factors. As noted above, producing a standardized set of diagrams does not ensure their standardized use, so it is strongly recommended that training on their standard use and supporting documentation (including the database of literature referred to in Brownscombe and Smokorowski (2021)), is provided.

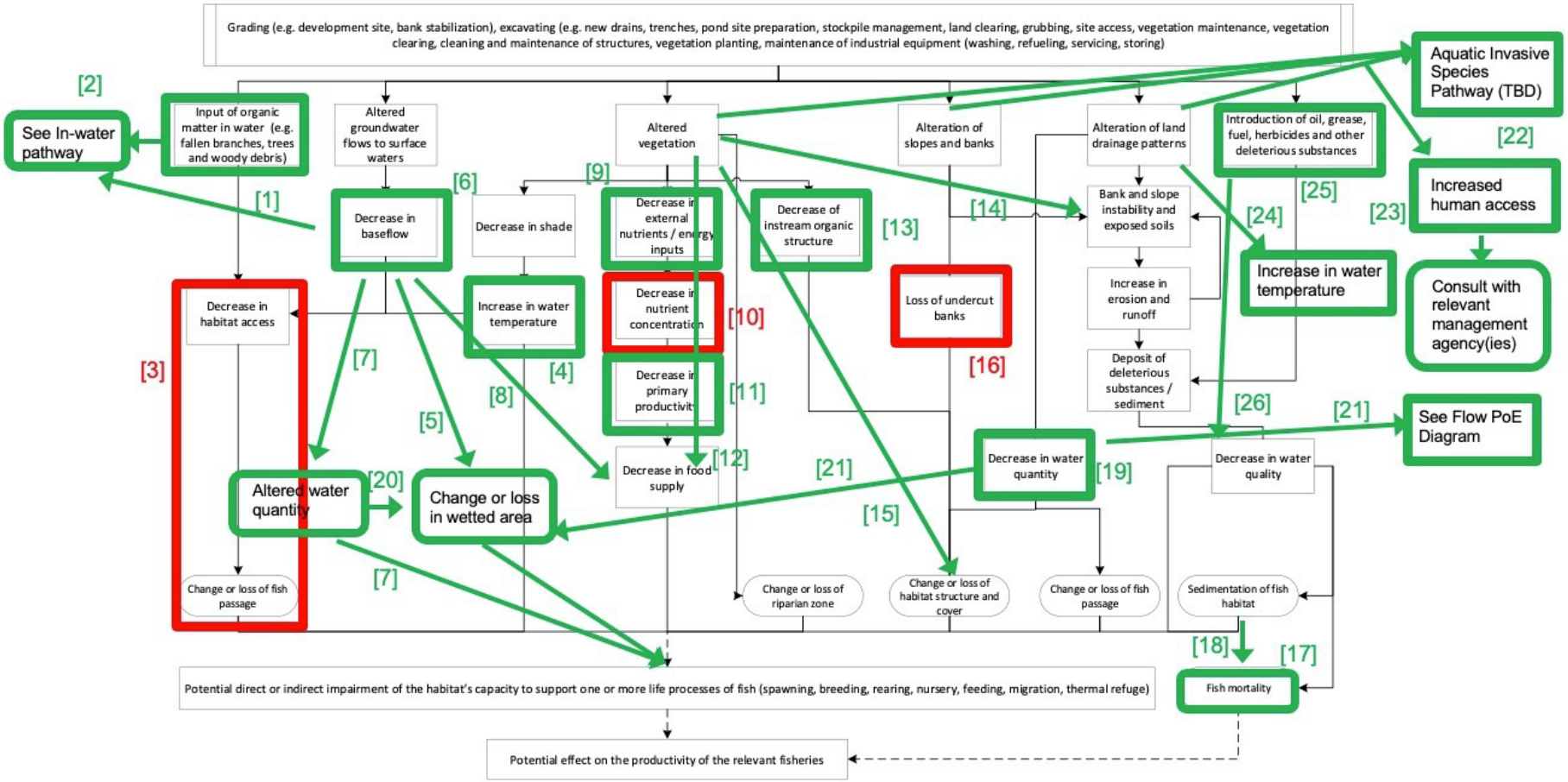

Figure 4: Overview of potential alterations to the draft (September 2020) Pathways of Effects diagram for land-based WUAs. Additional lines indicate connections that may be added (green) or removed (red); additional boxes indicate alterations or additions to pressures or endpoints.

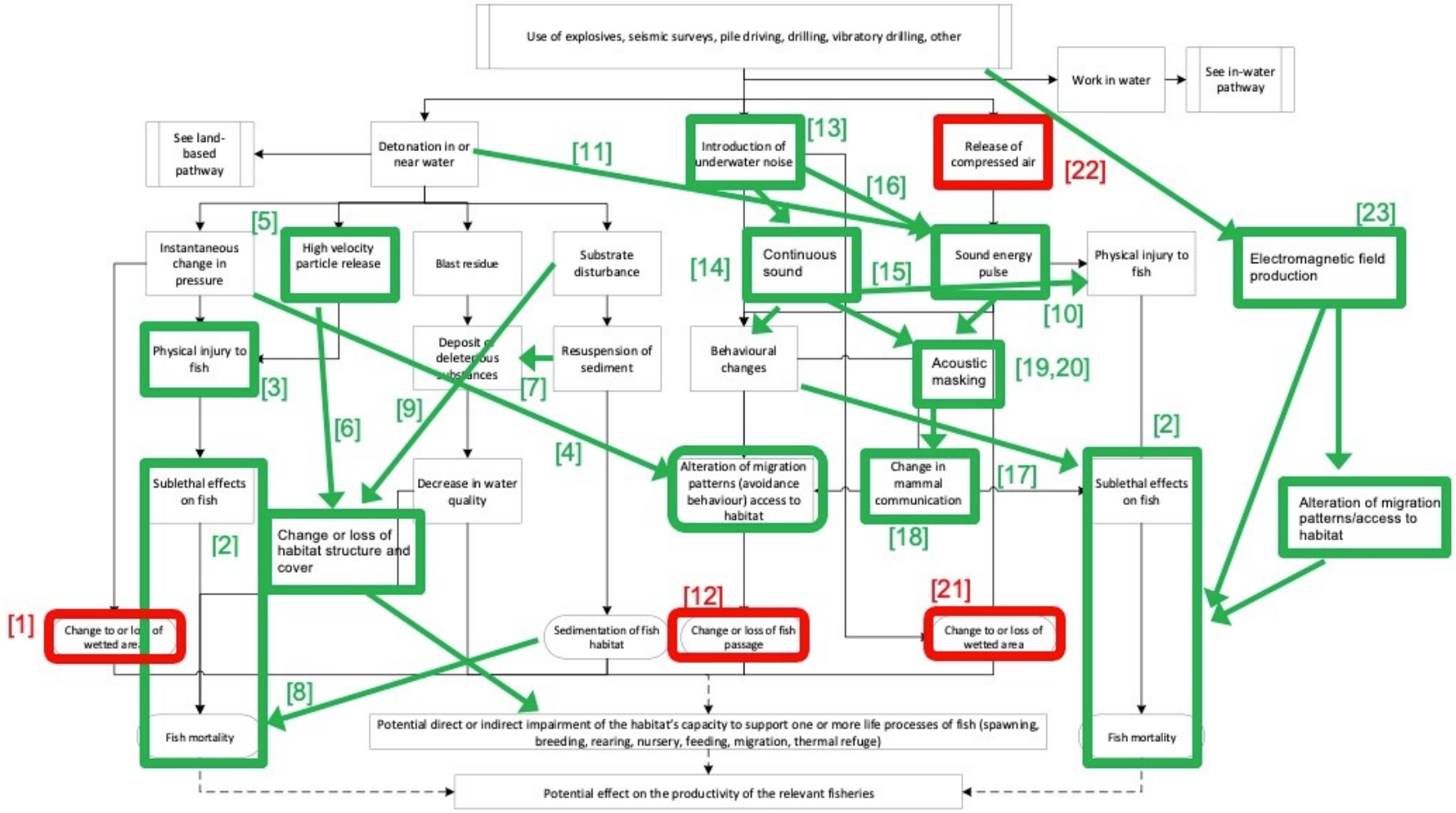

Figure 5: Overview of potential alterations to the draft (September 2020) Pathways of Effects diagram for noise and energy producing WUAs. Additional lines indicate connections that may be added (green) or removed (red); additional boxes indicate alterations or additions to pressures or endpoints.

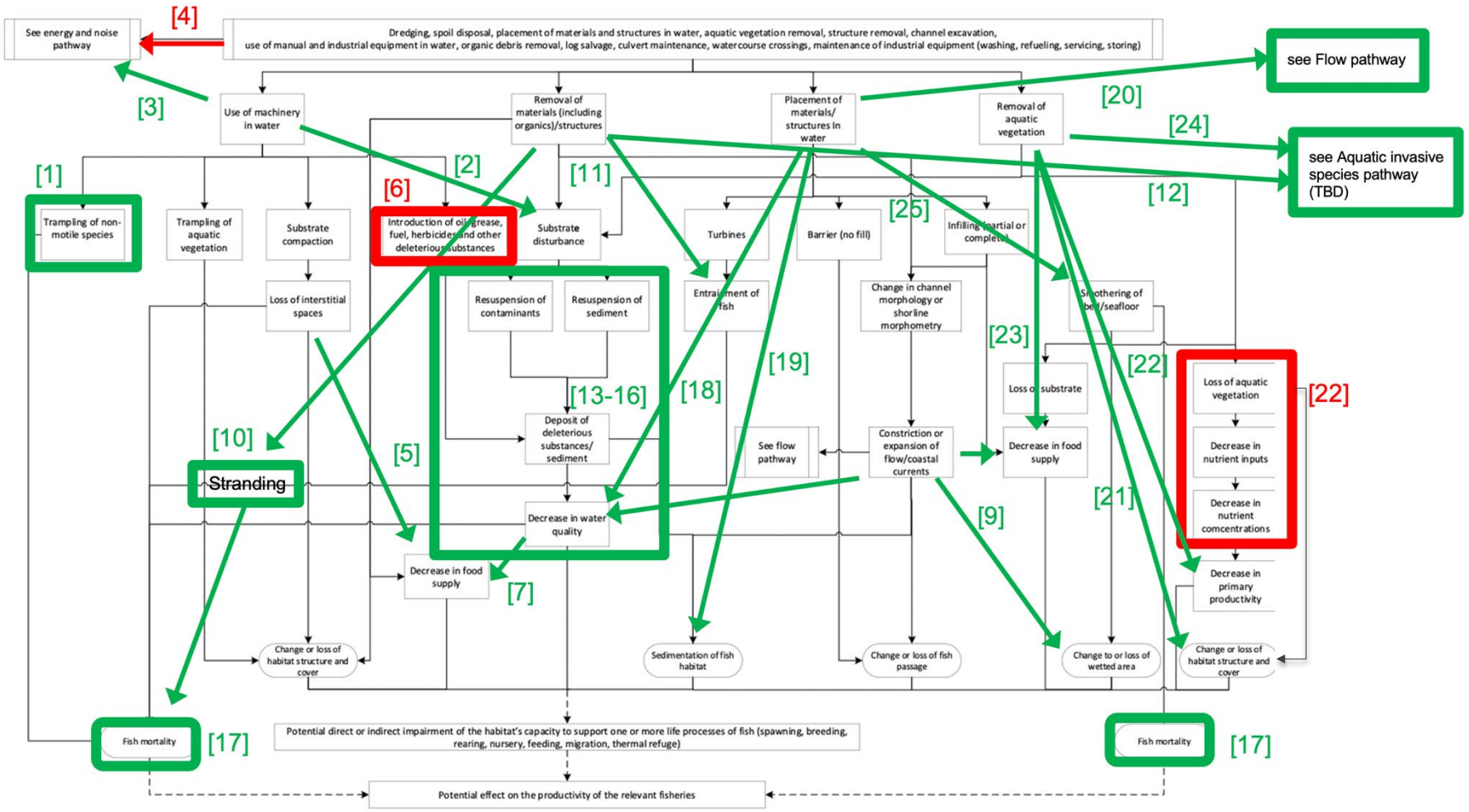

Figure 6: Overview of potential alterations to the draft (September 2020) Pathways of Effects diagram for in-water WUAs. Additional lines indicate connections that may be added (green) or removed (red); additional boxes indicate alterations or additions to pressures or endpoints.

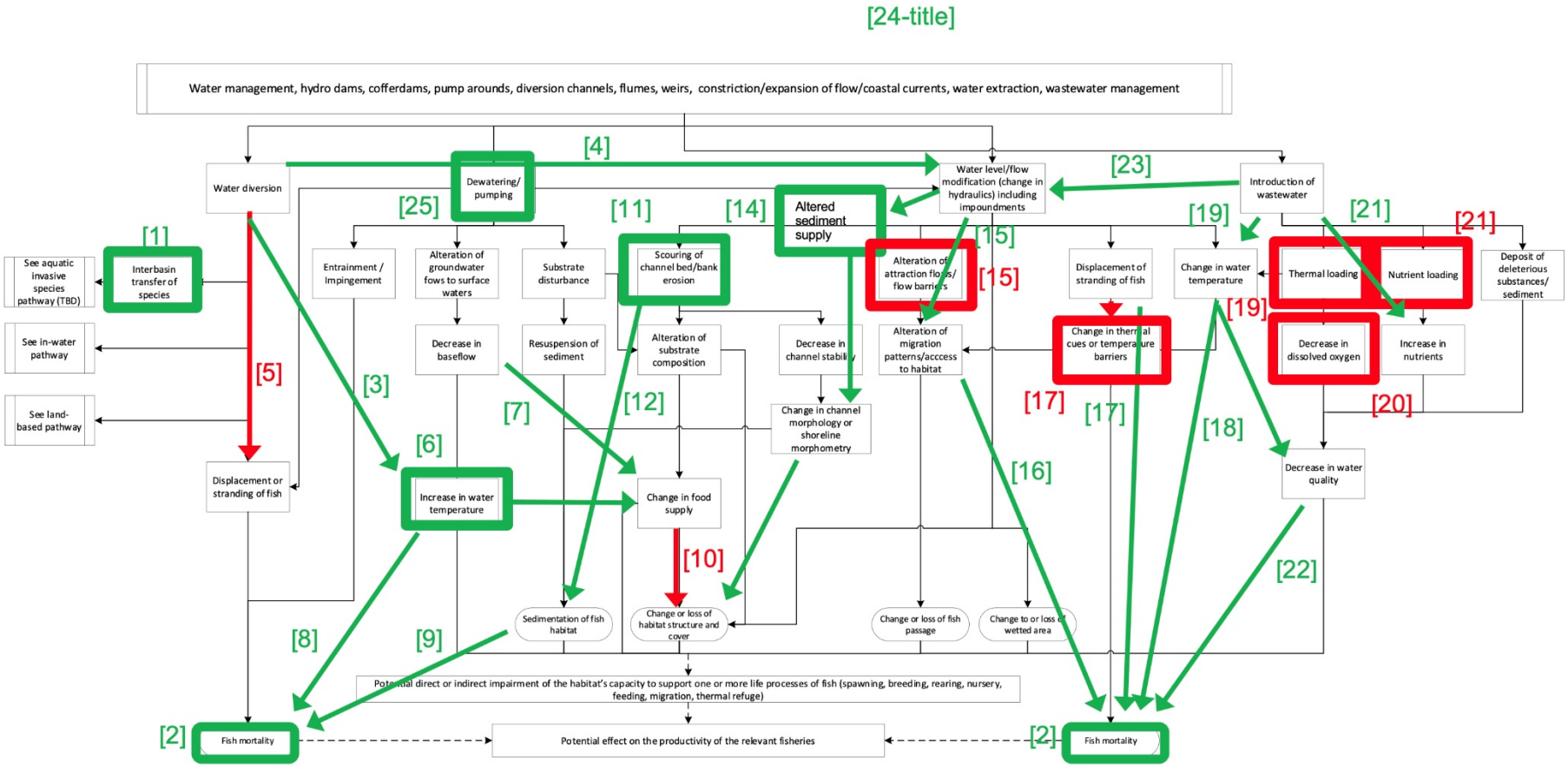

Figure 7: Overview of potential alterations to the draft (September 2020) Pathways of Effects diagram for WUAs affecting flows. Additional lines indicate connections that may be added (green) or removed (red); additional boxes indicate alterations or additions to pressures or endpoints.

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White, Hilary (Rapporteur)	DFO, Science, NCR
Wong, Melisa	DFO, Science, MAR
Yurk, Harald	DFO Science, Pacific

SOURCES OF INFORMATION

This Science Advisory Report is from the February 23-26, 2021, National Advisory Meeting on Science advice on revisiting Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

Brownscombe, J.W., Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.

DFO. 2014. A Science-Based Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/067.

DFO. 2018. Projects near water: Pathways of Effects. Last accessed May 18, 2021.

DFO. 2021. Projects near water. Last accessed on May 14, 2021.

APPENDIX 1 - TERMS AND CONCEPTS

Table Glossary of terms used in this advisory report.

Term	Description	Reference
Acoustic masking	This type of acoustic interference is referred to as masking and results in the reduction of a receiver's performance, as the sound of interest cannot be effectively perceived, recognized or decoded. In the case of 2-way communication involving a sender and a receiver, masking results in the reduction of both the sender's and the receiver's performance.	Clark, C.W., Ellison, W.T., Southall, B.L., Hatch, L., Van Parijs, S.M., Frankel, A. and Ponirakis, D., 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Marine Ecology Progress Series*, *395*, pp.201-222.
Continuous sound	Continuous sounds are those that are not characterized by abrupt onsets and rapid decay but release sound energy continuously over a longer period of time. Continuous sound sources include sound waves released by vibro-piling, dredging, drilling, vibro-densification of soils, and shipping.	ISO 1996-1:2016 - Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures.
Endpoint	Measurable change to fish populations or fish habitat components caused by a WUA through one or more pathways.	Brownscombe, J.W. and Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.
Fish	Fish includes (a) parts of fish, (b) shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals, and, (c) the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals; (poissons).	Minister of Justice, 2019. Fisheries Act.
Herbicide	An agent, usually chemical, for killing or inhibiting the growth of unwanted plants.	Encyclopaedia Britannica, 2021.
Impulsive sound	Impulsive sound means sound characterized by brief bursts of sound pressure, of short duration, usually less than one second, with an abrupt onset and rapid decay. Sources of impulsive sounds with high levels of acoustic energy/intensity include impact pile driving hammer strikes and airgun array shots.	ISO 1996-1:2016 - Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures.
Linkage	Directional connection between a WUA, pressure node, or endpoint.	Brownscombe, J.W. and Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.
Motile	The ability to move actively and on instinct, usually consuming energy in the process.	Biology Online. 2021.

Term	Description	Reference
Pesticide	Any toxic substance used to kill animals, fungi, or plants, often classified according to the type of organism they are intended to control (e.g., insecticides, herbicides, nematicides, fungicides, lampricides, rodenticides).	Encyclopaedia Britannica, 2021.
Pressure	A human driven change in any chemical, physical, or biological entity that can cause an effect on fish and/or fish habitat and may lead to harmful impacts.	Brownscombe, J.W. and Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.
Pressure pathway	A series of linkages from a WUA(s) to pressure nodes, terminating at endpoints.	Brownscombe, J.W. and Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.
Riparian zone (freshwater)	Riparian zones are defined as features outside the aquatic ecosystem which support the establishment and maintenance of deep and shallow pool features, supply food for migrating and juvenile fish of many species, and influence water temperature (e.g., tree shade).	Caskenette, AL, Durhack, TC, Enders, EC. 2020. Review of information to guide the identification of Critical Habitat in the riparian zone for listed freshwater fishes and mussels. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/049. vii + 67 p.
Riparian zone (marine)	Seaward of HHWLT (higher high water large tide) to limit of salt marsh or brackish marsh vegetation or to tidal elevation which is submerged <10% annually; and landward of HHWLT to spray limit, dune veg, or half potential tree height or 30m linear distance, whichever is greater.	Levings, C, Jamieson, G. 2001. Marine and Estuarine Riparian and their Role in Coastal Ecosystems, Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/109. 42 p.
Water quality	Water quality is a measure of the condition of water relative to the requirements of one or more species and/or to any human need or purpose.	Johnson, D. L., Ambrose, S. H., Bassett, T. J., Bowen, M. L., Crummey, D. E., Isaacson, J. S., ... & Winter-Nelson, A. E. (1997). Meanings of environmental terms. Journal of environmental quality, 26(3), 581-589.
Woody material	Hard fibrous plant material. Literature often refers to it as 'coarse woody debris' or 'large woody material' or variations therefor. Typically includes trees, branches, or wood debris.	Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., ... & Cummins, K. W. (1986). Ecology of coarse woody debris in temperate ecosystems. Advances in ecological research, 15, 133-302.
Works, undertakings and activities (WUAs)	Human actions that may impose pressures on fish and fish habitat.	Brownscombe, J.W. and Smokorowski, K.E. 2021. Review of Pathways of Effects (PoE) diagrams in support of FFHPP risk assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/079. iv + 55 p.

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