Peer Review of:
10-Year Panda Diversion Channel Monitoring Program Summary:

Prepared for:

INDEPENDENT ENVIRONMENTAL MONITORING AGENCY

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Table of Contents

Overview

The framework and content of my report is based on the presumption that I was asked to review this report at least in part because of my involvement in a detailed assessment of the Panda Diversion Channel (PDC) during its first 3 years of operation (1998-2000; with a bit of data from 2001), conducted by a University of Alberta research team. Thus, the reader of this "peer review" should make no mistake: I am not a completely independent, "arms length" observer, although I have had no direct connections with BHP Billiton since ca. 2001. The PDC project that I was involved in resulted in 5 peer-reviewed publications (Jones et al. 2003*a*,*b*, 2008; Jones & Tonn 2004*a*,*b*) that focused on quantitatively comparing various components of the PDC ecosystem to those from a suite of regional reference streams; a 6th publication (Jones et al. 2003*c*) summarized overall conditions of natural Barrenlands streams in the EKATI region. This series of publications established that during those first 3 years, the PDC was qualitatively providing many/most of the ecosystem characteristics and services of natural streams, but that it (the PDC) invariably fell quantitatively short in its provision of those characteristics and services, relative to values measured in the suite of reference streams.

That a newly constructed stream did not immediately perform "on par" with natural streams that have been developing for thousands of years is neither surprising nor alarming, of course. From a habitat compensation point of view, however, it's important to document the length of this "sub-par" period and/or the degree or rate at which the constructed stream approaches the functioning of natural, reference streams. This is because even if the new stream eventually achieves parity with natural references, the accumulated years of sub-par performance should be incorporated into "compensation ratios" and/or the productive capacity goal of the habitat compensation should be greater than the productive capacity of the natural, reference systems (Minns 2006).

Given the extensive and quantitative nature of those peer-reviewed publications, their use of reference systems (a basic component of any proper assessment in applied ecology, e.g., Downes et al. 2002), and the lack of reference systems in the official PDC Monitoring Program until 2003, I might have thought that the 10-year summary (Rescan 2010) would have provided extensive and quantitative comparisons of those early findings with the more recent conditions in the PDC, relative to current reference ecosystems. Of course, to make such comparisons meaningful, the same or comparable methods would need to be used. Indeed, by citing 2 of the 6 publications, Rescan's (2010) Overview seemed to imply that there would be some comparisons with at least some of our peer-reviewed data. However, that was the last we heard of our 1998-2000 "state of the PDC" investigations. Instead, we soon learned that even though most of the parameters that were being monitored in the latter period were the same or similar to what we had measured earlier (e.g., water temperature and quality, fish habitat, primary producers and invertebrate communities, summer fish residents, and growth/production of young-of-year Arctic grayling), (a) the methods used in the later years were mostly different and not comparable to those of our U of A group, and (b) even internally, the official PDC Monitoring Program sometimes changed methods without establishing any way to compare results from earlier and later methods. Both are unfortunate, and immediately compromises one's ability to rigorously assess the very different findings that are presented in Rescan (2010) for the 2003-2008 period, relative to the published findings for 1998-2000.

Another shortcoming that compromises the ability to assess the PDC Monitoring Program and its findings is that methods are often inadequately described, data are sometimes not presented in full, and statistical analyses are completely absent. I acknowledge that these steps were probably taken to reduce the length of this "summary", and that methodological details, a more complete presentation of data, and statistical results are presented in annual technical reports; nevertheless, this often made rigorous evaluation of this report, as a stand-alone document, challenging. Although I was given access to some of those annual technical reports, anything more than just a few cursory looks was beyond the scope of this review. Occasionally, from either those cursory looks or other sources, reference is made to one or another annual report, but those references should not be considered complete by any means.

Structure of this review

Initially, I provide some more general comments on the introductory material in Rescan (2010) and on general aspects of study design, methods, and analyses. Subsequently, I have organized the bulk of my comments around the 22 "key findings" of Rescan's (2010) Section 4: Conclusions. After this, I briefly summarize my review of Rescan (2010), of the 10-year PDC Monitoring Program, and of the "state of the PDC" as presented in Rescan (2010). Finally, I address three questions that were given to me to consider: Is the PDC working well? Is further monitoring required? if so, what should be monitored?

Review of 10-Year Panda Diversion Channel Monitoring Program

Executive Summary

The summary statements in this section are completely qualitative, e.g., "observations", "similar", "multiple" … Although this may be appropriate, given the contents of the report, the upshot is that the concluding statements are less than fully convincing.

1. Introduction

1.1 Overview.- As noted, the inclusion of 2 (of 6) U of A-based publications suggests that at least some comparisons with the 1998-2000 findings of Jones & colleagues would be included. Although that would have made sense, it was not to be.

1.2.1 Panda Diversion Channel.- According to this section, the PDC "was designed to replicate a natural stream in its physical dimensions… and substrate type." I found that somewhat surprising, since significant differences in "physical dimensions and substrate" between the PDC and natural streams in the area are among the few things that this report and the publications of Jones & colleagues agree upon (although we don't always agree on the details of the differences).

1.2.2 Reference Streams.- First of all, it's unbelievable that reference streams weren't added to the 'official' monitoring program until 2003; how can one possibly "assess the effectiveness of the fish habitat in the PDC relative to local reference streams" (section 1.1) without references (see, e.g., Downes et al. 2002)?? The U of A program (1998-2000/1), at least part of which this report claims to incorporate, included reference streams from the start. Including a summary of those U of A results (PDC and references) would have been invaluable in allowing an assessment of how rapidly different components of the PDC ecosystem were (or were not) converging on reference stream conditions. Unfortunately, as noted above, that really wasn't possible since the official PDC Monitoring Program chose (even from 2003 onwards) to use different methods from those established in 1998 by the U of A team, and changed some of their own methods in the middle of the program.

1.3 Objectives.- As noted, how could the objective of the 10-yr program (1998-2008) be "to assess the effectiveness of the PDC…" if reference streams weren't added to the program until 2003 (i.e., Year 6)? As a result, the 1998-2002 data from the PDC Monitoring Program are not particularly useful. Yes, one can confirm that there were fish, invertebrates, and epilithon in the PDC, but without reference to contemporary collections from natural streams, any resulting data will have limited value. Even after 2002, data from reference streams were far from complete.

2. Methods

It's one thing to say that a monitoring program "evolved" over a 10-year period, and it's understandable, indeed, commendable, that new components (e.g., reference streams) were added. Reducing the frequency of some measurements is also understandable, e.g., if "inter-annual variation was very low" (e.g., fish habitat assessment, although it's a bit unclear how one can be convinced that inter-annual variation in an arctic ecosystem is indeed "very low" after only 3 years). However, to completely drop a component (e.g., water quality) after only 2-3 years is questionable, especially in a new (and hopefully continuously developing) ecosystem like the PDC. Apparently, water quality data in the lower PDC has been collected annually in another Ekati program (T. Byers, IEMA, pers. comm.), but those data were not included in this 10-year Summary. How can one interpret changes (or lack thereof) in, e.g., primary producers, if no water quality data are reported after 2000? Very questionable also is having new methodologies replace older ones, e.g., collecting benthic invertebrates via Surber sampler (1999-2004) and by Hester-Dendy samplers (2005-2007), (a) without good justification, and (b) without establishing defensible ways of 'converting' data from the two methodologies, such that the continuity of the data is not destroyed. Although Table 2-1 summarized the components that were measured (at least in the PDC, not in the reference streams), there is no explanation/justification provided for what was meant by "sufficient data" or "very low inter annual variation", or why the switch from one method to another (e.g., Surber to Dendy). Furthermore, there are frequent inconsistencies between Table 2-1 and the subsequent text/figures/tables, which reduces the value of the table.

Given that the U of A's 1998-2000 study also examined every one of the categories listed here (although not always using the exact same variables), in both the PDC and in multiple reference streams, it's unfortunate that the official monitoring program didn't incorporate at least some of the U of A methods, such that results from early and later period would be comparable, thus allowing for a true 10-year assessment. While not claiming that the U of A study was perfect, it was the only source of data from reference streams for most monitoring components (and from the PDC for some components) during the early years of the PDC.

As mentioned earlier, the report is notable for the complete absence of statistical analyses, and in many cases for insufficient data presentation. Although one might argue that some of the results (at least of those that are shown) appear to be so clear that statistics are not needed, that's certainly not true in all cases, and then where do you draw the line. As noted earlier, I acknowledge that at least some statistics and more data were presented in annual technical reports but omitted from this summary report, but it's unlikely that any reader of this summary will want to read all of the annual reports, even if (s)he had access to all of them. The bottom line is that Sections 3 and 4 are full of qualitative, comparative statements about the PDC and natural streams, often without supporting tables or figures and always without reference to statistics, which inevitably weaken any conclusions that can be drawn. Finally for purposes of "truth in advertising", Section 3 should more properly have been entitled "Results and Discussion", since Rescan (2010) liberally adds interpretations of the results throughout the section.

Key findings & Conclusions

1. *Flow regimes in the PDC are similar in seasonal pattern and range (based on area-standardized hydrographs) to the two reference streams, showing that physical flow conditions are similar.*

   The main comment regarding this component is that because no data are shown, it's impossible to make any assessment. Not that reference streams have to be identical to the PDC to be useful, but there's a lot more to "physical flow conditions" than seasonal pattern and range of area-standardized hydrographs. Thus, I'd suggest that it's an over-generalization to say that "physical flow conditions are similar", given, e.g., that in 2008, the average daily flow in the PDC was 3.6 and 3.1 times greater than flows in Polar-Vulture and Pigeon, respectively (Rescan 2009). In short, the PDC is considerably bigger than the two reference streams; that's not inherently a problem, it just has to be recognized.

2. *Water temperatures in the PDC were lower than in Pigeon Stream in July and sometimes August (between 1 and 6^{o}C), which could affect Arctic grayling growth rates and food resources. The PDC temperatures were also slightly lower than Polar-Vulture Stream.*

   Again, no data are shown so no assessment of this component is possible. Section 3.1.2 provides a qualitative description of seasonal temperature patterns in the PDC relative to the two reference streams; it would be nice to quantify season-wide differences in water temperatures among streams, e.g., by providing data on cumulative degree-days.

   Jones et al. (2003*b*) concluded that temperature differences between PDC and Polar-Vulture, averaging only about 1^{o}C over the course of a summer, directly contributed ~10% of the differences in growth in Arctic grayling (ARGR) between the two streams. Presumably, the contribution could have been higher for Pigeon. Furthermore, if components of fish habitat, as well as food resources, are improving as the PDC becomes "seasoned", as this report claims, then one would assume that the *relative* importance of temperature differences would increase. Has there been any investigation as to the cause(s) of the lower temperatures in PDC? Is there anything that can be done to improve the PDC's thermal conditions?

   Section 3.1.2 also discusses water quality in the PDC. Again, no data are provided, only a few isolated factoids, so no assessment is possible. The discussion is quite limited since, as noted above, although apparently measured for other programs, water quality was not included in the PDC monitoring program after 2000, and possibly not at all in the reference streams, which also prevents meaningful assessment of the few factoids that are presented.

3. *Physical habitat differences were noted for the PDC including much greater wetted surface area, wetted width, wetted depth, more pool habitat and less glide habitat, although all streams had similar proportions of riffle habitat. These differences indicate that the PDC provides substantial amount of fish habitat to the region. The PDC physical habitat may be of equal or better quality for fish populations given that it is deeper therefore less prone to drying out.*

   Section 2.1.3 notes that this report "focuses on detailed assessments conducted in 2003 and 2004". As a result, there can apparently be no assessment of change in physical habitat over the 10-year period, although it was indicated in Table 2-1 that habitat assessments were made by the Monitoring Program in 1998-2000. Jones et al. (2003*b*, 2008) and Jones and Tonn (2004) also reported on physical dimensions, mesohabitat types, substrates, and amount of cover for all or part of the PDC and for a suite of natural streams for 1998-2000. Differences between Rescan (2010) and Jones et al. (2003*b*) in the percentages of PDC mesohabitats are very substantial. It seems likely (but ultimately unknown) that different classification methodology (Johnston and Slaney 1996 vs. OMNR 1987, respectively), rather than temporal change in physical habitat, is responsible (once again emphasizing the need for continuity of methods whenever possible). Nevertheless, both Jones et al. (2003*b*) and Rescan (2010) indicate major differences in the proportion of different mesohabitats between the PDC and natural streams.

Rescan (2010) seems to suggest that because the PDC is larger than the two chosen reference streams, "it provides substantial habitat". However, natural streams in the region exist that are larger than the PDC (Pigeon and Polar-Vulture both just happen to be smaller), and fish habitat managers are likely going to be concerned with the quality, as well as quantity of habitat created, relative to the destroyed natural habitat that the PDC was designed to replace.

The statement about deeper habitat being better habitat comes out of the blue with no supporting evidence. Over the 10 years, how frequently, and by what percentage, was habitat in Pigeon and Polar-Vulture streams affected by drying before the out-migration of ARGR? And if depth is such an integral component of fish habitat quality for these streams, why did Rescan (2010) always report fish data on a per m^2 basis, rather than per m^3 (which would incorporate depth)? A per m^2 basis might be appropriate for a benthic species such as slimy sculpin, but it's debatable for a water-column species like Arctic grayling (Jones and Tonn 2004*a*) By reporting fish (especially grayling) data on a per m^2 basis for both the deeper PDC and shallower reference streams, Rescan (2010) is clearly providing an 'advantage' to the PDC, i.e., there is more habitat to support fish production in a given m^2 of PDC than a given m^2 in the reference streams. This 'advantage' needs to be kept in mind in later comparisons.

4. *Substrates within PDC were similar to Pigeon Stream (mostly sand, some boulder and cobble) compared to the more steeply-graded Polar-Vulture (more boulders and cobble).*

   Both Rescan (2010) and Jones et al. (2003*b*, 2008) note differences in substrate types between the PDC and reference streams, although the two studies differ in their details, with Jones et al. indicating a significantly higher proportion of sand in the PDC relative to 9-10 natural streams, including both Polar-Vulture and Pigeon, whereas Rescan (2010) emphasized differences only with Polar-Vulture, and attributed this to the latter's greater gradient. However, Jones and Tonn (2004) compared Polar-Vulture to the lower (and steeper) 700 m of PDC; although the gradient of this section of the PDC was actually steeper than Polar-Vulture, the proportion of fine substrate (clay, silt, sand) in PDC was twice as high as in Polar-Vulture.

5. *Cover was quite rare in the PDC compared to the reference streams early on in the monitoring program. In the last few years, instream and shoreline vegetative cover has*

increased in the PDC, and instream structures (e.g., logs, rock structures) have been added to increase habitat diversity and available cover to fish.

Rescan (2010) is emphasizing results from habitat surveys conducted in 2003-2004 (total percent cover, Pigeon: 100%, Polar-Vulture: 75%, PDC: 25%), but it's unclear if these 3X-4X differences between natural streams and PDC from Years 6-7 represent "early on" or "in the last few years". In short, we have no temporal frame (much less statistical analysis) to judge the claim about increasing cover. The only "evidence" provided of increased cover are 3 isolated photos (from 2007-2009) of shrubs growing along the banks of the PDC. We are given no quantitative results supporting the claim of increasing cover, and we are not even shown photos of either the reference streams or the PDC "early on". Rescan (2010) notes that "this process naturally takes a number of years to occur", which is of course true. But this statement of findings/conclusions also emphasizes anthropogenic intervention (although the rock structures were added in 1998, so are incorporated into the above data from 2003-2004); are we (and the PDC's residents) supposed to wait tens, hundreds or thousands of years needed for this natural process to achieve equilibrium with the reference streams? As Minns (2006) has pointed out, habitat compensation and its assessment must account for the time required for the compensation habitat to achieve parity with reference systems, not just whether (or not) the new habitat eventually reached parity. Furthermore, although the shrubs pictured in Plate 3.1-1 *may* contribute coarse particulate organic matter (CPOM) to the PDC ecosystem (but see below), precious few of the shrubs pictured are close enough to the channel to provide cover for fish, so the "evidence", weak as it is, seems largely irrelevant with respect to cover for fish.

Although not mentioned in the key finding/conclusion statement, Section 3.1.3 brought up the issue of organic matter. Disappointingly, there are no measurements of CPOM mentioned in Rescan (2010), so there is no way of knowing if the paucity of CPOM in the PDC reported by Jones et al. (2003*b*) for 1998-2000 has improved "in the last few years" as a result of the alleged increases in shoreline shrubs and periphyton.

Sections 2.1.3 (Fish habitat) and 3.1.4 (Habitat enhancement and stability) note that rock and log structures were added to the PDC in 1998 and 2005, respectively, "for increased survival of Arctic grayling fry". Habitat stability surveys were conducted in 2000, obviously before the log structures were installed. It is indicated (without showing any data or analyses) that sections containing structures "had higher numbers of Arctic grayling fry in their vicinity". No date of the surveys was provided, so it's not clear if these results pertained to both rock and log structures or just the earlier rock structures, and no information was given regarding the relative performance of the different kinds of structures. Nevertheless, these "higher numbers" results are generally consistent with those of Jones and Tonn (2004*b*), who examined use of the rock structures by YOY ARGR, and further showed that despite higher local densities, YOY grayling in enhanced sections grew similarly to their cohort members in unenhanced sections. However, using before-after and control-impact comparisons, Jones and Tonn (2004b) also showed that the addition of these physical structures did not increase the density, biomass, or growth rates of age-0 Arctic grayling in the PDC as a whole, suggesting that stream-scale benefits of structures would not be fully realized until more allochthonous and autochthonous organic matter was available. In short, the fish appeared to be largely re-distributing themselves around the structures, but productive capacity of the stream did not increase simply because structures were added.

6. *Primary production in the PDC was consistently much higher than in reference streams based on abundance and biomass measures of periphyton. All streams show similarly high taxa richness, diversity, and are dominated by blue-green algae indicating similar food base for the systems.*

First, it's hard to justify "consistently" when there was only one year (2007) when periphyton was measured in all three streams, which was also the only year when the monitoring program measured periphyton abundance or biomass in Polar-Vulture. Likewise, with only one year in common with the reference streams, it's hard to understand the statement (3.2.1) that "these results indicate that the PDC behaves similarly to reference streams". Nevertheless, Rescan (2010) does show periphyton cell counts to be 4X higher in PDC than either reference stream in 2007. Such a dramatic difference between the PDC and the two reference streams would seem to cry out for an explanation: are nutrient levels comparable (can't tell without data from the PDC and reference streams)? maybe densities of herbivorous invertebrates are 4X higher in reference streams? However, Rescan (2010) only touts this as evidence that the PDC provides good quality fish habitat, without worrying about how such a dramatic difference could have occurred. Apparently, when component results are viewed as "good", we are not interested in learning the secret of the PDC's remarkable success.

Interestingly, periphyton biomass was only 2X higher in PDC vs. reference streams, indicating that cells were much larger in the latter. This would strongly suggest that compositions of the periphyton communities differed, although the 'community analysis' results reported by Rescan (2010) only tell us that all streams supported 6 major periphyton groupings (note: Cyanobacteria, aka "blue-green algae" are not technically algae), that all 3 streams were dominated by Cyanobacteria, and that total taxon richness and Shannon diversity were comparable among streams. With regards to total richness, we aren't told if sampling effort was equal (or results are standardized) between the PDC and the much smaller reference streams. Let's hope so, since sample size is usually a major determinant of "total" richness.

Jones et al. (2003*b*) also measured periphyton biomass (reported as ash-free dry mass, AFDM) in the PDC and a suite of reference streams (including Pigeon and Polar-Vulture) in 1998-2000. Interestingly, their results were opposite of those reported for 2007 by Rescan (2010), i.e., periphyton biomass was ca. 4X higher in the natural streams than in the PDC. Does this reflect a dramatic turnaround for the PDC? Maybe, but closer inspection of the two results show that actual biomass values reported by Jones et al., despite being AFDM, are orders of magnitude higher than those reported by Rescan (2010). What's going on? Unfortunately, the two studies used very different methods to collect periphyton. Jones et al. (2003*b*) used rock scrapings, i.e., they harvested the periphyton that was actually growing in the streams. In contrast, the monitoring program used Plexiglas plates that had been set out in the streams for only one month each year (see 2.2.1.1).

With regards to streambank vegetation, Rescan (2010) noted its need for lengthy natural development, yet with regards to periphyton, they standardize substrate ages to zero for both the reference streams and the PDC by using clean Plexiglas plates each year. The monitoring program is basically comparing rates of short-term colonization and primary succession between PDC and natural streams, not the periphyton communities that actually exist in these ecosystems; this may also explain the dominance in all three streams of the (generally rapidly colonizing) cyanobacteria reported by Rescan (2010). It still begs the question of how the PDC could accumulate more biomass onto clean Plexiglas plates, relative to natural streams, in only one month (assuming differences are significant…not reported), but that question, along with the issue of the opposing results between Jones et al (2003*b*) and Rescan (2010), cannot be resolved with the data at hand.

Thus, I have some trouble with the conclusion (p. 3-7) that the PDC "supports a healthy and diverse primary producer community". Perhaps I could accept a "healthy and diverse" set of early colonizing periphyton taxa. And dare I even bring up the topic of macrophytes? They weren't mentioned in Rescan (2010); presumably they weren't measured by the monitoring program, even though they are important sources of instream cover, primary production, and organic matter for stream ecosystems. For the 1998-2000 period, Jones et al (2008) noted that densities of macrophytes were ca. 15 X higher in reference streams than in the PDC, and that bryophytes were virtually absent from the PDC (both differences were statistically significant). Has the PDC made another remarkable turnaround in just a few years?

7. *Benthic invertebrate density was slightly lower in the PDC compared to reference streams, although data is* [sic] *limited. Benthic communities were comprised* [sic] *mainly of chironomids in all streams.*

To be frank, meaningful, comparable data were limited because the sampling design was lousy. According to 2.2.1.2, although benthic invertebrates were collected in the PDC by the monitoring program for 8 of 10 years (but only 6 are presented in Fig. 3.2-3), they were only collected for 3 years in Pigeon (starting in 2005) and 1 year in Polar-Vulture (2007). Compounding the problem, three different methods were used, with the result being, as with periphyton, in only one year were comparable data collected in all 3 streams. Given that the overall objective of the monitoring program was "to assess the effectiveness of the PDC…", which can only be done in relation to references, 1 for 10 is a poor batting average. And given that the main sampling methodology was changed from a Surber to a Hester-Dendy sampler in 2005 (initially in Pigeon, as no macroinvertebrates were sampled in the PDC in 2005-06), it's impossible to make any meaningful comparisons even within the PDC from "early on" vs. "in the last few years".

Furthermore, use of Hester-Dendy samplers raises the same major concerns as with the Plexiglas plate samples for periphyton: these are passive samplers that start "from scratch" and require active colonization (with organisms also needing to actively come out of the sediment to colonize), analogous to primary succession, rather than simply and actively collecting the organisms that are actually in the stream sediment (like Surbers). Active colonization is a selective process; is it any surprise that the Dendy-obtained samples contained an overwhelming proportion (86-95%) of chironomids in all three streams despite their differences, e.g., in age, flow rate, substrates, macrophytes? Although chironomids (early colonizers, active in the drift) were also important in the very young PDC during 1998-2000 (representing ca. 88%, by mass, of the macroinvertebrate community), based on Surber samples (Jones et al. 2003*b*, 2008), their proportion in the more mature natural streams was significantly lower (62%). Even if one thought that the benthic community could be changing rapidly in the PDC between 1998-2000 and 2007, there is no reason why composition in the already "seasoned" reference streams would change so dramatically, and especially show an *increase* in chironomids. Clearly, Dendy samplers are selective, resulting in what looks to be an artificial convergence in chironomid domination and thus likely in total density.

I also find that community summaries based only on richness, evenness and diversity, without a taxonomic-based analysis (e.g., classification and/or ordination), to be of limited value. As with periphyton, it is also critical to know, when comparing total richness values, that sampling effort among streams was equal or that richness values are based on a standardized level of sampling, otherwise the results are as incomparable as results based on different samplers. And were sampling sites matched by habitat among streams? Finally, given the size-selective foraging of YOY grayling (Jones et al. 2003*a*), and the large range in sizes among different macroinvertebrate taxa, it would be much more meaningful to report results as biomass, rather than as simply as density. To say that "the PDC is supporting healthy secondary producer communities similar to those residing in reference streams", based only on density, richness, diversity, and evenness, has limited meaning. That these conclusions are based on one year of data from Hester-Dendy samples reduces their value further.

This is unfortunate; although density, biomass, and richness of benthic invertebrates remained significantly lower in the PDC than in references streams in 2000 (Jones et al. 2003*b*, 2008), there were some signs that the differences were decreasing even after only 3 years. If conditions for benthic macroinvertebrates have continued to improve in the PDC since 2000, we lack quality data to demonstrate it.

8. *A more diverse community was found in the PDC compared to the reference streams. Species include Arctic grayling, lake trout, slimy sculpin, lake chub, burbot, round whitefish, and longnose suckers. The results point to the PDC providing an active migration and stream spawning corridor for a diverse fish community.*

It is a virtual law of ecology that larger ecosystems support more species than smaller ones (all else more/less equal), and this was shown to be true for Barrenlands stream fish assemblages by Jones et al (2003*c*). Thus, it is to be expected that the PDC, which is ca. 3X larger than the two reference streams, would contain more species. It should also be noted that fish box results are not statistically significant, although fyke net results are. Based on only a single sampling (August 2000), Jones et al (2003*c*) found up to 6 species in their larger natural streams. Furthermore, the PDC is bounded at both ends by lakes, which are obviously the colonization sources for streams that freeze solid during the winter, whereas both Pigeon and Polar-Vulture have only ponds at their upper and lower ends; given that several of the species mentioned are lake specialists, it is again expected that some individuals would be more available to move temporarily into the PDC than in the two reference streams.

The information on fish passing between Kodiak and North Panda lakes reported in Rescan (2010) is so vague ("a proportion of Arctic grayling") as to be virtually meaningless; actual data are presumably in various annual reports. No species other than grayling is reported as being able to travel through PDC as a migration corridor, and no data from reference streams are available. Jones et al. (2003*b*) suggested that other species, including slimy sculpin and burbot, could not get past one of the culverts in the lower PDC. Has this improved since 2000?

9. *Relative to the historical record and regional data, the PDC showed abnormally high abundance of migrating Arctic grayling in early years of monitoring (1998 to 2000), likely related to enrichment of Kodiak Lake through treated sewage disposal leading to increased food for fish populations. Arctic grayling abundance remained high (300 to 400) until 2006 when numbers have decreased. This decline has also been observed in Pigeon Stream from 2005 to 2008. Thus the PDC appears to behave similarly to reference streams in terms of adult population numbers in the past few years.*

   Of the 11 years of data on ARGR entering the PDC from Kodiak (Fig. 3.3-1), the first three years ranked 11th, 7th, and 1st, which hardly strikes one as "abnormally high". Given that the average age of spawners was ca. 7 years, it's rather surprising that their abundance could increase (by up to 5X) within just a year or two. And it could be mentioned that the addition of sewage to Arctic lakes, with their long period of ice cover, can also lead to a depletion of under-ice oxygen concentrations, and to increased mortality of salmonid fish, especially larger, older, mature fish. In short, without data on such things as invertebrate production, grayling growth, and mortality rates in Kodiak Lake, or abundance of spring migrants in reference lakes in the early years, explanations of the so-called "abnormally high abundance" of spring migrants in PDC during 1998-2000 (the existence of which seems unsupported) on the basis of sewage addition to Kodiak Lake during 1998-2000 are not convincing.

   Rescan (2010) further suggests that the steadily declining numbers of spring migrants in PDC since 2004 may represent a "naturally rebalancing … to baseline conditions of Kodiak Lake." But Rescan (2010) also notes a decline of spring migrants in Pigeon Stream since 2005, and uses that to suggest that the PDC is behaving like a reference stream, i.e., normally. But since sewage addition is not part of the Pigeon story, the Pigeon decline cannot be a "natural rebalancing". And there is also a decline in the number of spawners 2005-2008 in the upper PDC, where fish are presumably coming from Panda, not Kodiak. There is no mention of sewage addition to Panda L. What's happening in Polar-Vulture? Although a decline in Pigeon (and upper PDC) over the last 4 years may be somewhat comforting in light of the decline in the lower PDC, it's hard to put the lower-PDC decline in perspective, because monitoring spring migrants in Pigeon and other reference streams was not part of the design from the beginning.

10. *The proportion of adult Arctic grayling in the PDC that are return spawners was 12% on average, and has increased in the past three years. The presence of returning spawners every year indicates that the PDC is functional spawning habitat because fish are returning.*

   This text suggests that there has been a monotonic increase recently, which is not what Fig. 3.3-2 shows. A better statement might be that the percentage of returning spawners has been above the 10-year average for 4 of the last 5 years (Note: if 1998 was the first year of the PDC's operation, and certainly the first year of the monitoring program, how could there be 10% *returning* spawners that year?). While I don't disagree that "the PDC is functional spawning habitat", I don't see why you need repeat spawners to show that…doesn't the simple presence of spawning (and subsequent young) indicate "functional spawning habitat"? However, section 3.3.2.3 states that the frequency of repeat spawners is a measure of spawning habitat quality. I'm not sure how. I would suggest that mortality rates of existing spawners and numbers of new fish recruiting into the spawner population have greater influence on the percentage of returning spawners, and those factors seem generally independent of spawning habitat quality. Interestingly, if mortality rate is an important determinant of % of repeat spawners, then the earlier argument that survival was high in 1998-2000 because of sewage addition to Kodiak Lake is inconsistent with lower percentages of repeat spawners in the early years. The argument can't work both ways.

Regardless, 12% is just a number without a context. Is that a good percentage? a bad one? Without data from reference streams, any number (even 0%) is not very informative. But I'm not even sure what purpose data from reference streams would serve. Because this percentage should be primarily influenced by factors external to the stream (e.g., lake survival), I really don't know what this parameter tells us about stream spawning habitat.

11. *The residency time for spawning Arctic grayling was between 6 and 15 days, matching other regional studies. This indicates that Arctic grayling spawning behaviour is occurring over the same span in the PDC as in other stream sites. Arctic grayling populations in the PDC thus show similar behaviour to other regional populations.*

    One of two studies (Kristiansen and Dowing 1996) cited by Rescan (2010) in support of their conclusion is from Norway, and on a different species. The other reference (Scott and Crossman 1998) is a Canada-wide summary, so it's not clear (but unlikely) if the information came from nearby, similar natural ecosystems (my earlier edition makes no mention of spawner residency). Again, without comparative data from EKATI-area references, the number for the PDC is not particularly meaningful.

12. *The relative fecundity of Arctic grayling in the PDC (6.7 eggs/g, ranging from 2.9 to 9.3 eggs/g) was slightly lower than the value of 10.9 eggs/g reported for a population in the north by Bishop (1971) but overlaps the range (6.5 to 16.9 eggs/g) reported for a population on the Great Slave Lake (Falk et al. 1982; as cited in Northcote 1995).*

    Rescan (2010) report that fecundity is not correlated with length or weight, although, interestingly, the two graphs in Fig. 3.3-4 look very similar… I'm not sure that I'd bet the farm on a sample size of 19, with a relatively limited range of sizes…if one outlier is removed from this small collection, the relationship with weight is significant). If fecundity is not related to body weight, what is the value of reporting relative fecundity (scaled to body weight)?

    One could more quantitatively describe the difference with Bishop by saying that the relative fecundity was 39% lower in the PDC (and Bishop's absolute fecundity average of 9700 eggs/female dwarfs the PDC values of ca. 1000-3000); statistics could have helped decide whether or not that was "slightly lower". Although an overlapping range provides a bit of comparative information, it is not a valid statistical comparison. As section 3.3.2.5 notes, fecundity can be influenced by a number of regional factors, so it's best to have comparable reference systems.

    But as with other aspects of the spawner populations, I would guess that fecundity more likely reflects conditions in the lake where the spawners reside for the vast majority of the year, rather than conditions in the spawning stream. It's a parameter that really tells you little about conditions in the PDC.

13. *Density of Arctic grayling spawners (>300 mm in length) in the PDC were [*sic*] the within same range as those of Pigeon and Polar-Vulture streams.*

From 1998 to 2004, spawner density in PDC was estimated from visual surveys. Spawner density estimates in the two reference streams were not begun until 2003. After 2004, visual surveys were not permitted in the PDC, but instead of estimating spawner numbers using the relationship between visual estimates and fish-box counts from PDC during 1998-2004, Rescan (2010) used the relationship from Pigeon (2005-2008). Why? Was it established that the ability to see spawners were the same in the two streams? (no) Why not use the 1998-2004 relationship from PDC, providing both a longer record and using the same system, with the same biases affecting visibility?

As noted earlier, PDC is bounded at both ends by reasonably sized lakes (especially at the downstream end, where most of the spawners come from), which should provide easy access for the reasonably sized source populations of ARGR in those lakes. In contrast, both Pigeon and Polar-Vulture streams are bordered by one or a series of small ponds. Landscape factors alone would predict higher densities in PDC. Still, it's nice that this prediction is upheld.

14. *Body condition of Arctic grayling spawners in the PDC has ranged from 1.02 to 1.43 g/mm^3, averaging 1.15 g/mm^3 and remaining consistent from 2003 onwards. These values are similar to condition values recorded for 18 other lakes of the region.*

This is all very nice, but what does this have to do with the PDC? The spawners are resident of Kodiak (or Panda) Lake, not the PDC.

15. *Arctic grayling fry in the PDC showed emergence timing overlapping the two reference streams, ranging from June 19 to July 8 over the ten years. This indicates that environmental conditions (particularly water temperature) in the PDC are quite similar to those of reference streams, driving egg hatch and emergence timing.*

If Rescan (2010) is really interested in comparing water temperatures among streams, there are better ways to do it than by estimating ARGR emergence dates. Indeed, we've already been told that "there were differences in temperature between the PDC and the two reference streams" (section 3.1.2), so the conclusion here confuses me. Perhaps what Rescan (2010) wanted to say was that the temperature differences among streams did not result in strongly divergent dates of emergence? But no data were provided, only ranges. It's no surprise that in the variable arctic, such ranges would overlap. One would really want to match emergences dates year-by-year. If emergence in reference streams were consistently 2-3 days earlier than in PDC, year-in and year-out, that would be far more informative than simply saying that ranges overlapped.

16. *Visual surveys of the PDC and reference streams indicated that the PDC produced an order of magnitude higher numbers of fry than reference streams. Density of fry in the PDC was at an intermediate level to that observed in the two reference streams. Its large area and suitable habitat thus indicate that the PDC is an important stream for local Arctic grayling populations in the EKATI area.*

I've got to say that the methodology of these surveys is confusing at best; I have been informed subsequently that at least part of the confusion stems from errors in Section 3.3.3.2 (T. Byers, IEMA, pers. comm..). Were any independent methods used to validate the accuracy of visual surveys among streams? Because there were "marked differences in total percent cover among the three streams" (see section 3.1.3), one might suspect that there would be "marked differences" in visibility of fry among streams, so validation would be especially important when comparing numbers among streams. Electrofishing surveys in PDC and a suite of reference streams in 1998-2000 found significantly higher densities of fish and biomass of YOY grayling in the reference streams, when sites were matched as pools vs. riffles (Jones et al. 2003*b*). In short, it's impossible to assess the quality of these data based on the information provided.

Rescan (2010) stated clearly that "density measures are more useful in comparing productivity among streams due to large differences in total wetted areas". And let's not forget that the PDC is deeper, which is not accounted for in comparisons of "total wetted area". In addition to fry densities based on visual surveys, it would have been interesting to compare the estimated number of (observed) fry with the estimated number of eggs (number of spawners * average fecundity). Apparently, egg-fry survival is reported in annual reports (T. Byers, IEMA, pers. comm..), but such information is absent from the 10-year Summary.

17. *Dipnet and electrofishing data indicated that growth rates of Arctic grayling fry in all three streams were fairly similar in range and showed a trend of higher growth in 2003 and 2004 followed by slower growth in 2005 and 2006, with an increase in following years. Therefore, the PDC populations of fry grew at similar rates to other reference populations during summer months.*

Growth rates of fry were determined as the average increases in length from one survey to a second, divided by the number of days between surveys (ca. 30 days, from late July/early August to late August). This change in average cohort size in a stream will be affected not only by growth but also by size-selective mortality, and it would be impossible to partition the contribution of each mechanism to the overall change in average length. More importantly, because this procedure only measures change in size during the month of August, and fry are generally emerging in late June, we don't know what happened before August. Since emergence dates were apparently similar, I would think a better measure of net productive capacity (see 2.2.2.2) would be the average size attained by fry on a common date in late-summer (before out-migration is too far along), which would incorporate growth (and mortality) over the entire post-emergence period, not just over a part of the summer. Furthermore, using fish weight, rather than length, is a better measure of size (& thus growth). After all, the size (biomass) that young-of-year have attained at the end of summer will be more important in influencing their subsequent overwinter survival than the growth rate they experienced during a 30-d slice of late summer.

Thus, because of their method of measuring growth, the discussion in section 3.3.3.3 regarding differences in growth being influenced by differences in hatch or emergence dates is irrelevant (but would be very relevant if growth/production were measured simply by the size obtained late in the summer). Likewise, the discussion of higher growth in Pigeon because of higher water temperatures in June and July is also irrelevant for growth measured from late July/early August until late August, but again would be incorporated by simply comparing sizes (weights) of fry attained late in the summer. Indeed, by only measuring growth during a one-month period in late-summer, Rescan (2010) is cancelling out this potential benefit of warmer early-summer temperatures in the reference streams. It would also be nice to show error bars in Fig. 3.3-8 (statistical analysis would be better); e.g., the 0.2 mm/d difference in growth between Pigeon and PDC in 2008 would translate into a 6-mm difference after 30 d and substantially more if extended over the entire summer. Thus, based on the information contained in Rescan (2010), we still don't know if the 2.3X larger sizes (weights) of YOY attained in a suite of natural streams relative to the PDC during 1998-2001 (Jones et al. 2003*b*) has persisted over the years (and if not, how many years did it take to reduce or eliminate the difference). However, an examination of Fig. 3.4-10 of the 2008 annual technical report (Rescan 2009) indicates that on a common date, ca. Aug 7 (day 220), YOY grayling averaged ca. 43 mm in the PDC but were ca. 59 mm in Pigeon and 54 mm in Polar-Vulture streams. Using Fig. 3.4-11 from the same annual report suggests that these lengths translate into weights of ca. 0.75 g for PDC grayling, 1.3 g for Polar-Vulture and 2.1 for Pigeon. Roughly similar results were reported in the 2007 annual report (Rescan 2008), albeit only for the PDC and Pigeon. Based on these data, not much has changed since 2000.

18. *On average, the total abundance of all outmigrant fish species was highest in the in the PDC compared to Pigeon and Polar-Vulture streams, particularly for slimy sculpin, lake chub, and burbot.*

    As section 3.3.4.1 notes, total number comparisons of outmigrants among streams "may reflect the larger size of the PDC, habitat preference/usage and access issues (i.e., proximity to productive Kodiak Lake) more than habitat quality." This lack of useful comparison is exacerbated by Table 3.3-3. In contrast to all other tables in Rescan (2010), which report means and standard errors, Table 3.3-3 provides only minimum and maximum values for the 2003-2008 period. It's impossible to assess exactly what the differences were, much less whether or not any differences were statistically significant. The verbal description of out-migrant density is equally uninformative. At least the table includes per m^2 densities (# fish/m^2). I can neither confirm nor refute the conclusion of this section.

19. *Density of Arctic grayling was the highest of all species, and densities in the PDC fell within ranges in reference streams. Burbot showed the next highest densities in streams, followed by slimy sculpin and lake chub. Lake trout and round whitefish had lowest densities in streams. The PDC showed densities within ranges of references sites indicating that it is suitable fish habitat for these species.*

    Again, the presentation of total numbers and density, for grayling as well as the other species, is really quite poor in Table 3.3-3 and the related text (there is also a 4 orders of magnitude difference in the maximum densities reported between table and text). That densities in PDC averaged 1.8X higher than Polar-Vulture suggest a major turnaround from the values reported in Jones et al. 2003*b*) for 1998-2000, although both sampling methods and the parameter used to measure density differed between studies (#/m^2 vs. g/m^3). It's unfortunate that yearly data aren't presented here, to know how long it took for the alleged turnaround to develop.

20. *Lipid content in PDC fry was slightly higher than in reference streams, suggesting that outmigrating PDC Arctic grayling fry are in an equal or better state of preparedness for winter compared to outmigrant fry in Pigeon and Polar-Vulture streams*.

    Having similar relative lipid content (given the means and standard errors, it's unlikely that the streams differ significantly) as reference streams is encouraging for the PDC grayling. However, % lipid content is only half of the story, as overall body size (and thus absolute amount of lipids) is also important, given various metabolic allometries. As noted above, Rescan (2010) did not present data on sizes of YOY grayling but figures in Rescan (2009) suggest that by mid-August in 2008, YOY grayling were ca. 3X heavier in the reference streams than in the PDC, and therefore reference-stream grayling would have had ca. 3X more lipids.

21. *The adipose fin clipped Arctic grayling captured in 2008 demonstrated that fish that hatch in the PDC (in 2003) return to the PDC five years later*.

    I agree with the statement in 3.3.4.3: “no definite conclusions could be made other than saying that an Arctic grayling that hatched in the PDC has returned after five years”. It is true that “it is expected that the greatest number of returning clipped Arctic grayling would be observed between 2010 and 2012 when they would be returning at ages 7 to 9”, thus, it would be nice to continue monitoring, as DFO has indicated. However, I don’t agree with Rescan (2010) that the lack of definite conclusions is because of “the low number of expected clipped fish returning” in 2008. The lack of definitive conclusions is because there are no references with which to compare these numbers. Even during 2010-2012, when the greatest number of returning clipped grayling are expected, any numbers of returning clipped fish will have limited value without reference systems. The conclusion will still be limited to the same “*fish that hatch in the PDC (in 2003) return to the PDC*”. And although first overwinter survival will depend a lot on the growth of the YOY during their first summer in their natal stream, survival over the subsequent 4-8+ years will be primarily or exclusively due to factors in their resident lake. Without more information, it would be impossible to disentangle lake vs. stream influences.

22. *Arctic grayling production (total and standardized to total wetted area) was consistently highest in Pigeon Stream, while the PDC tended to have slightly higher production than Polar-Vulture Stream. Therefore, the PDC provides a similar level of Arctic grayling productivity to one of the two reference streams*.

    I have some concerns with regards to the approach that Rescan (2010) used to compare grayling production among streams. Production was based on the summed weight of all fry migrating out of each stream, *at the time that they migrated*. That would be fine if fish migrated out of each stream at the same time. However, although not presented in Rescan (2010), annual reports indicate that YOY grayling do not stay in the 3 streams for the same amount of time. In 2008, for example, 95% of out-migrating Arctic grayling left lower Polar-Vulture by August 10 and departed from Pigeon by August 18 (Rescan 2009). However, that same proportion of grayling didn’t migrate out of the PDC until October 11 (lower PDC) or October 18 (upper PDC). In other words, some YOY from the PDC continued to reside and grow in the PDC for an additional 2 months compared to fish in the reference streams. As a result, growth during those 60 days would, for PDC grayling, be counted towards PDC’s production. In contrast, for YOY grayling from the reference streams, which were able to achieve sizes suitable for out-migration ca. 60 days earlier, growth and production during those 60 days would not being credited to the natal streams. It makes no sense to credit cohort production in one ecosystem but not credit production in other ecosystems over the exact same period of time, just because the former occurred in a stream while the latter occurred in lakes or ponds. How much of this “out-of-stream” production contributed to the true production of the YOY cohorts of the reference lake-stream systems is not known. However, because YOY from Polar-Vulture left the earliest of the three populations, this "penalty" would have been the largest, and because Polar-Vulture and PDC had similar levels of production as measured by Rescan (2010), this "penalty" to Polar-Vulture could have affected the conclusions of this section (3.3.4.4).

Conclusions

So exactly where does this leave things with regards to the 'state of the PDC' after 10 years? Specifically, I was asked to address three questions in my review: Is the PDC working well? Is further monitoring required? if so, what should be monitored? This summary report (Rescan 2010) and the PDC Monitoring Program that was behind it do not make those easy questions to answer. Qualitatively, the PDC is providing the basic ecosystem functions of natural streams in the EKATI region: it provides environmental conditions and biotic and abiotic resources that support communities of producers and consumers at lower trophic levels, fish migrate in from upstream and downstream lakes to spawn within the PDC and at least some individuals of Arctic grayling can move through the entire length of the PDC (although the question about whether or not the PDC allows fish of other species to traverse its length apparently remains unanswered), grayling eggs hatch successfully and fry survive and grow, migrate out to overwinter in the lakes, and at least a few grayling are documented to have returned to spawn themselves in their natal stream several years later. However, except for the last point, all of those qualitative observations were known during the first few years of operation (e.g., Jones et al. 2003*b*).

What about quantitative observations? After all, the main objective of the 10-year monitoring program was "to assess the effectiveness of the PDC as productive fish habitat"; in applied ecology, the accepted approach to assessment typically involves, whenever possible, quantitative comparisons with references (e.g., Downes et al. 2002), especially if "before" data are not available. In the Canadian fisheries habitat compensation context, Minns (2006) has argued cogently that assessment should also consider the time required for the system to achieve productive fish habitat on a level comparable to the reference systems. Based on my review of this 10-year monitoring program summary, I would generally suggest that because of deficiencies in sampling design and analytical approach taken over the years by the monitoring program, as well as because of limited methodological details and data presentations in this Summary Report, I can neither accept nor reject with reasonable confidence the conclusions of Rescan (2010) that "the PDC provides fish habitat comparable to local streams" and that "this compensation habitat is within the range of productive capacity of reference stream within the area." As I have discussed in my review, virtually every "key finding" and/or conclusion stemming from them has a problem, some quite minor but others not so minor, that prevents their acceptance *carte blanche*. So to the first question (*Is the PDC working well?*), I would have to reply: It certainly is 'working', and it seems probable that for at least some components it is working better than in 1998-2000, but I can't really tell overall if it's 'working well'.

And even if/when one could reach quantitative conclusions regarding the state of the PDC in 2008, Rescan (2010) did not frame their summary in a way that would facilitate determining when, and at what rate, the PDC achieved its status of being "comparable to local streams". There is evidence in a series of peer-reviewed research papers published by N.E. Jones and colleagues to indicate that this status was not achieved before 2001, and I would argue by default that it could not be shown to occur before 2003, simply because the monitoring program lacked reference systems before that year. If “comparable to local streams” has been established, which Rescan (2010) concludes but about which I remain unconvinced, when did this occur and how much production was “lost” during the years required to achieve parity?

Is further monitoring required? if so, what should be monitored? Although I noted that I had at least some level of question about virtually all of the “key findings”, in some cases, what is required is mainly greater clarity and detail (e.g., from annual technical reports) in this summary, so additional monitoring should not be necessary. In other cases, the basic underlying data are probably adequate; because my concerns focused more on the analytical approach or specific methods, I would think that some additional analyses, not additional monitoring, is all that is needed. At the other extreme, I think some of the problems are more historic and/or systemic to the way the data were (or weren’t) collected. And since one can’t go back in time, additional monitoring won’t help.

Is there anything left that additional monitoring could help? There are a few components for which updated sampling, using methods comparable to those used earlier, could be useful. Apparently, measurement of cover has had limited updates since 2004, despite additions of log structures and continued “seasoning” of the stream. The official monitoring program has never measured CPOM in the PDC or reference streams. As DFO has indicated, an assessment (or re-assessment; see Jones and Tonn 2004*b*) of each type of added habitat structure would be helpful. I am not aware of any stream-wide quantification of macrophytes and bryophytes in the PDC or reference stream since the early work of Jones and colleagues, so a follow-up would be worthwhile. Although Rescan can say that periphyton has been measured consistently in the PDC since 1998 (although only once in Polar-Vulture), I would personally recommend habitat-specific (e.g., pools vs. riffles) rock scrapings (in PDC and reference streams), as done by Jones et al (2003*b*, 2008), to be able to compare current conditions to their early results. Benthic (and drifting) invertebrates have not been sampled consistently since the early years, so I would suggest that a return to Surber sampling would be informative to compare current communities with those found in the early years. With regards to fish, it’s not clear that passage of any species other than grayling throughout the PDC has been examined directly, and almost certainly not in the reference streams.

These efforts can fill in some gaps for the PDC, and some relatively simple but meaningful sampling should be maintained even if on a less than annual basis, e.g., quantitative electrofishing in early August to obtain densities and sizes (seasonal growth) of YOY ARGR,. But frankly, the main benefit of my review will be if the next monitoring and assessment program can avoid the errors of omission and commission that were all too evident for the PDC over its 10 year program.

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