INTERVIEW: John P. Smol – Oil sands and lake ecosystems study – Part 1

This is a comprehensive 2 Part interview with Professor John Smol, (Department of Biology, Queen's University) using excerpts from his study:

Legacy of a half century of Athabasca oil sands development recorded by lake ecosystems

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Edited by John P. Giesy, University of Saskatchewan, Saskatoon, SK, Canada, and accepted by the Editorial Board November 19, 2012 (received for review October 11, 2012)

DOWNLOAD THE STUDY HERE:

Legacy of half century of Athabasca oil sands development recorded by lake ecosystems
Joshua Kurek[a], Jane L. Kirk[b], Derek C. G. Muir[b], Xiaowa Wang[b], Marlene S. Evans[c], and John P. Smol[a],[1]
http://www.pnas.org/content/110/5/1761.full.pdf+html

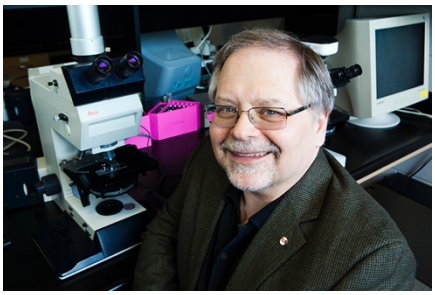
Background Information from the study:

Bituminous oil sands in northern Alberta and Saskatchewan comprise 97%of Canada's proven oil reserves. They represent the world's third largest reserves (1) and are a significant North American economic driver, with a staggering growth trajectory. In 1980, oil production was 100,000 barrels per day. Production today is ~1.5 million barrels per day and is projected to increase by 150% (to 3.7 million barrels per day) between 2010 and 2025. (2)

PAHs are a diverse group of organic compounds with multiple aromatic rings and are produced by the incomplete combustion of fossil fuels and biomass. They are relatively insoluble in water and bind to organic particles in the water column, persist in lake sediments, occur in complex mixtures, and have the potential to impact aquatic organisms at several trophic levels, particularly in the presence of other stressors (18–21). With similar properties to PAHs, the sulfur-containing dibenzothiophenes (DBTs) are a related class of aromatic compounds. C1-C4– alkylated PAHs and DBTs are both recognized as prominent components of Athabasca oil sands bitumen (6, 22).

STUDY EXCERPT

Study Quote: "We show that polycyclic aromatic hydrocarbons (PAHs) within lake sediments, particularly C1 C4–alkylated PAHs, increased significantly after development of the bitumen resource began, followed by significant increases in dibenzothiophenes. Total PAH fluxes in the modern sediments of our six study lakes, including one site ~90 km northwest of the major development area, are now ~2.5–23 times greater than ~1960 levels."


Professor John P. Smol

INTERVIEW

GCV: Knowing how toxic these chemicals are, would they have a severe effect on aquatic life?

JPS: Several PAHs are known carcinogens and rank in the top 10 hazardous substances on the US Agency for Toxic Substances and Disease Registry. PAHs are widespread and at high concentrations are toxic to aquatic organisms. The dose, duration, and exposure pathway to toxic substances, such as PAHs, are all important factors to consider. Additionally, the age, sex, condition, and physiology and behaviour of organisms also are important factors. Canadian interim sediment quality guidelines (CISQGs) and probable effects levels (PELs) for 13 specific PAHs have been estimated (Canadian Council of Ministers of the Environment 1999). These guidelines inform on whether biological effects are likely to occur as a result of exposure to PAHs in sediments. However, the CCME guidelines do not account for petrogenic PAHs (i.e. those associated with hydrocarbon-based combustion processes), which are as much as 10 times more toxic than PAHs associated with other combustion processes (e.g. forest fires) (Hodson 2013).

Study Quote: Canadian interim sediment quality guidelines for PAHs have been exceeded since the mid-1980s at the most impacted site. A paleoecological assessment of Daphnia shows that this sentinel zooplankter has not yet been negatively impacted by decades of high atmospheric PAH deposition. Rather, coincident with increases in PAHs, climate-induced shifts in aquatic primary production related to warmer and drier conditions are the primary environmental drivers producing marked daphniid shifts after~1960 to 1970. Note: Daphnia is the focal zooplankton indicator, is an established model organism used worldwide in toxicology assessments and represents a promising indicator for understanding multiple environmental stressors, including contaminants (24).

GCV: Is this breach in interim sediment guidelines for PAHs a result of not having an adequate and comprehensive monitoring system for the oil sands development at the onset?

JPS: Comprehensive monitoring of ecosystems is often initiated only after an environmental problem is obvious or well recognized by a majority of stakeholders. Therefore, indirect approaches, similar to those used in the Kurek et al. (2013) study, can be extremely valuable. Clearly, some aspects of previous environmental monitoring efforts in the oil sands region
were unable to effectively characterize background conditions prior to when commercial development began decades ago (discussed for example in the Dowdeswell et al. 2010
report commissioned by Environment Canada). We are hopeful that the new, "world class" federal-provincial environmental monitoring plan for the Alberta oil sands announced in 2012 lives up to its billing.

Study Quote: Because of the striking increase in PAHs, elevated primary production, and zooplankton changes, these oil sands lake ecosystems have entered new ecological states completely distinct from those of previous centuries.

GCV: Can you explain how these changes will affect the ecosystems?

JPS: We exist in a world of multiple environmental stressors. Broadly, this means that ecosystems face several major stressors at the same time. In the oil sands region, these stressors may include habitat destruction, contaminant deposition, climate change, etc…The cumulative impacts of these stressors are difficult to predict. Yet, the Kurek et al. (2013) study highlighted how ecosystems in the region, such as lakes, have responded to long-term environmental change. These lakes are now exposed to a variety of stressors leading to major differences in their physical, chemical, and biological properties compared to decades ago.

Study Quote: *Some of the controversy results from a lack of systematic environmental monitoring of industrial activities before the establishment of the industry-funded Regional Aquatics Monitoring Program (RAMP) in 1997. Furthermore, weaknesses highlighted by scientific reviews of RAMP, in its inability to recognize effects on freshwaters (10–12), leads to additional criticism by some stakeholders.*

GCV: What proof is there that scientific reviews of RAMP showed "its inability to recognize effects on freshwaters?"

JPS: Limitations of RAMP have been pointed out clearly by several comprehensive reviews of its monitoring efforts, including for example those by Fisheries and Ocean Canada (Ayles et al. 2004), Environment Canada (Dowdeswell et al. 2010), and The Royal Society of Canada (Gosseilin et al. 2004), and several others. In addition, peer-reviewed studies such as those by researchers based primarily at the University of Alberta (Kelly et al. 2009, 2010) have identified shortcomings of RAMP and criticized RAMP's ability to measure environmental impacts of the oil sands industry with confidence.

Study Quote: *Almost two decades of environmental monitoring within the oil sands region has failed to establish background concentrations of highly toxic contaminants…The lack of consensus among the few temporal-focused PAH studies to date, and the shortcomings of oil sands monitoring programs to adequately recognize the deposition patterns of atmospheric contaminants (6, 7), leave justifiable cause for concern as to the ecological implications of oil sands development.*

GCV: What is the solution then if production is well underway and increasing in the future?

JPS: The first step is to recognize that a problem exists and then to determine its full extent. A major part of this is to understand long-term environmental conditions, such as Kurek et al. (2013) accomplishes. This is done by asking the right questions using appropriate scientific techniques. Stakeholders must then determine the next course of action, but in my opinion, science-based evidence is critical to guiding policy on future oil sands development.

Study Quote: As noted repeatedly in previous assessments of the impacts of the Alberta oil sands operations, insufficient monitoring data and a poor understanding of predevelopment conditions have hampered attempts to determine the scope of pollution from oil sands development (11).

GCV: What do you attribute the "poor understanding of predevelopment conditions" to, ignorance, poor planning or a lack of concern for the environmental integrity of the region or all of the above?

JPS: This problem is not peculiar to the Athabasca oil sands. Often we lack comprehensive monitoring and only start dealing with problems after-the-fact. Environmental monitoring is often completed in a haphazard fashion. It is simply too easy for individuals, government, and corporations to ignore our shared environmental responsibility. Current environmental costs must be accounted for by our economy. This has got to change or we will simply saddle future generations with a crushing environmental debt.

Study Quote: Daphnia, our focal zooplankton indicator, is an established model organism used worldwide in toxicology assessments and represents a promising indicator for understanding multiple environmental stressors, including contaminants (24).

GCV: How important was the Daphnia focal zooplankton indicator and how accurate is the model organism in toxicology assessments?

JPS: Daphnia are key invertebrates in many aquatic ecosystems and form an important link between primary producers (algae) and secondary consumers (waterfowl, small fish, large invertebrates). They are a bellwether of ecosystem conditions and their physiology, ecology, and genetics are very well understood compared to other aquatic invertebrates. Daphniids are used frequently around the world to assess the toxicity of chemicals and provide important context to biomedical research. In those respects, they are critical to our understanding of how multiple stressors affect organisms at an intermediate trophic level.

Study Quote: Collectively, our temporal insights, coupled with findings from spatial contaminant surveys (6, 7), leave little doubt of the unprecedented increases of PAHs and the overarching influences of recent climatic changes on northeastern Alberta's lake ecosystems.

GCV: Regarding this quote, are you implying that the climate change in the region is solely due to oil sands production or could other influences be responsible for the climate change in the region like changes in the sun affecting the earth for example?

JPS: No, regional climate change cannot be solely attributed to oil sands production, although the oil and gas industry in particular represents an important portion of Canada's greenhouse gas emissions. The Kurek et al. (2013) study recognized that while PAHs have increased substantially, the impacts of climate change are also recognizable within the lake sediment records examined to date. Again, multiple environmental stressors are affecting these remote ecosystems. This is another example of a multiple stressor. For example, with warming we can get enhanced evaporation, which decreases water levels and can further concentrate pollutants.

Study Quote: Collectively, the C3-DBT/C3-PHE and C2-DBT/C2-CRY ratios, along with other indicators of combustion sources, suggest a shift to petrogenic and unweathered alkylated PAH sources in the modern sediments of our five lakes proximate to the major oil sands development area.

GCV: Is this conclusive evidence that indeed the oil sands development is causing great damage to the ecosystems in the Athabasca region?

JPS: This provides strong, science-based evidence that the PAHs observed in these sediment records are clearly linked to industrial activities, particularly the processing and upgrading of bitumen.

Study Quote: Focused environmental monitoring of oil sands aquatic ecosystems did not exist before the establishment of RAMP in 1997 through industry funding. Furthermore, before 2000, Canada's mandatory National Pollutant Release Inventory (NPRI) did not require industrial facilities to report PAH emissions. Therefore, indirect monitoring, provided by our paleolimnological approach, is the only method available for establishing background conditions of PAHs before extensive development of the oil sands began. Together, the historic timings of PAH increases measured from our lake sediments (Fig. 1), including the temporal shifts in characteristic PAH ratios suggesting more petrogenic sources (Fig. S3), and the results of a spatial PAH deposition survey (6) provide compelling science-based evidence that local industrial activities are important contributors of PAHs to aquatic ecosystems in the Athabasca oil sands region. Additionally, lakes to the east of the Athabasca River record particularly striking contaminant increases, consistent with the prevailing winds blowing across local upgrading facilities and surface-mining areas. Atmospheric depositions of PAHs from upgrader emissions and/or unweathered bitumen in the form of dust particles from surface-mining areas are now likely a major source of PAHs entering regional aquatic ecosystems. Industry's role as a decades-long contributor of PAHs to oil sands lake ecosystems is now clearly evident.

GCV: Considering that monitoring has not been adequately done, would you agree that governments and industry have failed the people of this region, in particular, First Nations residents who rely on healthy ecosystems for their way of life? In your opinion, how can the damage be mitigated in the future as oil sands production increases?

JPS: My students call me an optimist and to some degree I self-identify as one. Therefore, instead of failure, I tend to see opportunity or at least like to consider some positive aspect of most situations. While there are real challenges that exist for First Nations in the oil sands region and across Canada, the issue is complex. Nonetheless, First Nations are an important stakeholder in the oil sands region and their unique experience, knowledge, and perspective needs to be considered.

Study Quote: Canadian interim sediment quality guidelines (CISQGs), which are available for 13 specific PAHs (30), are currently exceeded for seven compounds [i.e., phenanthrene, pyrene, benz(a)anthracene, chrysene, benzo(a)pyrene, dibenz(a,h)anthracene, 2-methylnaphthalene]at NE20, the site receiving the highest deposition of PAHs through time. Sediment concentrations of five PAHs at NE20, including 2-methylnaphthalene, benz(a)anthracene, chrysene, benzo(a)pyrene, and dibenz(a,h)anthracene, have exceeded CISQGs for about two decades.

GCV: Knowing that the guidelines have been exceeded for seven compounds (PAHs), and with sediment concentrations of five PAHs being exceeded for two decades in one lake NE20, can you project how this will affect the aquatic ecosystems in the Athabasca region without strict monitoring in the future?

JPS: Monitoring now seems to be increasing with the new program for the region – at least I am giving it the benefit of the doubt. If your question would be what I think will happen if no safeguards are put into place in the future, then I would answer that industry itself projects increases in operations of around 150% in 15 years, and so if nothing else happens these pollutants will just increase.

Study Quote: Environmental change driving both shifts in the physical and chemical conditions of aquatic ecosystems, coupled with modern sedimentary PAH concentrations several-fold greater than "natural" background levels, warrants much further research consideration. Nevertheless, considering predictions of future climate warming and accelerating oil sands development, there exists great potential for Athabasca oil sands ecosystems to experience marked changes in their function and ecological organization.

GCV: Considering the initial poor planning and the lack of environmental safeguards in place for the long-term with respect to oil sands development, would you agree that Northern Alberta will be unrecognizable given that the increase of future oil sands production will have an expansive detrimental effect on the land and water?

JPS: Unrecognizable is a very strong word. But, if you compare a remote boreal forest landscape to an active surface mining operation, there is little similarity. This is also true for other intense mining operations across the country. Currently, 10 mines covering ~170,000 ha have government approval to operate (Rooney et al. 2012). The surface-mining "footprint" has increased considerably, from 40 ha in 1974 to 71,000 ha in 2010 (Evans and Talbot 2012). Converting to American football fields = from 90 football fields in 1974 to 160,000 football fields in 2010 (a ~1700 fold increase). In addition, the Canadian Association of Petroleum Producers (CAPP, 2011) forecasts that in 15 years, production will be ~3.7 million barrels per day- a 150% (or 2.5 fold) increase from today's levels.

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http://www.pnas.org/content/110/5/1761.full.pdf+html

Op-Ed: John P. Smol - Environmental oil sands commentary - Part 2

DOWNLOAD PETER V. HODSON'S COMMENTARY AND THE STUDIES HERE:

Commentary - Biological Sciences - Environmental Sciences, *History of environmental contamination by oil sands extraction*, http://www.pnas.org/content/110/5/1569.extract
Peter V. Hodson, *Proc Natl Acad Sci USA 110 (5) 1569-1570; published ahead of print January 11, 2013, doi:10.1073/pnas.1221660110.*

Kelly EN, et al. *(2010) Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. Proc Natl Acad Sci USA 107(37):16178–16183.* http://www.pnas.org/content/107/37/16178.full.pdf+html?sid=f76708b3-c4a1-43ca-9329-d27ed1c5660b

Kurek et al. (2013) *Legacy of a half century of Athabasca oil sands development recorded by lake ecosystems.* http://www.pnas.org/content/110/5/1761.full.pdf+html
Proc Natl Acad Sci USA 110 (5) 1761-1766; published ahead of print January 7, 2013, doi:10.1073/pnas.1217675110.

Intro: *John P. Smol - Environmental oil sands commentary - Part 2* is a continuation of questions asked of John P. Smol based on the commentary by Peter V. Hodson[1] about the Kurek et al (2013) oil sands study. The title of this commentary is called *History of environmental contamination by oil extraction.*

INTERVIEW

GCV: In the report *History of environmental contamination by oil extraction* http://www.pnas.org/content/110/5/1569.extract by Peter V. Hodson, he clarifies the debate concerning the extraction and processing of Canada's massive oil sands in the Athabasca region of Northern Alberta. He claims the "debate has been characterized by accusations, denial, emotional and few reliable or appropriate data to clarify the issue." Then he goes on to mention your oil sands study. How does your study "clarify the issue" of oil sands contamination once and for all and do you support his statement in quotes?

JPS: The Kurek et al. (2013) study http://www.pnas.org/content/110/5/1761.full.pdf+html
adds the ever-important time dimension to the oil sands pollution story and refutes the idea that contaminants from sites such as ours are from natural sources. Without this indirect approach used by Kurek et al., the background conditions would remain unknown. So, yes, we did clarify the issue - PAHs have increased significantly as industry has developed the bitumen resource.

GCV: What was the goal of your study and the parameters that you created before starting the study?

JPS: The goals of our paleolimnological-based study were to address the following questions: 1) Have sedimentary PAHs associated with the oil sands increased since commercial development began in 1967 and 2) How have zooplankton assemblages responded to long-term environmental change? The mechanism of pollution is through atmospheric deposition of contaminants. We chose to avoid lakes that were/are flood prone (Hall et al. 2012). Instead, we examined sediment records from lake systems that reflect the atmospheric deposition of PAHs from nearby bitumen upgraders. In addition, the catchments of all of our study lakes are not currently disturbed by nearby mining operations. We were able to clearly link the timing of increased PAHs (late 1960s-early 1970s) and the signature (composition) of PAHs (from wood to hydrocarbon-based sources) with the commercial development of the oil sands post 1967.

GCV: In the *History of environmental contamination by oil extraction* http://www.pnas.org/content/110/5/1569.extract by Peter V. Hodson, it states regarding the Kelly et al. 2009, 2010 study, http://www.pnas.org/content/107/37/16178.full.pdf+html?sid=f76708b3-c4a1-43ca-9329-d27ed1c5660b that the "synoptic survey was not a comprehensive description of the area affected or duration of contamination. It did not account for mass transport of contaminants in river particulates, biotic transfer in migrating fish species, total annual emissions, or seasonal distributions of airborne contaminants by prevailing winds. Interpretation was also hampered by the absence of true baselines in an already contaminated landscape."
Can you explain this comment?

JPS: In many respects, his comments suggest we provided an overly optimistic view. Kelly et al. (2009) is a spatial survey of PAHs within snowpack deposited in the winter of 2008. They demonstrated that Alberta oil sands development released PAHs into the environment at high levels within ~50 km of the main development area (site AR6). Kelly et al. estimated that over 4 months, ~400 kg of PAHs (equivalent to 600 T of bitumen) were deposited. While the very important spatial data presented by Kelly et al. recognized the modern, spatial signature of PAH deposition across a 4-month winter period, they could only speculate how long this pattern has persisted in time (i.e. commercial development began in 1967). Our study provides the "temporal perspective" necessary to place contemporary PAH loadings in their historical context. Our study reconstructs past contaminant levels, before regular monitoring was initiated, and show that for our study lakes, PAH levels increased.

GCV: As stated in the *History of environmental contamination by oil extraction* http://www.pnas.org/content/110/5/1569.extract commentary regarding one of the controversial issues of oil sands development is the following: "A major point of contention has been the extent to which oil sands contaminants (PAHs, metals, airborne particulates; oxides of nitrogen and sulfur) are distributed downwind and downriver of mining and processing," thus leading to deformity of fish and other health issues in the area. Have the results of your study confirmed that there is indeed contamination and therefore it is worth doing a follow-up study?

JPS: We show that PAHs have increased substantially since development began in 1967. This trend is not natural and the pattern we highlight differs from other remote lakes in north-central North America, where PAHs have mostly decreased since the mid-1900s. Our findings represent an important step forward in recognizing the impacts of oil sands development. And yes, further research at Queen's University on oil sands pollution impacts is currently ongoing.

GCV: Also, in the same Peter V. Hodson commentary, it states why your study has been more thorough than most. "By chemical and biological analyses of dated sediment cores, they link PAH contamination to the history of air emissions from oil sands industries, track the growth of oil sands activities since the 1960s, discriminate industrial from "natural" sources of PAHs, establish a predevelopment baseline of PAH fluxes to sediments, expand the area known to be affected by emissions, and raise new questions about potential impacts on freshwater ecosystems." Knowing the results, how will increased oil sands development affect freshwater ecosystems to the detriment of aquatic life?

JPS: From our data, sedimentary PAH concentrations at only one study site NE20 exceeded Canadian interim sediment quality guidelines (CISQGs) for the protection of aquatic life. At NE20, 7 of 13 PAHs now exceed CISQGs. Sediment concentrations of 5 PAHs have exceeded CISQGs for ~2 decades. PELs were not exceeded at NE20. The location of NE20, northeast of the upgraders and south of a major surface-mining area likely have resulted in the high deposition of PAHs at this study site- about 23x more ΣPAHs today than predevelopment. Given that oil production from the Alberta oil sands is forecasted to increase by ~150% over the next 15 years (CAPP 2011) and the mining footprint will also expand, we predict that sedimentary concentrations of PAHs will only increase. Therefore, the threat for adverse biological effects to occur is real.

GCV: How did you prove scientifically the contamination in the pre-1967 sediment cores compared to the post-1967 sediment cores differed? What were the results given the contrast of oil sands chemical imprints?

JPS: We measured the concentrations of 46 specific PAHs within dated sediment intervals from our six study sites. We were able to pinpoint the timing of PAH increase and also the composition shift to more hydrocarbon sources post commercial development.

GCV: Who funded your study *Legacy of half century of Athabasca oil sands development recorded by lake ecosystems?* Why was this study funded and done now and not before omnibus Bills C38 and C45 passed?

JPS: Environment Canada and Natural Science and Engineering Research Council of Canada (NSERC) funded this study. The Environment Canada funding was not part of the new federal-provincial environmental monitoring plan for the Alberta oil sands announced in 2012. The timing of our study has nothing to do with omnibus Bills C38 and C45.

GCV: After doing this study and knowing what exactly is at stake, do you believe it is possible to minimize damage done to the environment in the Athabasca region as oil sands production increases?

JPS: Industry is very resourceful and can likely find cost-effective solutions to mitigating their environmental impacts in the oil sands region. Leadership is the key here; either Alberta or the federal government must provide some direction.

GCV: In one lake NE20, the concentrations of seven PAHs exceeded Canadian interim sediment quality guidelines. Since there has been a 23-fold increase in sediment PAH concentrations over the past 50 years and there is a projection of 150% increase in oil sands production over the next 15 years, what would you surmise the quality of soil and water in Northern Alberta will be like then?

JPS: It's obvious that if nothing else changes, then PAHs will only increase in the region as industry develops the bitumen resource at a greater rate than current production levels- even industry would freely admit this. That said, PAH concentrations in these remote lake systems may only approach levels typically observed in urban areas. But the trends are clear -- PAHs have increased and will continue to do so.

GCV: Personally, what did you learn from doing this study? Would you ever consider residing in the area knowing the results of this very comprehensive study? Can you empathize with people that live in the Athabasca Chipewyan First Nation Treaty 8 region where the oil sands production is taking place?

JPS: A surprising finding of our study is that remote Namur Lake, ~90 km northwest of the major bitumen upgraders, records a generally similar, albeit weaker PAH signal (in time and composition) to our five study sites closer to the major development area. This demonstrates that atmospheric emissions of PAHs from bitumen upgraders are likely travelling further (almost double the distance) than previously recognized. However, it should be noted that, the data from Namur Lake represent only one distant site from the major upgraders. But, it is likely that as the "footprint" of oil sands development expands and oil production from today's levels increases, high deposition of PAHs will most certainly be detected at greater distances.

Kingston, Ontario, is my home, but plenty of people I know (e.g. colleagues and former students) enjoy living in northern Alberta. There are several legitimate concerns that First Nations face with respect to oil sands development. These are not easy to solve, but the First Nations concerns need to be adequately addressed. The first step is sound science and communicating it effectively.

GCV: From your perspective as a scientist, what are the necessary steps to be taken next considering the data results? If asked, would you collaborate to do more studies financially backed by the government and industry to assist in the process of environmental recovery thereby taking part in innovative-based solutions?

JPS: A couple of key questions remain. First, what is the relative importance of contaminant sources to the deposition signal (e.g. upgraders versus dust from surface mines)? Which factors determine the spatial pattern of contaminant deposition (e.g. wind, distance from source)? What are the impacts on ecosystem health? How will future expansion influence contaminant emissions and deposition patterns? Therefore, lots to be done! Paleolimnology provides an important perspective on long-term environmental change, especially in the absence of adequate direct monitoring data. As practitioners of this science, we are well-positioned to contribute significantly toward a comprehensive monitoring program in the oil sands region. My lab looks forward to further research on the impacts of oil sands development to aquatic ecosystems.

REFERENCES:

Kelly EN, et al. *(2010) Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. Proc Natl Acad Sci USA 107(37):16178–16183.*

Kurek et al. (2013) *Legacy of a half century of Athabasca oil sands development recorded by lake ecosystems. Proc Natl Acad Sci USA 110 (5) 1761-1766; published ahead of print January 7, 2013, doi:10.1073/pnas.1217675110*.

Commentary - Biological Sciences - Environmental Sciences, *History of environmental contamination by oil sands extraction*, Peter V. Hodson, *Proc Natl Acad Sci USA 110 (5) 1569-1570; published ahead of print January 11, 2013, doi:10.1073/pnas.1221660110.*

VIDEO LINKS

Nature of Things
Tipping Point: Age of the Oil Sands
http://www.cbc.ca/natureofthings/episode/tipping-point.html

PEARL MEDIA RELEASE PAGE ABOUT STUDIES

PEARL Paleoecological Environmental Assessment and Research Laboratory
http://post.queensu.ca/~pearl/press_releases.htm

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http://www.pnas.org/content/110/5/1761.full.pdf+html

Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries
Erin N. Kelly[a], David W. Schindler[a],1, Peter V. Hodson[b], Jeffrey W. Short[c], Roseanna Radmanovich[a], and Charlene C. Nielsen[a]
http://www.pnas.org/content/107/37/16178.full.pdf+html?sid=f76708b3-c4a1-43ca-9329-d27ed1c5660b

Alberta Lakes show chemical effects of oilsands, study finds
Pollutants from 50 years of oilsands production found in lake 90 km from facilities
http://www.cbc.ca/news/politics/story/2013/01/07/pol-oilsands-alberta-lakes-pollution-pah.html

ADDITIONAL OIL SANDS PUBLICATIONS AND LINKS

Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries
http://www.pnas.org/content/107/37/16178.short

OIL SANDS RESEARCH AND INFORMATION NETWORK
http://www.osrin.ualberta.ca

SCHOOL OF ENVIRONMENTAL STUDIES, QUEEN'S UNIVERSITY
Toxic contaminants released by Tar Sands Industries
http://www.queensu.ca/ensc/news-events/news/peterhodsontarsands.html

NATURE
Tar sands mining linked to stream pollution
http://www.nature.com/news/2009/091207/full/news.2009.1127.html

GERMAN SCIENTISTS QUIT OIL SANDS RESEARCH PROGRAM
The Canadian Press, posted on CBC website
http://www.cbc.ca/news/business/story/2013/03/19/edmonton-german-scientists-leave-oilsands-research.html