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Food for Thought

Chasing inter-species communication: what marine mammals are telling us about our oceans

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Food for Thought articles are essays in which the author provides their perspective on a research area, topic, or issue. They are intended to provide contributors with a forum through which to air their own views and experiences, with few of the constraints that govern standard research articles. This Food for Thought article is one in a series solicited from leading figures in the fisheries and aquatic sciences community. The objective is to offer lessons and insights from their careers in an accessible and pedagogical form from which the community, and particularly early career scientists, will benefit.
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I describe my path through a series of opportunities that provided stepping stones from childhood years in the landlocked US Midwest to a 45-year-long career focused on cetacean behaviour and ecology. My early interest in the ocean and dolphins led me to switch from majoring in journalism to biology during my undergraduate years. While pursuing a master's degree focused on bioacoustics, I was employed as a contract scientist with the US Navy's marine mammal laboratory. During 20 years there, my work ranged from dolphin calling behaviour to marine mammal distribution in Alaskan waters, culminating in a Ph.D. dissertation on cetacean habitats in the Alaskan Arctic. Subsequently, I enjoyed a 20-year career with the US NOAA National Marine Fisheries Service. There, I developed and advanced the idea that marine mammals can act as sentinels of ocean variability. To interpret the messages that marine mammals convey about the ocean, we must broaden science discourse to include Indigenous Knowledge and lessons from the experiences of people whose livelihoods depend on the sea. My advice to students and young professionals is to follow your passion while seeking the perspectives of colleagues from a variety of disciplines and people from all cultures and backgrounds. Coupled with a healthy dose of luck, this approach worked for me.

Keywords: Arctic ecosystems, Arctic Marine Pulses (AMP) model, bioacoustics, cetaceans, Distributed Biological Observatory (DBO), Indigenous Knowledge (IK), marine mammals.

Introduction

People often ask me how I have been able to craft a career out of looking for marine mammals from ships and planes. To be paid to do what I do seems too good to be true, and so it has been. There was no clear path that brought me to this juncture of drafting a retrospective look at my career. Rather, here I describe my responses to a series of unforeseen opportunities that offered career stepping stones, each one a bit more challenging than the one before it. My inclination to take those steps was founded on my parent's mantra to me and my brothers that we could be whatever we wanted to be, if we worked hard. I believed that and so set about creating a future that unfolded in a truly fortuitous way.

When I was invited to write this retrospective, it was suggested that a useful approach might be to answer two questions: (1) What kept you engaged and motivated during various stages of your career? (2) What do you think the future of the field is? My goal is to answer those questions, the first in a linear fashion touching on major steps along my path and the second by way of contemplating how existing and forthcoming observational tools may shape marine mammal science and how insights from that science can contribute to understanding and forecasting the future states of our oceans. For context, I begin this essay with a brief summary of relevant aspects of my childhood years and end with thoughts on looking back at my career through the lens of the current focus on Diversity, Equity, and Inclusion in science.

My earliest inspiration was simply a love of the ocean. That was soon followed by a fascination with dolphins and a desire to somehow communicate with them, which inspired the title to this essay. Later, I found myself captivated yet again, this time with bowhead whales (*Balaena mysticetus*), which sparked my interest in the broader ecological role of mammals in subarctic and Arctic marine ecosystems. And so, while drafting this paper, I came to consider my career arc as "chasing inter-species communication" in pursuit of understanding the ecological role mammals play in marine ecosystems, and how that knowledge can help us better understand how oceans work. It has been quite a lot of fun, this path I have been on and continue to walk. I have had the support and mentorship of family, friends, and colleagues all along the way and quite simply could not have done it without them. While I cannot mention everyone who buoyed me up, I do thank them all.

Growing up in Detroit (the "Wonder" years)

When I was 3 years old, my family moved to Detroit Michigan, as my father became the manager of the Wonder Bread bakery there. The move caused some trepidation for my Ohio-based parents, but it was seen as a clear economic step-up for our family. What I remember about the move was the exhilaration of going somewhere new. Even before leaving Ohio, my earliest memories revolve around a love of being outdoors. I

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would chase after my older brothers on my tricycle, only to be easily outdistanced as they rode off to nearby playgrounds, open fields, or stream banks. Once in Michigan, my forays grew longer and more varied, and by the time I was a teenager, I can remember lolling under autumnal trees just drinking in the colour and wondering how the leaves did that. These home-based experiences were augmented by seasonal visits to my grandparent's rural home, where I enjoyed hours with my grandmother outdoors in her garden and nearby woods. She was a farm woman, but also a keen observer of nature, quick to point out common birds, very mindful of local weather patterns, and could tell you the date by the place on the horizon that the sun rose in the morning.

When I was 14, we took a family vacation to Florida. Although I had seen the ocean before, it was on this trip that I felt such a strong connection that I was inspired to get up in the middle of the night to write a short "essay to the ocean," to somehow try to capture the elation I felt. A year or so later, I happened upon a book by John Lilly, wherein he described his efforts to "crack the code" of dolphin language (Lilly, 1967). This was augmented by my weekly viewing of the Flipper television show, wherein the characters Bud and Flipper (a dolphin) conversed with ease. Not only that, Flipper was clearly a master of the ocean realm, as demonstrated by his fantastic swimming, leaping, and perception of danger! I knew immediately that communicating with dolphins and scuba diving were things that I very much wanted to do! Much of this was just idle dreaming, however, as while my high school offered a good curriculum in English Literature, it was quite poor with regard to Science classes.

At 18, I entered the University of Michigan (UM) as a journalism major, with absolutely no thought of pursuing training in science. The curricula requirements for freshman and sophomore students included elective science courses, and I found myself choosing the slightly more "rigorous" versions of biology and anthropology classes that allowed the student to follow a science path if they chose to do so. I found the journalism curricula comparatively easy, but rather boring. The writing was formulaic, with speed and efficient phrasing the hallmarks of mastery of the craft. These divergent feelings culminated in an "epiphany" of sorts during the first semester of my sophomore year, propelling me to drop out of the journalism track and enrol in science courses, including introductory oceanography and scuba diving! While this big shift was marked by some elation, I was immediately stymied by the "foreign language" I encountered in science classes; I had never heard the words "xylem" or "phloem" before, for example. Later that same year, I decided I needed to live near the ocean to pursue my dream of working with dolphins and soon settled on a move to San Diego, California, where the Scripps Institution of Oceanography (SIO), the Navy's Marine Mammal Programme, and Sea World seemed to provide potential opportunities.

Science training and practice (small and big steps)

Early years (1974–1981)

I arrived in San Diego in late August 1974 and was soon accepted at the University of California San Diego (UCSD) for the upcoming winter quarter. I had the goal of completing a Bachelor of Science degree in Biology within the same time frame as I would have graduated with a journalism degree. This meant taking on a heavy course load, while maintaining a source of income. Initially, I worked as a sous chef at a tennis club, having parlayed my food preparation experience as a short-order cook at a residence hall on the UM campus. The tennis club job did not pay well, but the hours were flexible enough to accommodate my class schedule and included the option to take leftover food home, which helped with living expenses. I enrolled in an Invertebrate Zoology course during my first quarter at UCSD, which confirmed for me that I had made the right choice in shifting my undergraduate training to a focus on marine science. The final exam for the course included a laboratory-based test where students were asked to identify various invertebrates to species. That exam turned out to be a precursor to a big change in my employment, as later that week I found a description for a technician position in the Ecology Laboratory at SIO on a student jobs board and immediately applied. Part of the interview for the job included the identification of invertebrates to species, which I sailed through and landed the job. I was walking on air—I was a SIO employee!—only six months after arriving in San Diego.

The Ecology Laboratory at SIO was led by Dr Paul Dayton, who inspired a legion of graduate students while conducting numerous research projects on benthic and coastal ecosystems in Antarctica, the US west coast, and elsewhere (Dayton, 2020). Thea Schultze, a longtime SIO staff research technician, was the heart of the lab and my direct supervisor. Thea had immigrated to the US from Germany in the late 1950s and found her way to SIO, in part, due to the cadre of German scientists then at the school. She had received her marine science training working for various SIO professors and was very exacting about ensuring the quality and efficiency of my sorting and counting of invertebrates for Dayton. As it turned out, I liked the microscope-based work and very much enjoyed working with Thea. She baked birthday cakes for all of Dayton's student's, sang snippets of opera in the hallway, and counselled students when they became uncertain about their ability to complete their degrees. We became friends in these early years, and it was Thea who came to my graduation from UCSD in June 1976 and who later buoyed me up when I returned to SIO decades later seeking my own Ph.D.

My undergraduate degree in Biology focused on mammalian physiology, in large part because UCSD had a medical school and most of my student colleagues were intensely focused on pre-med training. I briefly considered joining their ranks, but instead completed an independent study on diving mammal physiology during my last quarter at UCSD. While this satisfied my urge to focus on marine mammals, after graduation I still felt I was lacking a strong background in the natural history and ecology of vertebrates. So, after considering various options, I applied to the graduate programme in Ecology at San Diego State University (SDSU) and began classes there in January 1977, while continuing to work at SIO. The graduate classes were just what I was seeking, focused on vertebrate zoology, ornithology, animal behaviour, field ecology, and evolution. Dr Frank Awbrey taught the evolution class, dressing up as Darwin in the process, and I found his animated teaching style and research focus on the acoustic behaviour of frogs and dolphins a good match for my interests.

At the time, Frank led a study aimed at finding ways to mitigate the bycatch of dolphins during tuna purse-seine fish-

ing in the eastern Tropical Pacific. The work was conducted in partnership with researchers at the Hubbs-Sea World Research Institute (HSWRI). My initial proposal for my Master's thesis was to investigate the underwater soundscape (i.e. sounds from both the dolphins trapped in the net and noise associated with fishing operations) associated with the setting of the nets. This proposal had to be abandoned when local tuna fishermen refused to take me on their boats due to my gender, which was perceived to bring "bad luck" both for fishing and morale. In seeking an alternative project, Frank suggested I talk with Steve Leatherwood, who worked with Dr Sam Ridgway at the Navy's marine mammal laboratory at the Naval Ocean Systems Centre (NOSC). I certainly knew of Dr Ridgway, as the sole author of an iconic text book on marine mammal physiology (Ridgway, 1972), which I had relied upon while completing my undergraduate independent study. When I met Steve at the NOSC, he encouraged me to seek employment there through an SDSU programme meant to foster hands-on training of graduate students. As my employment at SIO had recently come to an end, I took Steve's advice and became a student research technician at the NOSC's marine mammal facility while continuing to search out a new project for my Master's thesis.

In a short time, Frank and I settled on a project focused on the calling behaviour of Pacific tree frogs (*Hyla regilla*), through which I could gain experience recording and analysing acoustic data on species that could be easily observed and thereby shorten the time it would take to complete my Master's degree. Frank provided only one lesson in catching and marking frogs before I found myself on my own overnighting at one or the other of two study sites. As I recorded data, I would take it to the sound analysis laboratory at HSWRI, where Frank provided advice on the running of a Kay-sonograph, which burned a spectrogram of the frog calls onto paper rotating on a drum—such was the technology at that time! I finished the project over the 1979 spring frog-mating season and surprised Frank with the result that it was not the biggest males, but the ones that initiated the frog-calling choruses that the female frogs chose for mating (Moore, 1979). Not only that, my data showed that female frogs sometimes came back and chose males for amplexus 2–3 times in a season. When Frank asked how I knew this, I said I had marked the females just as I had all the males. He looked at me astonished and said "you toe-clipped the females?, we never do that"; I said "yes, I marked all the females, they have the eggs"—he threw back his head and roared out a laugh and said "you are right they do have the eggs!." It was a fun project and foundational to my acoustic training, but more so to a budding realization that I could actually do something novel in science.

After graduating from SDSU with a Master's degree in Biology, Frank encouraged me to apply to Cornell University's Ph.D. programme to continue my research on frog bioacoustics and behavioural ecology. While I found the idea compelling, by this time I had been hired as a contract scientist at the NOSC and was assisting Dr Ridgway in a study meant to determine if female dolphins changed anything in their calling behaviour in association with progesterone spikes associated with ovulation (Moore and Ridgway, 1997). We established a sampling protocol whereby we monitored all sound output over 24 h from two female dolphins representing two species: common dolphins (*Delphinus delphis*) and bottlenose dolphins (*Tursiops truncatus*). I had the overnight stint (1800–0600), and we conducted these watches to correspond to new and full phases of the moon, then took blood samples from the dolphins the next day so as to correlate our acoustic and physiological findings as closely as possible. We were 18 months into this study, which was shaping up to become my Ph.D. project through UC Riverside, when one day to my surprise, I arrived at work to find the dolphins being lifted from their tanks and driven over to Sea World! Sam explained that Sea World actually owned the dolphins and wanted them back to exhibit and for shows. The news landed like a bomb, and I thought my science career was screeching to a halt, but then another door opened, and I found myself headed to the Arctic.

The NOSC was known for its expertise in underwater acoustics, so when the US Minerals Management Service (MMS) was seeking federal agency partners to determine if noise from oil and gas development off the north shore of Alaska was shifting bowhead whale distribution offshore they contacted Steve Leatherwood. With his strong background in marine mammal science and access to underwater acoustics experts, Steve quickly assembled a team to conduct aerial surveys over the Beaufort Sea from a plane equipped to deploy sonobuoys (expendable hydrophones) to record the underwater soundscape while documenting whale distribution and behaviour. Steve had been running this project for two years, when he left NOSC for a position at HSWRI and turned the programme over to Don Ljungblad. On learning that my project with Sam had ended, Don approached me in the parking lot and asked "do you get sick in small planes?"—I assured him that I did not, having flown in small planes with an uncle—and on the spot I was offered the opportunity to go to Alaska "for the summer" to join the aerial survey team. I was also advised not to "talk too much" on the headset microphone during surveys, as the previous woman on the team had done.

In hindsight, this opportunity marked a major turning point in my career trajectory. I flew my first surveys over offshore Alaska in May 1981 and, as previously mentioned, was awestruck the first time I saw a bowhead whale. Bowheads are the only baleen whale endemic to the Arctic and are extraordinary animals in many ways). They are large (adults ~18 m), with their bowed-head comprising roughly 1/3 the body length, black overall with white markings on the chin and tail stock, they can live over 150 years and break through sea ice ~45 cm (18 in) thick to breathe. As I looked down from the plane, this enormous animal seemed weightless and very flexible as it meandered and twirled around in the open-water lead in sea ice offshore Wainwright, Alaska. I was truly in another world.

Transition years (1981–1997)

During my first three years on the NOSC aerial survey project, I was a field team leader and had primary responsibility for preparing the annual report to the MMS, as well as manuscripts submitted to the International Whaling Commission (IWC) Scientific Committee (SC). I first presented our work as an Invited Participant (IP) to the 1987 IWC SC meeting, and we began publishing results in the IWC Reports routinely series thereafter (e.g. Ljungblad *et al.*, 1986; Moore *et al.*, 1989; Clarke and Moore, 1993). NOSC retired from the aerial survey programme in 1988 due to a hiatus in funding, and my employment as a contract scientist shifted to multiple short-term projects. Then, in 1989, my longtime colleague

Table 1. Steps towards synthetic thinking: selected references representing "Big Steps" in career trajectory.

YEAR	Steps towards synthetic thinking	Reference
1993	Pan-Arctic review of bowhead whale distribution and movements—the Bowhead Whale book	Moore and Reeves, 1993
1997	Ph.D. Dissertation: habitat selection for three cetacean species in the Alaskan Arctic	Moore, 2000; Moore *et al.*, 2000
2003	Marine Mammal Commission (MMC) Portland Workshop: long-term environmental change and marine mammals—concept of ecological scale	Moore et al. 2005
	APL NEPTUNE Workshop: including passive acoustic sampling in large-scale ocean programmes	Moore *et al.*, 2007
2006	Fostering the application of broad scale and long-term passive acoustic sampling with NOAA and academic colleagues	Moore *et al.*, 2006
2008	Marine mammals as ecosystem sentinels; invited paper *Journal of Mammalogy* Special Issue	Huntington and Moore, 2008; Moore, 2008; Moore and Huntington, 2008
	Conceptual model of marine mammal responses to Arctic sea ice loss based regional oceanography based on species' ecology	
	Guest-editor of "Marine Mammals and Climate Change" *Ecological Applications* Special Issue ##, MMC Project	
2010	Bio-Ice Workshop launching the initiation of the Distributed Biological Observatory in the Pacific Arctic	Moore and Grebmeier, 2018
2014	Development of the "Cogs" figure to show interconnectedness of ecology and health of Upper Trophic Level (UTL) species (marine fish, birds, and mammals)	Moore and Gulland, 2014; Moore *et al.*, 2014
	Suggested ways to link marine mammal ecology and health to improve sentinel capacity in a rapidly changing Arctic	
2016	Baleen whales as sentinels of "boom times" resulting from advection of prey in the Pacific Arctic	Moore, 2016
2018	Arctic Marine Pulses (AMP) conceptual ecosystem model for the Pacific Arctic region	Moore and Stabeno, 2015; Moore *et al.*, 2018a; Moore *et al.*, 2018b
	Guest editor SOAR Special Issues of *Progress in Oceanography* (2015) and *Deep-Sea Research II* (2018)	
2019	Using the annual cycle as a bride to foster connections between Conventional Science (CS)-Indigenous Knowledge (IK)	Moore and Hauser, 2019; Moore *et al.*, 2019
	Pan-Arctic baleen whale ecology-compare and contrasting the Atlantic and Pacific Arctic regions	
2022	Grey whale ecology in the Pacific Arctic: when a sentinel species does not provide the "expected answer" regarding skinny whales	Moore *et al.*, 2022

and friend Janet Clarke and I were awarded a contract directly from MMS for the aerial survey programme, which launched us back to the Alaskan Arctic for an additional three years. At that juncture, MMS decided they would provide a modicum of support to assemble a book on the bowhead whale research, in part to showcase the work that they had funded. I teamed up with Dr Randall Reeves on a chapter describing pan-Arctic bowhead distribution and movements (Moore and Reeves, 1993). At the time, I thought that this work would provide a fitting culmination to my decade of aerial surveys. Instead, writing the chapter was really the start of what became a series of steps along a path of synthetic thinking (Table 1). In short, I found that I wanted to dive more deeply into the ecology of bowhead whales to investigate how the patterns of distribution and movements we had summarized could be related to regional oceanography. So, I contacted Paul Dayton about the possibility of applying to SIO as a graduate student with the goal of using the 10-year database as the foundation for a Ph.D. dissertation in Biological Oceanography.

Paul encouraged me to apply to SIO, but to also seek guidance from someone at the Southwest Fisheries Science Centre who could act as a co-chair of my committee. I contacted Dr Douglas DeMaster, whom I had met at various marine mammal meetings, and he was enthusiastic about my application. Thus, I began work towards my Ph.D., while continuing to work full-time as a contract scientist. Six years later, I completed my Ph.D. with a dissertation entitled "Cetacean Habitats in the Alaskan Arctic" (Moore, 2000; Moore *et al.*, 2000), which boosted me to a much higher science-orbit than I could have anticipated.

Building years (1998–2008)

Shortly after completing my Ph.D., Doug asked if I would be interested in applying for the position of Cetacean Programme Leader at what was then called the National Marine Mammal Laboratory (NMML), a component of NOAA's Alaska Fisheries Science Centre (AFSC) in Seattle, Washington. I applied and, to my surprise, was selected; my first salaried position! After moving to Seattle in late 1998, I dived into my duties, which included oversight and administration of multiple cetacean research projects in Alaska, as well as supervision of roughly 15 NOAA employees and contractors. The work was interesting, but restricted my direct participation in research to field-site visits at ongoing projects, augmented by occasional invitations from academic colleagues to join cruises wherein my cetacean acoustic or visual survey expertise was desired.

Three years later, following Doug's promotion to AFSC Director, I applied for and was selected as the first female Director of the NMML. This promotion was a big step career-wise, but further isolated me from pursuing research opportunities. Conversely, I was able to expand my contributions at the annual IWC SC meetings, first as the co-chair of workshops on the ecological role of whales in both Arctic and Antarctic marine ecosystems, and ultimately as the Chair of the Ecosystem Concerns Working Group. I also began participating in two Arctic Council Working Groups (AMAP and PAME)[1], primarily to contribute to assessments of the impact of climate change, anthropogenic noise and commercial shipping, and fishing on marine mammals and their habitats. While I enjoyed these opportunities to contribute to international marine conservation efforts, I found myself experiencing height-

ened despair over the increasing distance between my duties as a "manager" and my desire to be a "doer" of science. I missed developing sampling protocols, analysing data, and thinking about how the patterns that emerged connected animals to their variable habitats. In short, I missed the experience of ecological discovery.

In 2003, I was invited by the US MMC to a workshop focused on the "Future of Marine Mammal Science and Conservation." My charge was to evaluate how long-term environmental change might impact marine mammals. This challenge and guidance from Levin (1992), provided an opportunity to introduce the idea of "ecological scale" based upon a species' natural history, whereby ecosystem variability can be tracked by shifts in patterns of marine mammal distribution and movements (Moore, 2005). Using a modified Stommel diagram, I depicted how mammals can reflect integrated ocean processes over comparatively broad spatiotemporal scales and noted that this "ecological scale" was often a poor fit to the "management scale," which usually has short temporal and more regional requirements. In retrospect, this paper was a first step towards including a conceptual framework in my findings, and the process of thinking that somewhat ameliorated my feelings of being at arms-reach from research.

(At about the same time, I was invited to a workshop focused on the development of the NEPTUNE array)[2] deployed offshore Washington state. Dr Bruce Howe at the Applied Physics Laboratory (APL) at the University of Washington (UW) chaired the meeting and requested that I lead discussions on marine mammal bioacoustics. Afterwards, Bruce contacted me to ask if I was interested in joining a team at APL working on adding passive acoustic sampling capability to their autonomous seagliders. It was like someone had thrown me a lifeline back to doing science! I saw this invitation as an opportunity to return to applied research and, by securing funding to cover my NOAA salary, was able to relinquish my position as Director of NMML to join the APL team as a Senior Oceanographer on a four-year work detail. In addition to demonstrating the utility of including passive acoustic sampling capability on seagliders (Moore *et al.*, 2007), my detail at APL freed me to join a research cruise to the high Arctic (Moore *et al.*, 2010), and to focus more time on publishing peer-reviewed science, especially on matters related to the application of long-term passive acoustic sampling to better understand marine mammal ecology (Moore *et al.*, 2006).

In 2005, the MMC invited me to join their Committee of Scientific Advisors (CSA), and soon after to act as a Co-editor of a Special Issue Ecological Applications focused on Marine Mammals and Climate Change (Huntington and Moore, 2008). The charge was to invite specialists across a broad range of disciplines to summarize findings and, as possible, to predict futures for marine mammals facing ecosystem shifts related to the rapid warming of our planet. The volume consisted of 12 peer-reviewed papers, one of which introduced a conceptual model predicting how Arctic marine mammal species would respond to the loss of sea ice in the context of regional changes in ocean productivity and shifts in trophic structure (Moore and Huntington, 2008). During this period, and as a result of the aforementioned 2003 MMC Workshop, I was invited to submit a paper to the Journal of Mammalogy, wherein I presented a weight-of-evidence argument that marine mammals were reliable sentinels of environmental variability, using grey whales (*Eschrichtius robustus*) as a case study (Moore, 2008). I felt proud of these papers and realized that I was able to complete them because, at the APL, I was free from administrative duties and had the time to focus my thinking on science. In short, the lesson I learned was that doing science was far more rewarding for me than facilitating science.

Synthesis years (2009–2022)

In 2008, I returned to the NOAA as a research scientist at the Pacific Marine Environmental Laboratory (PMEL). I felt quite at home there among the physical oceanographers, marine chemists, and sea ice scientists. (The invitation to the lab came from Dr Jim Overland who was working with polar bear biologists to predict how the rapidly disappearing sea ice might impact various of the 19 genetically recognized polar bear populations)[3]. Jim and I talked about the mismatch in spatial scale between the large areas used in sea ice analysis and prediction versus the smaller regional areas occupied by each bear population. In short, the sea ice predictions were for spatial areas that were much too large to be informative at the bear population level; that is, an ecological scale mismatch when seeking to predict outcomes for specific bear populations.

Scientists at the PMEL focused on questions related to the biophysics of the Bering Sea and Pacific Arctic regions because NOAA's AFSC has responsibility for managing commercial fisheries there. The record-shattering sea ice minimum that occurred in September 2007 (Stroeve *et al.*, 2008) begged the question of how biological processes were responding to this unprecedented ecosystem perturbation. Dr Jacqueline Grebmeier, a specialist in Pacific Arctic benthic ecology, had similar questions and (with Jim) the three of us teamed up to host the Bio-Ice Workshop at PMEL in 2009. By the end of the workshop, we had outlined the idea for an ocean observatory comprised of standardized sampling protocols focused on five benthic "biological hotspots" where we could track connections between physical drivers and biological responses (Moore and Grebmeier, 2018). (We named it the Distributed Biological Observatory)[4], or DBO for short, to emphasize the need to learn more about the nature and timing of biological responses to the physical forcing associated with sea ice loss, ocean warming, fresh water intrusions, and storm mixing. The DBO was initiated in 2010, with annual sampling since that time fostering two special issues of peer-reviewed papers describing results thus far (Grebmeier *et al.*, 2019).

The initiation of the DBO fostered a sense that researchers and resource managers could benefit from efforts to synthesize existing data. Initially, this resulted in a book focused on the Pacific Arctic region (Grebmeier and Maslowski, 2014), followed by a PMEL-led project called the Synthesis of Arctic Research (SOAR), which resulted in two special issues of peer-reviewed papers (Moore and Stabeno, 2015; Moore *et al.*, 2018). By teaming up with AFSC colleagues and seabird specialists, I was able to craft a chapter suggesting that all UTL species could act as sentinels to changes in marine ecosystems (Moore *et al.*, 2014). I have used the "cogs diagram" from that chapter several times since its publication as a simplified schematic showing how the "big driving cog" of climate change can initiate ecological responses that lead to physiological changes in body condition and health in UTL species (Figure 1). Combining observations of eco-

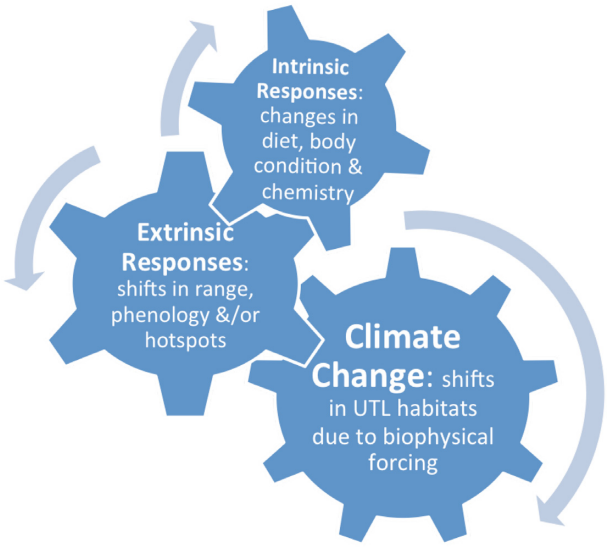

Figure 1. Marine birds and mammals are UTL species that reflect ecosystem alterations by changes in habitat use (extrinsic) and body condition (intrinsic). Tracking both extrinsic and intrinsic responses in UTL species can reveal fundamental changes in marine ecosystems (modified from Moore *et al.*, 2014).

logical and physiological changes in marine fishes, birds, and mammals can enhance their sentinel capacity by expanding the breadth of ecological scales represented across that UTL species' spectrum. The value of linking indices of health and ecology for marine mammals in a rapidly changing Arctic was emphasized in a subsequent paper (Moore and Gulland, 2014).

I lack the skill set to develop quantitative ecosystem models, so it was with some trepidation that I crafted the AMP conceptual model as part of the introductory paper for the first SOAR special issue (Moore and Stabeno, 2015). In brief, the AMP model uses the concept of ecological domains (Carmack and Wassman, 2006) as a framework to interpret the effects of seasonal oceanographic pulse events over an annual cycle in the Pacific Arctic region. The AMP model was further developed in Moore *et al.* (2018), wherein the phenology of pelagic-benthic coupling and advective processes are described and linked to examples of how benthic macrofaunal (e.g. Grebmeier *et al.*, 2019) and UTL species (e.g. Moore, 2016) are responding to changes in ecosystem structure. The AMP model aims to foster inter-disciplinary research and, with its focus on the phenology of events over an annual cycle, may serve to facilitate communication between scientists and indigenous communities. The later idea was expanded upon in a separate paper (Moore and Hauser, 2019), wherein we suggest that the annual cycle built into the AMP model might provide a bridge for communication between CS and IK. Specifically, we note that the strong seasonal cycle of Arctic environmental events could be leveraged as a shared framework to provide common ground for joint CS–IK communication and the development of novel approaches to shared questions and concerns.

In 2017, I set out to craft a pan-Arctic-subarctic review of baleen whale ecology that demonstrated contrasts in habitats, species composition, and diet between the Atlantic and Pacific sectors (Moore *et al.*, 2019). I had discussed this idea with two of my colleagues at IWC SC meetings over the course of two decades, and we agreed that it was time to combine our observations. In brief, the diverse habitats of the Atlantic sector support a far greater number of seasonally migrant baleen whales (e.g. humpback, fin, and minke whales) than the Pacific sector. These species all exhibit flexible diets, focused primarily on euphausiids (krill) and forage fishes (e.g. capelin, herring, and sand lance). Conversely, the Pacific sector now supports a far greater number of krill and copepod-feeding bowhead whales than the Atlantic sector, a large population of seasonally migrant grey whales that can feed on benthic and pelagic prey, and a much smaller (but growing) component of seasonally migrant species. Currently, migratory timing serves to restrict prey competition between the Arctic-endemic bowhead whale and seasonally migrant baleen whale species in both sectors.

As with the 1993 chapter on bowhead distribution and movements, I thought of this paper as the culmination of my contributions on baleen whale ecology; but then came reports of a marked uptick of skinny and dead grey whales in the breeding lagoons of Baja Mexico and on shorelines along their migration and feeding range. [Although I retired from NOAA in 2018, I remained on the NOAA marine mammal Unusual Mortality Event (UME) advisory group, which declared the increase in grey whale mortalities an UME in May 2019][5]. A similar mortality event had occurred in 1999–2000, with the ultimate cause unknown, although large population size and environmental perturbations were considered likely contributors (Moore *et al.*, 2001). As in the earlier event, the grey whale population had hit record numbers, and many (but not all) of the dead whales were thin. Recent extremes in sea ice loss and ocean heat have been implicated in other marine mammal and seabird die-offs (e.g. Kuletz *et al.*, 2020; Suryan *et al.*, 2021), although specific links to prey availability remained tenuous. There is an extensive record of grey whale benthic prey abundance from sampling now incorporated in the DBO, so we drew upon that as well as ocean temperature and wind records to examine how the grey whale prey field may have changed recently in offshore northern Alaska (Moore et. al., 2022). We concluded that while benthic grey whale prey has continued to decline in one feeding area in the northern Bering Sea, as we initially reported in 2003. , prey abundance had not declined in three other known feeding areas in the years prior to the UME. While the areas sampled reflect only a small portion of the grey whale feeding range, these results did not strongly support the idea that grey whales were running out of benthic prey. Furthermore, a correlational analysis of regional winds in the northeastern Chukchi Sea suggested that grey whales there may have switched to feeding on krill rather than benthic amphipods. This more complex story has been challenging to convey to colleagues and the general public, and there remains a strong belief that all skinny grey whales are starving due to climate change and its impacts on their food. Unfortunately, tracking disease transmission and the impacts of contaminants (Figure 1: the third cog) on grey whale body condition is very difficult, so the possible contribution of these factors to the UME remains unknown.

Recent activities and looking ahead

(I continue to pursue questions related to baleen whale ecology and their role in Arctic ecosystems as an Affiliate Professor at the Centre for Ecosystem Sentinels)[6], in the Biology

Department at the UW. [This has allowed me the flexibility to join research cruises, such as the recently completed Synoptic Arctic Survey (SAS)][5], while seeking ways to mentor students and early career colleagues. To my great surprise, I was awarded the International Arctic Science Committee (IASC) medal in 2020, in recognition of Outstanding Achievement in Understanding Marine Mammals as Ecosystem Sentinels and How Climate Change is Influencing the Phenology of Arctic Species. I was honoured again this year, as the recipient of the 2023 Alaska Ocean Leadership Award in Marine Research. I especially cherish these awards, as they signify recognition by science colleagues that I hold in high esteem. (Similarly, my recent appointment as a Commissioner to the US MMC)[7] is an honour that I certainly did not foresee. My primary duty as a Commissioner is to uphold the tenants of the Marine Mammal Protection Act, which was the first US law to champion an ecosystem-based approach to marine species management.

As evident in this essay, my early mentors were all white males, as was typical for the times. Indeed, years after I worked with him, one of my early mentors said to me "I just did not see you," as he congratulated me on completing my Ph.D. We find ourselves collectively seeking ways to improve Diversity, Equity, and Inclusion in all aspects of our society, including the sciences. Notably, a small but important dose of Diversity was included in my career path via a few key individuals, including: Thea Schultze (post-WWII German immigrant and Ecology Lab Manager @ SIO), Frank Shipp (African American Marine Technician @ NOSC), Harry Brower (Inupiat hunter and Mayor North Slope Borough, Alaska), and Vera Metcalf (Saint Lawrence Island Yupik, Director Eskimo Walrus Commission, and MMC Native Liaison). These friends and colleagues provided me a broader cultural view than I would have had otherwise.

In 2015, I closed my plenary presentation to the Society for Marine Mammalogy by saying "I think of science as an extended conversation, across disciplines, cultures, and generations" and I still feel that way. I am thrilled to see the number of mid-career women now in science leadership positions, as well as those in graduate-level and early-career stages coming up through the ranks. Yet even with these advances, there is still a long way to go to achieve Diversity and Equity, while the full Inclusion of women (as well as people from all ethnicities and cultures) in science seems an even more elusive goal. This is because achieving inclusion requires trust, which often takes years to build among colleagues coming from a variety of cultures and circumstances (e.g. Varanasi, 2021).

The future of marine mammal science will be chock-full of technological and analytical innovations, providing more nuanced information on all aspects of their ecology, physiology, behaviour, and genomics. My own experience of this is the strides made over the past 40+ years in marine mammal acoustic ecology: from dipping hydrophones and expendable sonobuoys to arrays of long-term recorders and seagliders capable of sampling broad ocean areas. A bigger challenge, I think, is changing how the questions themselves are developed. While we have made some progress in our ability to conduct multidisciplinary marine science, we still have a long way to go towards fostering research questions that arise through multicultural discussions. This is due, at least in part, to a lack of research that includes participants from diverse backgrounds. In addition, it often seems that discoveries only a couple of decades old are forgotten if they do not pop-up after a quick web search. For questions related to the impacts at the climate time scale, the multigenerational records that both CS and IK offer can provide a strong foundation, but require time to develop. Last but not least, we need to ensure that observational data inform the development of marine ecosystem models. Models with no fundamental connection to the realities of the natural world can derail substantive conservation and management actions.

People care about marine mammals, which offer a connection to the ocean that crosses cultures and generations. Through changes in phenology, distribution, diet, and body condition, the animals themselves are telling us something about the state of our oceans. To act more responsibly, we need to include what we learn from that form of "cross-species communication" in our approach to ocean exploration and management. While I could never work out what the dolphins were saying to each other with their whistles, buzzes, and clicks, I like to think that I have offered some useful interpretation of how cetaceans are responding to ecosystem alterations in subarctic and Arctic seas. I will continue to champion that idea in my work, as I continue along my path.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Data availability

No new data were generated or analysed in support of this research.

Competing interest statement

As the sole author of this essay, I am responsible for all content. I have no competing interests.

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