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Historical Perspectives

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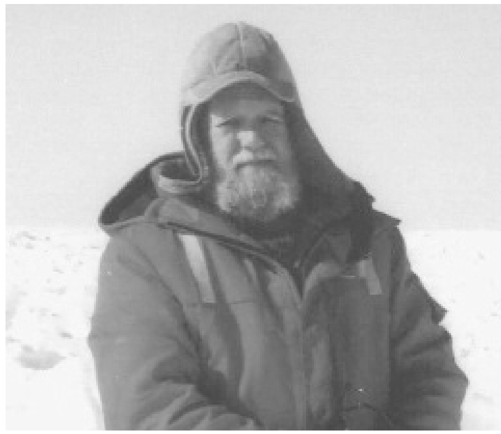
(born August 1944)

Brief Biography



Dr. Jack Terhune has been a member of the Department of Biology of the University of New Brunswick in eastern Canada for 35 years. Following Bachelor of Science (Agriculture) and Master of Science degrees from the University of Guelph, he completed a Lic.Scient./Ph.D. at Aarhus University in Denmark. He has studied the hearing, vocalizations, and impact of noise on polar seals for over four decades and, closer to home, the behaviour and distribution of harbour seals and harbour porpoise in the Bay of Fundy. Jack has taught a wide variety of undergraduate courses; supervised undergraduate honours, master's, and doctoral students and served in a number of administrative roles during his career. In 2010, he was awarded the President's Medal for his service to the University of New Brunswick.

From Switches to Menus and Students to HQPs— The Evolving World of Marine Mammal Bioacoustics

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I began my research on seal hearing and communication in 1968, a little after Roger Gentry and Ron Schusterman, two previous contributors to this Historical Perspectives series (Gentry, 2010; Schusterman, 2010). As an undergraduate Zoology major at the University of Guelph in southern Ontario, I developed an interest in animal behaviour. Rather unexpectedly, I had the opportunity to join Keith Ronald's lab to work with a Danish post-doctoral fellow, Bertel Møhl, on a harp seal (*Pagophilus groenlandicus*) hearing threshold project. The primary question being examined was "How does a seal dive down into complete darkness, find food, catch it, and eat it before having to return to the surface to breathe?" Forty years later, a number of researchers are still working on this same question.

Keith Ronald was the head of the Zoology Department and, while working as a parasitologist, he developed an interest in marine biology and seals (Figure 1). He began an undergraduate marine biology programme at the University of Guelph and brought a few harp seals from the Gulf of St. Lawrence, Canada, to support diving physiology and (possible) echolocation studies. During my master's thesis research, and for a year and half after when I stayed on with the seal lab in a "pre-doctoral" position, I conducted a number of harp seal audiograms. I was able to join three field trips to record harp and hooded (*Cystophora cristata*) seals during their March breeding season. I also attended the 7th "Sonar and Diving Mammals" conference at Stanford in 1970 where I met Ron Schusterman and Roger Gentry. For a number of years, Ron and I were conducting similar hearing studies—Ron with his California sea lions (*Zalophus californianus*) and I with harp and later ringed (*Pusa hispida*) seals. We kept in touch with each other's projects and progress and occasionally exchanged our findings prior to publication (Terhune & Ronald, 1972).

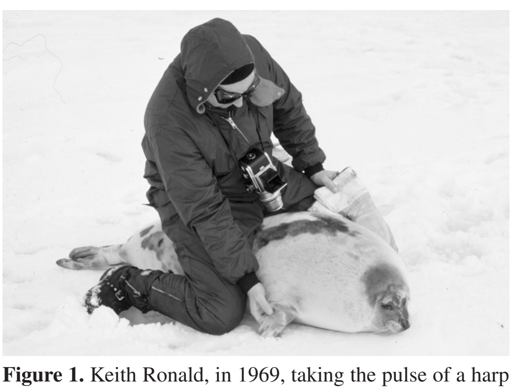

Figure 1. Keith Ronald, in 1969, taking the pulse of a harp seal performing a dive/possum response on the ice; the seal was fully conscious but not breathing and had dropped her heart rate to < 30 beats per minute.

In 1971, I went to Aarhus University in Denmark and became Bertel Møhl's first doctoral student. The Danish degree program had just undergone a major revision and was essentially a research degree with a master's degree as an entry requirement. It was patterned after the doctoral degree in the United Kingdom. Initially I had proposed a project that Bertel did not think would work. After three months of trying to develop an appropriate research proposal, I agreed with him and switched to a directional hearing study of harbour seals (*Phoca vitulina*) and later humans to clarify a discrepancy between the two species. I have always appreciated having the opportunity to try something and have it not work out while still a student. I also appreciate that I learned a great deal from Bertel and, in many ways, he was a major influence on my subsequent career, in addition to being a good friend.

Following my doctoral work, I rejoined Keith Ronald's lab at Guelph as a post-doctoral researcher. The lab had 20 seals in captivity, and we were running over 22 different projects. Helping out with those projects broadened my experience, which was very useful in my subsequent teaching career. In 1975, I obtained a teaching position at the Fredericton campus of the University of New Brunswick (UNB) in eastern Canada. Five years later, I joined the Department of Biology at the smaller campus of UNB in Saint John as an assistant professor. Saint John is on the Bay of Fundy, and the availability of harbour seals made the position particularly attractive. Since then, I have conducted projects on the acoustic communication abilities of harp and Weddell (*Leptonychotes weddellii*) seals (Terhune & Ronald, 1986; Terhune & Dell'Apa, 2006), the hearing abilities of harbour seals (initially with a seal from Joe Geraci's lab at Guelph and lately as a collaborator with Ron Kastelein in the Netherlands) (Terhune, 1991; Kastelein et al., 2010), and behaviour/distribution studies on harbour seals and porpoises (*Phocoena phocoena*) (Jacobs & Terhune, 2002; Haarr et al., 2009). Most of my time, however, has been with my "day job" as a university professor and mid-level administrator. I became most familiar with the graduate student situation during a seven-year appointment as the Associate Dean of Graduate Studies for our campus. I also have served as a departmental chair and acting dean of the faculty. In addition to my teaching duties, these administrative tasks took up lot of my time. Fortunately, I have often had sufficient research grant support to take on a few graduate and undergraduate students, and I have continued my research interests via these talented individuals. While there are a number of marine mammalogists working as full-time researchers (albeit with lots of report writing and grant applications to prepare), I think it is important for current students to recognize that such positions are rare and that many of us are fitting in our marine mammal research when time and funding permit.

I feel very fortunate to have had a career at a university. Although my research funding levels have generally been low, and occasionally interrupted, I have been able to supervise undergraduate and graduate students in a variety of projects ranging from short, lab-based analyses of seal calls to yearlong overwintering field trips in Antarctica (Figure 2) (Abgrall et al., 2003; Rouget et al., 2007). The main Canadian federal funding agency, the Natural Sciences and Engineering Research Council (NSERC), has a policy of partial funding of research programs rather than full funding of specific projects. Currently, their Discovery Grants run for five-year periods, and student training (training Highly Qualified Personnel [HQPs]) is a necessary component. NSERC funding permits following up on opportunities as they arise, and there is a lot of latitude to change directions or emphasis within the research programme. This seed money enabled me to successfully apply for full field support for myself and three students from the Australian Antarctic Division to study Weddell seal vocalizations.

Figure 2. Recording in-air sounds (person on left) and photographing (person on right) Weddell seal mums and pups near Davis, Antarctica; the seals were virtually undisturbed by the human presence.

I am fortunate in that I have had a cadre of excellent students over my career. The majority of my undergraduate honours thesis students and all of my master's and doctoral students have published their research in refereed journals, usually as the senior author (e.g., Pauli & Terhune, 1987; Turnbull & Terhune, 1993; Serrano & Terhune, 2002; Haarr et al., 2009). If the students fully take control of their project and prepare the initial draft of the resulting manuscript, they also take on the responsibility of being the senior author. I feel that following a project through to publication is an integral aspect of research training, and being published is an important achievement when applying for scholarships or employment.

From Switches to Menus

Electronic instruments in the 1960s were rather basic and generally characterized by one switch or knob controlling a single function. While high-quality instruments were available, many were difficult to obtain because of their cost and operating requirements. This was particularly the case for battery-operated portable tape recorders. Most of my experience was with Uher recorders that were temperamental when it got cold as was often the case when recording seals on sea ice (Figure 3). They had a bandwidth up to ~20 kHz at the highest tape speed of 19 cm/s. A five-inch

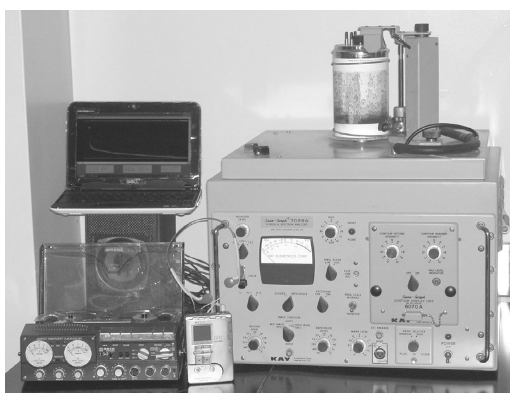

Figure 3. The Uher reel-to-reel tape recorder (lower left) and the Kay 7029A spectrum analyzer (right side, showing a sonagraph on the drum) were much larger than the Sony DAT recorder (middle) and laptop (upper left) with a spectral analysis program.

reel would last about 15 min, and so the researcher had to stay with the recorder continuously just to change tapes. The dynamic range was limited, so judging the balance between recording the ambient noise level and the loudest call was a challenge. Battery life was a problem, especially on very cold days.

Then, as now, transportation to the seal herd was usually by helicopter, but prior to the advent of GPS, getting back to a particular location using a compass bearing or a radio direction bearing from a transmission tower and flying time estimations was tricky. I remember seeing a helicopter coming to pick us up on the sea ice begin to fly a search pattern about 2 km to the south and then have to head back to land to refuel before eventually returning and finding us. Modern navigation aids and portable radios have made working in the field much safer but, unfortunately, marine mammal field work still must be recognized as being dangerous.

In the 1970s, once recordings were made, the initial analysis consisted of listening to the tapes and simultaneously viewing the waveform on an oscilloscope. Calls were first classified by ear and then clear, representative samples were analyzed via a Kay 7029A spectrum analyzer (Figure 3). The Kay analyzer consisted of a rotating drum that held a piece of paper onto which the spectrum analysis was literally burned. The sound sample was re-recorded on the edge of a turntable at the base of the drum and then the paper was loaded onto the drum and adjusted so that the end of the paper did not occur in the middle of the call. During the analysis stage, the drum rotated quickly and a screw continuously adjusted the band pass frequency of a filter as a stylus brushing the paper was simultaneously moved up along the Y axis of the spectrogram. The X axis location denoted time since the start of the sample. Whenever sound occurred within a frequency band passed by the filter, the stylus possessed a charge which would burn a mark onto the paper. When the frequency range had been completed, the paper was removed and measurements of frequency and time were made with a ruler. The process was lengthy and tedious. The resulting smoke from the burning process on the spectrograph paper had one of those characteristic smells that researchers of the time could immediately identify today.

To my knowledge, one of the most extensive sets of sound analyses at that time was performed by John Ford (1984) during his killer whale (*Orcinus orca*) studies for his doctoral research:

> I measured an average of 8.4 time and frequency variables from about 3600 calls. As each spectrogram on the old 7029A only fit a single call, that would be about 3600 spectrograms! I'm not sure I ever timed the creation of a spectrogram, but I'd estimate that by the time one captured the 2 sec bit of sound on the turntable, mounted the paper, spun the turntable up to speed, placed the stylus on the paper and watched it creep up the paper while issuing much smoke and sparks, that about 10 minutes had passed. So, that would be about $3600 \times 10 = 36{,}000/60 =$ 600 hours! My grad studies were around the time of the transition to digital, so I was able to take advantage to some extent of computer technology. Although I made the spectrograms the old fashioned way, I measured the time and frequency variables from the spectrogram using a digital tablet plugged into an old Apple II computer. Although that speeded things up a bit, I recall that making those 30,000+ measurements and analyzing them still took me about a year! (not including the time to make the spectrograms). (J. K. B. Ford, 2010, pers. comm.)

The 1990s saw the advent of digital devices, especially digital audio tape (DAT) technology and the very small "Walkman" DAT portable recorders. These units could record for 2 h on a single cassette (4 h at a lower frequency range), had a frequency range of 20 Hz to 20 kHz, and a dynamic range of 80+ dB. Another useful feature was the absolute time stamp on the tape that enabled relocating a specific location on the recording with a 1 s accuracy. The analogue to digital converters also were used by computer-based spectral analysis programs. These enabled display of the sound spectrogram in real time while listening to the recordings. It was also much easier to capture a specific spectrogram and use a cursor to obtain time and frequency measures. One of my students, Birgitta Pahl, made 6 to 15 measurements from each of 11,029 Weddell seal vocalisations during her master's thesis research (Pahl et al., 1997). Also at this time, personal computers with sophisticated statistical analysis programs capable of handling very large data sets became available. Once the data were entered onto a spreadsheet, the actual analysis went rather quickly.

Modern autonomous bottom-mounted recorders are capable of recording low-frequency blue whale (*Balaenoptera musculus*) calls continuously for a year. Perhaps it is more important to note that these long recordings can be examined using automated call detection software, thus enabling a practical analysis of the recordings (Širović et al., 2009). This is not to say that today's researchers are not faced with long manual analysis times. A report on crabeater seal (*Lobodon* *carcinophaga*) calls required manually extracting 17,052 calls from a series of PALAOA recordings (Klinck et al., 2010). The PALAOA underwater recording site is set up on the Ekström Ice Shelf in Antarctica by the Alfred Wegener Institute for Polar and Marine Research and is capable of continuous recording from 10 Hz to 15 kHz (Klinck et al., 2010). The site can be monitored on the World Wide Web (www.awi.de/en/home). As I am writing this, I am also listening to real time trills of male Weddell seals defending their territories half a world away—something I would not have thought possible over 40 years ago!

Digital electronics have reduced the power requirements of many instruments and greatly increased the nature and complexity of the tasks that can be undertaken. My 40-year-old Wavetek 112 signal generator, which I still use, has five switches, five dials, one push button, and came with a printed manual. My modern Tabor WW5061 waveform generator has one dial and 29 buttons, signal production can be enhanced via connection to a computer, and it comes with the manual on a CD. The later instrument is menu driven, and the variety of signals it can produce is orders of magnitude greater than the analogue device. The learning curve associated with such specialized instruments is a great deal steeper than was the case with the simpler tools. Digitization and microelectronics have enabled much more detailed studies in a variety of research areas that simply would not have been considered possible even 20 years ago.

Electronic communication has facilitated collaborative research projects and enabled individuals with different expertise to effectively pool their resources and specialized knowledge. The average number of authors per article published in *Aquatic Mammals* increased from 1.8 in 1985 to 2.1 in 1995 and then to 3.3 in 2005. The proportion of single-authored articles in *Aquatic Mammals* dropped from 0.5 to 0.3 and then to 0.1 over those same three time periods. The increase in multiple authorships makes it more difficult for new scientists to develop the independent research programs required by many granting agencies and employers. I have been on appointment committees for which we were assessing applicants who were co-authors on each others' papers. Where such individuals were not the lead author on the article, it was not possible to assess the contribution of the various applicants to these joint projects. This will require many hiring and grant assessment committees to re-evaluate their selection criteria.

Currently, there has been a strong increase in the interest in marine mammal bioacoustics and potential problems associated with anthropogenic noise. Two international conferences on "The Effects of Noise on Aquatic Life" (Nyborg, Denmark, 2007; Cork, Ireland, 2010) have been well attended and, along with recent "Biology of Marine Mammals" (Quebec, Canada, 2009) conferences, have showcased some very extensive sound recording and analysis projects. The continued development of automated recording and analysis capabilities, coupled with high-frequency sampling, very large digital memory storage, and direct to disk recording, etc., suggests that in the near future researchers will undertake studies that were technically impossible a decade ago. Although some very massive, and expensive, bioacoustic projects have been undertaken in recent years, there are still many "small science" workers remaining active and productive with very limited resources.

From Students to HQPs

In the 1960s in Canada, there were fewer young people at university. There is now a much higher postsecondary student enrollment at the university level (both undergraduate and graduate). A bachelor's degree in Biology (B.Sc.) is typically a four-year program with a diversity of subjects, and often an honours thesis is available. A master's degree is typically two years with a major research project and a limited number of courses. Doctoral studies may require one or two years of coursework, a comprehensive examination, and a substantial thesis, but following a master's, the coursework requirement is often lessened. The average time to completion of a doctoral degree in Biology in Canada is a little over five years. This is typically followed by a series of post-doctoral appointments prior to obtaining permanent employment. The time from the start of a B.Sc. to completion of a Ph.D. is often 9 to 14+ years.

In the UK, course specialization begins in secondary school. Undergraduate degrees are typically three years and cover only a few subjects in depth. The doctoral degree can follow immediately (there are very few master's programs) and is intended to be completed in three years. It is typically a thesis-only degree. The time from the start of a B.Sc. to completion of a Ph.D. is often 6 to 8+ years, much shorter than the typical North American situation.

These time frames have not changed over the past 40 years. The expectations of employers and granting agencies have also remained relatively constant in spite of the increasing demands being placed on doctoral students and new researchers. Generally, it appears that human knowledge may double every five years. Even with a ten-year period per each doubling of information and the likely corrections and clarifications that accompany new data, the sheer amount of reading that new researchers have to do to gain some insight into their increasingly subdivided and specialized areas of research is so much greater than I first encountered. Richard Fay's (1988) *Psychophysics Databook* presents data from only four marine mammal underwater audiograms published in or before 1970. In most subject areas, there has been an increase in the number of marine mammal articles being produced. There were nine, 17, and 40 articles per year published in *Aquatic Mammals* in the 1980s, 1990s, and 2000s, respectively. The rapidity with which some marine mammal research areas are expanding and diversifying is evident via the 1,100+ presentations at the Biennial Marine Mammal Conference in Quebec in 2009. The young researchers of today have much more background work to do than did those of us who are now adjudicating grants, scholarships, or applications for employment.

Recently, there is evidence that many governments are promoting shorter time-to-completion of degrees and, thus, the faster production of HQPs. There was a proposal in the UK that undergraduate students not take the summers off so that they could complete their undergraduate degree (six terms) in two calendar years. Some universities in the UK have a regulation that the doctoral student must present his or her thesis within four years or be failed. In the UK and Australia, if doctoral students do not complete within four years, then universities face financial penalties. This has led to less robust doctoral projects being planned to accommodate a shorter (likely) completion time. Some students I have spoken with have felt that their goal was to publish five articles, each in a different journal, during their three years of studies. While this is unrealistic, and not an official policy, the fact that some students feel this pressure to complete so much so quickly is detrimental to their program. Such expectations may have a basis in the perception of the expectations of potential employers and granting agencies. The most prestigious federal government Canadian doctoral scholarships provide funds for only three years at the doctoral level. With a mean completion time of five years, this leaves most students with funding difficulties and often mounting debt. Running out of funds before completing a doctoral dissertation often requires students to take on part- or full-time employment that exacerbates the time-to-completion problem and does not make good use of their time and expertise. The financial impetus to complete doctoral training faster is not working and may be counterproductive in that, upon completion, the students are still expected to have obtained the wide range of experiences previously associated with longer degree completion times. Many faculty members feel that the rush to completion is leading toward poor science and the publication of the smallest publishable units rather than the fewer but more substantial pieces of work that we would like to see our students achieve.

Unfortunately, many recent doctoral students are encountering employment problems because of a lack of positions resulting from the impact of the general economic downturn on research and university funding. This is particularly the case in the UK where recent budget cuts to university teaching appears to be resulting in "have" and "have not" disciplines. There is an ongoing dearth of post-doctoral positions during which newly minted doctoral graduates can learn new techniques; get the rest of their dissertation publications out; and, for those interested in working at a university, obtain teaching experience.

The Times They Are a-Changin' (Dylan, 1964)

Roger Gentry very kindly sent me a draft of his Historical Perspectives essay "Marine Mammal Research Then and Now" (Gentry, 2010) while I was preparing this perspective. I had been thinking through what I wanted to say here for some time, and I found that I was in agreement with many of Roger's comments and concerns. As he ably points out, I too have found that the size of some conferences is overwhelming; many of us got into marine mammal research by chance; a few professors and early mentors had a profound influence on our careers; Principal Investigators (PIs) are increasingly managers of other people's research; and some regulations and permitting are unduly restrictive and time consuming. Although access to e-mail, satellite phones, and the World Wide Web have made field work more efficient, they are intruding on what Roger referred to as "the gift of solitude." Being able to sit quietly or walk about and observe nature is a "fragile gift that needs protection." It gives a scientist time to just think and a setting in which to observe what is going on and wonder "Why?"

I feel that I owe a great deal to my colleagues and friends who have enhanced my career and helped clarify my thoughts. Every journal reviewer has contributed to my producing a better manuscript, and a few have kept me from publishing conclusions that would have been contradicted later by others. While preparing this perspective, I became more aware of the profound influence Bertel Møhl and Keith Ronald had on my career. I can only hope that I have helped some of my students in a similar manner.

As outlined above, I think that we will have to change our expectations of our newer colleagues and provide them with appropriate guidance and support. These are hard working, intelligent, dedicated scientists who have the tools and experience to make significant advances. This has to be recognised in an appropriate context and permitted to flourish. Fundamental science must be strengthened and not trivialized by governments or granting agencies by referring to it as being merely "curiosity-based research." Strategic funding has its place but must not completely overshadow the quest for new knowledge.

Change is an integral aspect of science and, when dealt with appropriately, will allow us to make great strides. Marine mammals present a myriad of good questions, and developing new tools and specialized expertise to address these puzzles will be a difficult but exciting task. I began with "How does a seal dive down into complete darkness, find food, catch it, and eat it before having to return to the surface to breathe?" I then became interested in hearing and the myriad vocalizations of seals while a graduate student. This led to addressing the "cocktail party" aspects of seal vocal communication and the impact of background noise on communication. I also have been able to take advantage of devising studies on the behaviour of harbour seals and harbour porpoises in the nearby Bay of Fundy. I plan to continue introducing students to these projects, and I hope that some of them will be fortunate enough to derive their own questions that they can spend a career trying to answer.

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