Entomology on the Antarctic Peninsula: The Southernmost Insect

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It had been four days out at sea from Tierra del Fuego on the National Science Foundation's (NSF) icebreaker, the *Laurence M. Gould*, across the infamous Drake Passage, and finally the continent that eluded even Captain Cook became faintly visible through the mist. We were a team of five with our eyes set on Antarctica's largest free-living land animal, a wingless midge known as *Belgica antarctica* Jacobs. Richard Lee from Miami University was the veteran of the group, having spent two summer seasons at Palmer Station 25 years ago. Joining Lee on this mission were David Denlinger and Joseph Rinehart from Ohio State University, Scott Hayward, now at the University of Liverpool, and Luke Sandro, a high school biology teacher from Springboro, Ohio (Fig. 1). Scott also was not a novice in this part of the world. He had experienced Antarctica as a graduate student working with the British Antarctic Survey before receiving the Fulbright fellowship that brought him to Ohio State for a couple years. Our grant proposal, funded by NSF's Polar Program, takes our team to Palmer Station for three consecutive field seasons.

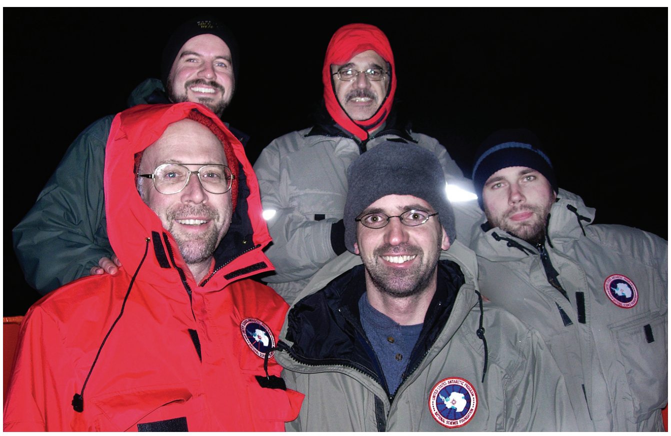

Fig. 1. Research team at midnight on New Year's Eve, 2005 while crossing the Drake Passage. Back row, left to right: Luke Sandro and Dave Denlinger. Front row: Rick Lee, Joe Rinehart, and Scott Hayward.

Fig. 2. The *Laurence M. Gould* along the Antarctic Peninsula. Photograph courtesy of Cara Sucher.

NSF is the U.S. authority for Antarctica, and it is their charge to foster U.S. research interests on the continent and to make certain that our citizens spending time "on the ice" abide by the guidelines set out in the 1959 Antarctic Treaty. The treaty, now ratified by 45 nations, sets aside all national claims to the continent, thus making Antarctica a truly unique land, one that is to be used only for peaceful purposes and for scientific discovery that is to be freely shared with the international community. The United States operates bases at the South Pole, McMurdo, and Palmer stations; but it is only Palmer Station on the Antarctic Peninsula that has a habitat suitable for the midge.

Getting There

Scientists going to South Pole or McMurdo can catch a U.S. Air Force flight from Christchurch, New Zealand, but the much smaller Palmer Station does not have an airport and can be reached only by ship (Fig. 2). We departed from Punta Arenas, Chile, the world's southernmost city, on 29 December 2004. After being outfitted with our allocation of extreme weather clothing, we headed east through the Magellan Straits, down the Argentine coast, and then across the open water through the Drake Passage. Remember how Darwin felt on the

Fig. 3. Humpback whale breaching along Antarctic Peninsula.

Beagle as they rounded the tip of South America? Fortunately, meclizine and cyclizine can now help abate some of the symptoms of seasickness, but you still get tossed around violently, and the kitchen staff can count on a day off! Twenty-foot waves are routine, but we felt lucky to sneak through the passage between two major storms that were generating waves twice that high. During periods of calm, we were rewarded with frequent sightings of humpback and minke whales, dolphins, and several species of albatrosses and petrels that followed the ship. One humpback breached seven times in a span of five minutes (Fig. 3).

Palmer Station

Palmer Station is a delightful little outpost (Fig. 4). The smallest of the three U.S. bases, it houses about 45 people during the summer months: about 20 of the people on station are scientists, and the others are support staff hired by Raytheon Corporation to run the station. Experiments in such a remote location require much more advance planning than we normally lavish on our experiments; thus, a half year before our departure, we compiled an extensive list of everything we might possibly need and forwarded it to Raytheon. (One key chemical forgotten can doom a whole project!) We were impressed with the facilities already available, even for molecular work; and Raytheon brought in all the specialized equipment and chemicals we requested. This allowed us the luxury of focusing totally on our work during our stay. The midges we were seeking could be found on many of the small islands within a few miles of the station, and Zodiacs were at our disposal for getting from island to island (Figs. 5 and 6). The view from our laboratory window was hard to beat—five species of seals, whales, and penguins and other birds all could be sighted from the laboratory (Fig. 7). During our first field season at Palmer, we shared the laboratory building, which also doubles as a dormitory and kitchen, with diverse groups of U.S. biologists working on Antarctic microbes, krill, nesting sea birds, and terrestrial plants.

Fig. 4. Palmer Station in early January 2005.

Fig. 5. Top: Zodiac fleet adjacent to the Boathouse at Palmer Station. Bottom: Luke Sandro in Arthur Harbor with Palmer Station in the background.

Most of the scientific work at Palmer occurs during the austral summer (December–February), but a dozen or more Raytheon personnel overwinter there, maintaining the facility and engaging in new construction projects. Palmer does have a medical doctor on station, but a quick evacuation is not possible; therefore, all personnel going to Palmer must undergo extensive physicals before being cleared for deployment.

Antarctic Peninsula

The fingerlike Antarctic Peninsula projects from mainland Antarctica. Palmer Station (64°46′S, 64°03′W) is located slightly north of the Antarctic Circle on Anvers Island. Because of its northerly extension and the moderating influence of the surrounding oceans, the climate is relatively mild at Palmer Station, with the annual average tempera-

Fig. 6. Views from a Zodiac in the vicinity of Palmer Station.

ture a balmy –3 °C (26.6 °F), compared with the McMurdo and South Pole stations that average –17 and –49 °C (1.4 and –56.2 °F, respectively—hence the disparaging appellation from denizens of the other stations that Palmer researchers are *touristas* working on the Banana Coast. Winter values here are also mild, averaging –10 °C (14 °F) and rarely dropping to –30 °C (–22 °F).

Global warming has drastically impacted abiotic and, consequentially, biotic features of the Antarctic Peninsula. In fact, during the past 30 years, this region has warmed 2.5 °C (4.5 °F), much more than the ~1 °C (1.8 °F) reported elsewhere in the world. Major retreat of ice shelves and changes in the seasonal extent of sea ice have altered the landscape profoundly.

In the years since Lee's first visit to Palmer Station in 1980, conspicuous changes in the summer landscape have occurred. Previously, the station was located at the base of a glacier whose melt water provided the sole source of summer drinking water. Since then, the massive glacier has retreated 250–300 m, and it continues shrinking at a rate of 10 m/yr, making it necessary to produce fresh water for the base by reverse osmosis of seawater. Some of the station workers now camp in tents in the extensive area behind the station, referred to as the "back yard." Glacial retreat on the fringes of Anvers Island has revealed new islands that were once thought to be peninsulas; in fact, one of our study sites known as Norsel Point should now be called Norsel Island.

Bird and mammal populations also have undergone dramatic changes. Adelie penguins are highly dependent on the underside of sea ice, where they forage for krill. Reduction in the amount and duration of seasonal sea ice significantly reduced the Adelie population; in the vicinity of Palmer Station, the number of breeding pairs dropped from 15,000 to 4,000 between 1975 and 2002. Paradoxically, increasing temperatures and melting sea ice increase the amount of snowfall. The delayed spring melt water invades nests and addles penguin eggs, causing substantial mortality. In contrast, chinstrap penguins, which feed in open water, are expanding their range on the peninsula. Fur seals, once rare near Palmer Station, are now frequently seen in late summer; more than 200 subadult males commonly occupy nearby Stepping Stones Island, comprising only a few hectares.

Belgica antarctica—Southernmost Insect

Seasonal melting of ice and snow on small islands and narrow projections from the Antarctic Peninsula have allowed the development of

Fig. 7. Noninsects observed during field work. Top: Leopard seal and humpbacked whales. Bottom: Fur seal and giant petrel with chick.

Fig. 8. Collecting *Belgica antarctica* on Torgerson Island.

primitive plant communities composed primarily of algae, mosses, lichens, and the only indigenous vascular plants in Antarctica, *Deschampsia antarctica* and *Colobanthus quitensis*. These simple communities support a limited fauna of microarthropods: mites and noninsectan hexapod collembolans.

A notable addition to these terrestrial communities is the terrestrial chironomid *B. antarctica*, which is unique because its distribution extends farther south than any other free-living insect. Furthermore, since Antarctic vertebrates are essentially marine, it is the largest entirely terrestrial animal in the Antarctic. This endemic species is sporadically dispersed, though locally abundant at some sites, on the west coast of the Antarctic Peninsula and its islands (Fig. 8). Its ancestor is believed to have arrived 5,000–6,000 years ago from South America, where its closest relatives are found. This species is one of only two flies occurring naturally in the Antarctic. The other species, *Parochlus steinenii* (Gerke), also a midge, is found on the northern tip of the Antarctic Peninsula, as well as in southern South America. This paucity of insect species stands in stark contrast to the larger and more diverse Arctic insect fauna that is dominated by Diptera, particularly Chironomidae.

B. antarctica has a two-year life cycle, which includes four larval stages (Fig. 9). Overwintering may occur in any of these larval instars. Larvae feed on moss, terrestrial algae (particularly *Prasiola crispa*), plant and animal detritus, and microorganisms. Pupation and adult emergence occur in late spring to mid-summer. Typical of many insects living in wind-swept alpine and oceanic habitats, the adults are wingless. (Active fliers would be quickly blown out to sea in windy Antarctica.) Adult life is short: 7–10 days at most. In contrast to the male swarms of winged midges in temperate and arctic regions, the flightless males make do with mating aggregations on the ground. Females mate within 1 day of eclosion and lay several clusters of eggs within 1–2 days.

Environmental Stress Tolerance in *B. antarctica*

Although ambient air temperature may occasionally reach winter lows of –40 °C on Anvers Island, *B. antarctica* survives freezing to only –15 °C, a relatively modest level of cold tolerance compared with many alpine and polar insects. Thermal buffering by snow and ice cover within its microhabitat explains this apparent anomaly; at a depth of 1 cm, substrate temperatures remain between 0 and –2 °C for more than 300 days of the year and rarely decrease to –7 °C. Thermal conditions on small islands and peninsulas are further ameliorated by the surrounding seawater, which remains between 0 °C and –1.8 °C throughout the year. Unlike most temperate insects that markedly increase their cold tolerance in preparation for winter, *B. antarctica* remains freeze-tolerant throughout the year.

Fig. 9. Larvae of *Belgica antarctica* in algae and detritus from penguin rookery.

In spite of residing in a thermally buffered winter hibernaculum, larvae experience highly variable and often unpredictable conditions, directly or indirectly related to water availability. Overwintering larvae endure desertlike conditions because free water is biologically unavailable as ice or snow. During the summer, terrestrial microhabitats may dry out, depending on the vagaries of precipitation, wind, temperature, and insulation in relationship to the types of soil and vegetation, aspect, and drainage. During the spring thaw or following rain, larvae may be immersed in fresh water for days to weeks. Alternatively, through the summer, larvae in vernal pools may be subjected to increasing salinity caused by evaporation and occasional saltwater splash. Outwash from penguin rookeries or elephant seal wallows may inundate larval colonies with detrital effluent that is anoxic and acidic (e.g., pH 4.0, Torgerson Island).

Our previous research demonstrated that the midge possesses extreme tolerance to a diverse range of environmental stresses. The focus of our current 3-yr project is to define the thermal and hydric diversity of *B. antarctica*'s microhabitats and to assess its physiological and molecular responses to cold and desiccation stress.

One of the interesting discoveries we made during our first summer season was that the gene encoding the major heat shock protein (Hsp70) is turned on continuously in the larvae during the summer. This is quite unusual for an actively growing insect. Although a few diapausing insects express this gene continuously during diapause, in all other cases, the heat shock proteins are turned on only for brief periods during acute stress, most notably heat stress. The adult displays a more conventional response: Hsp70 is not expressed continuously, but only comes up in response to high-temperature stress. Though air temperatures remained in the 0–5 °C (32–41 °F) range during the summer, the temperatures of the rocks, where the adults spend much of their short lives, were as much as 20°C (36 °F) higher (Fig. 10). "High temperature," of course, is relative, and neither the larvae nor adults could survive for more than a day or so at "high" temperatures of 15–20°C (59–68 °F). The high temperature limits are quite low, as one might expect, in this Antarctic species.

We also were excited to find a critical role for desiccation in the life of the larvae. Most insects cannot survive the loss of more than 20% of their body water, but the midge larva can easily lose up to 50% of its body water. This impressive dehydration dramatically enhances the larva's tolerance of low temperature. Whereas fully hydrated larvae die at temperatures below –5 °C (23 °F), larvae that were dehydrated could tolerate temperatures as low as –15 °C (5 °F). We thus suspect that cryoprotective dehydration is a feature that contributes to the larva's survival through the long winter months.

With permits in hand, we were able to bring living larvae back to the United States. By simulating the polar summer in cold rooms in our home laboratories, we were able to extend our experimental season for several months and initiate some of the molecular studies that were difficult to complete during our short stay at Palmer Station.

Outreach to Teachers and their Students

Our research objectives are complemented by our commitment to provide outreach to elementary and secondary educators and their students. Indeed, this is the reason that a high school teacher was a member of our team. Luke Sandro functioned as a full team member during the 2004–2005 season, helping in the field and in the laboratory; he monitored the critical changes in hemolymph osmolality as we subjected the midges to a range of environmental stresses. In addition, he was busy firing off photographs, journal entries, and potential lesson plans to more than 140 teachers and their students, who followed our daily activities at the bottom of the earth. Our Antarctic website and his diary, complete with photos and video clips, can be viewed at http://www.units.muohio.edu/cryolab/education/antarctic.htm.

Each year a different teacher will join us, broadening the audience that we hope to reach. We have prepared a PowerPoint program for presentation in school classrooms and at national meetings of science teachers. In addition, we have already submitted the first of several articles for publication in science education journals.

Future Prospects

Our initial field season has given us a good overview of the midge's adaptations for life during the austral summer. Next, we hope to dig a bit deeper into the unknown events of the Polar Night, the long cold season when the midge remains encased in ice. We also look forward to the upcoming International Polar Year 2007–2008, a year in which the international community will come together to launch new, integrated research initiatives in polar

Fig. 10. Microhabitat temperature adjacent to midge larvae in moss bank on Stepping Stones, near Palmer Station.

research. Just as 50 years ago, at the height of the Cold War, the 1957–1958 International Geophysical Year marked the beginning of the modern era of international cooperation in atmospheric and geological research in polar regions, this initiative is intended to provide impetus for biologists and other scientists to cooperate and ask questions that capitalize on the unique biological and physical features of these fascinating geographic regions at the top and bottom of the earth. It is our hope that insects and other arthropods will play a prominent role in this new era of polar research.

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Suggested Readings

Ainley, D. G. 2002. The Adélie penguin: bellwether of climate change. Columbia University Press, New York.

Atkinson, A., V. Siegel, E. Pakhomov, and P. Rothery. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Nature 432: 100–103.

Baust, J. G., and R. E. Lee. 1983. Population differences in antifreeze/cryoprotectant accumulation patterns in an Antarctic insect. Oikos 40: 120–124.

Baust, J. G., and R. E. Lee. 1987. Multiple stress tolerance in an Antarctic terrestrial arthropod: *Belgica antarctica*. Cryobiology 24: 140–147.

Campbell, D. G. 1992. The crystal desert: summers in Antarctica. Houghton Mifflin, Boston.

Convey, P. and W. Block. 1996. Antarctic Diptera: ecology, physiology and distribution. Eur. J. Entomol. 93: 1–13.

Convey, P., P. J. A. Pugh, C. Jackson, A. W. Murray, C. T. Ruhland, F. S. Xiong and T. A. Day. 2002. Response of antarctic terrestrial microarthropods to long-term climate manipulations. Ecology 83: 3130–3140.

Danks, H. V. 1990. Arctic insects: instructive diversity, pp. 444–470. *In* C. R. Harrington [Ed.]. Canada's missing dimensions: science and history in the Canadian arctic islands. Canadian Museum of Nature, Ottawa.

Day T.A., C. T. Ruhland, and F. S. Xiong. 2001. Influence of solar ultraviolet-B radiation on Antarctic terrestrial plants: results from a 4-year field study. J. Photochem. Photobiol. B 62: 78–87.

Fraser, W. R., and D. L. Patterson. 1997. Human disturbance and long-term changes in Adélie penguin populations: a natural experiment at Palmer Station, Antarctic Peninsula, pp. 445–452. B. Battaglia, J. Valencia and D. W. H. Walton [Eds.] *In* Antarctic communities: species, structure and survival. Cambridge University Press, Cambridge, UK.

Holmstrup, M., and P. Westh. 1994. Dehydration of earthworm cocoons exposed to cold: a novel cold hardiness mechanism. J. Comp. Physiol. B 164: 312–315.

Kennedy, A. D. 1993. Water as a limiting factor in the Antarctic terrestrial environment - a biogeographical synthesis. Arctic Alpine Res. 25: 308–315.

Matthiessen, P. 2003. End of the earth. National Geographic, Washington, DC.

Shirihai, H. 2002. A complete guide to Antarctic wildlife. Alula Press, Finland.

Smith, R. C., W. R. Fraser, S. E. Stammerjohn, and M. Vernet. 2003. Palmer long-term ecological research on the Antarctic marine ecosystem, pp. 131–144. *In* Antarctic Peninsula climate variability: historical and paleoenvironmental perspectives. American Geophysical Union, Washington, DC. E. Domack, A. Leventer, A. Burnett, R. Bindschedler, P. Convey and M. Kirby [Eds.].

Stonehouse, B. 2000. The last continent. SCP Books, Great Britain **Norfolk.**

Sugg, P., J. S. Edwards, and J. G. Baust. 1983. Phenology and life history of *Belgica antarctica*, an Antarctic midge (Diptera: Chironomidae). Ecol. Entomol. 8: 105–113.

Usher, M. B., and M. Edwards. 1984. A dipteran from south of the Antarctic Circle: *Belgica antarctica* (Chironomidae), with a description of its larva. Biol. J. Linnean Soc. 23: 19–31.

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