Annual Progress Report (#3 of 3 to USGS BRD)

Study of Atmospheric Deposition Effects on Surface Waters and Watershed Resources
Paired-gauged watershed research at Acadia National Park

Cooperative agreement 1434-HQ-98-AG01927

Project period: March 1 1999 - February 29, 2002

Principal Investigators:
Steve Kahl, Director, Senator George J. Mitchell Center for Environmental and Watershed Research (kahl@maine.edu)
Ivan Fernandez, Professor of Soil Science, University of Maine, Orono
David Manski, Chief, Natural Resources Division, Acadia National Park
Federal Collaborators:
Terry Haines, Biological Resources Division, USGS, Orono, ME
Robert Lent, Chief, Water Resources Division, USGS, Augusta, ME

Park location: Acadia National Park, Bar Harbor, Maine

Distribution:

USGS		UMaine	NPS	EPA
Tony Frank	Edward Pendleton	J. Steve Kahl	Mary Foley	Bill Hoggsett
Terry Haines	Charles Roman	Ivan Fernandez	David Manski	
Robert Lent	Janet Wise	Stephen Norton	Kathy Tonnessen	
			Tamara Blett	

Overview

This project is part of long-term ecological research using two gauged-watersheds instrumented at Acadia National Park (ANP) through collaborative funding by USGS-BRD and EPA-PRIMENet. The funding for the mercury module of this project was augmented by National Park Service money in 2000 to compensate for the third year of EPA funding which was eliminated program-wide shortly after the EPA award was made. The EPA funding period is complete, so the project continues on USGS funding only through February 2002. The focus of this portion of the project is atmospheric deposition, including episodic acidification and nitrogen deposition/cycling. This project was recommended by the Water Resources planning workshop in 1997, and in the Water Resources Management Plan completed in 2000.

The study design includes instrumentation and monitoring of two headwater watersheds. One of these watersheds is in the zone burned by wildfire in 1947 (Cadillac Brook) and one is located outside of the burn (Hadlock Brook). We are using the natural landscape contrasts provided by fire (Table 1 and Figures 1a and b) to compare patterns and processes in N sequestration and mobility, and acidification processes.

Table 1. Watershed characteristics for the study sites.

		Hadlock	Cadillac
Watershed Area (ha)		47.2	31.6
Average Slope (%)		20	28
Elevation (m)	*Gauge*	151	135
	Highest Point	380	468
Vegetation Coverage (%)	*Open*	0.76	0.04
	Scrub	45.24	41.29
	Hardwood	1.08	12.34
	Mixedwood	1.82	36.27
	Softwood	51.10	10.08

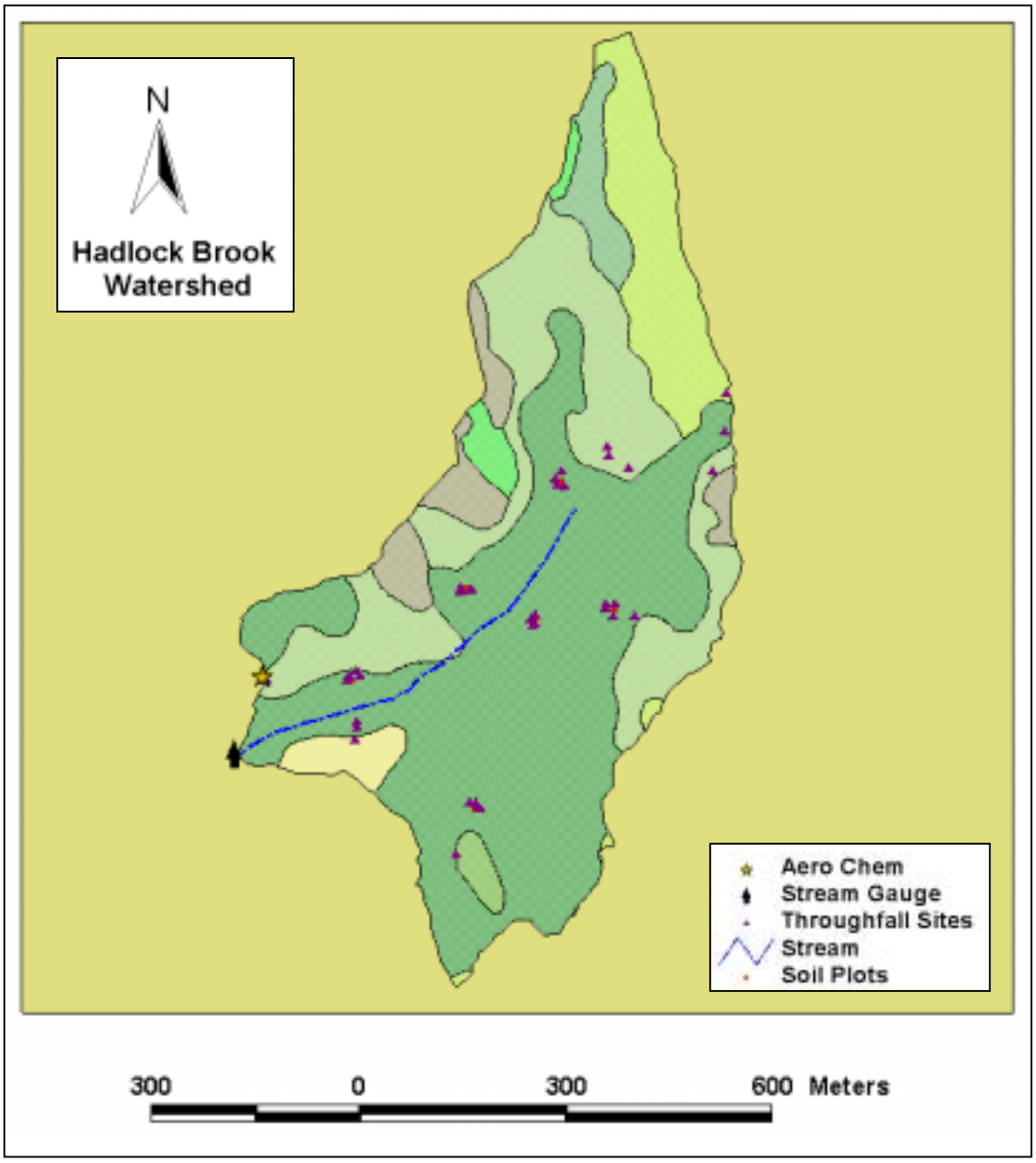
This project offers the advantages of a) co-funding for cost-effectiveness; b) a natural experimental design for the two watersheds because of a major forest fire in part of the Park in 1947; c) parallel design with the acidic deposition experiment on paired-watersheds at the nearby Bear Brook Watershed, Maine (BBWM); and d) prior research at Acadia and BBWM that supply background data, and provide the basis for ecosystem indicators to be applied at Acadia.

Our approach uses input/output measurements at the watershed scale to define the unknowns of acidic deposition inputs to landscapes as a function of factors such as aspect and forest canopy characteristics. The USGS-WRD in Augusta is providing 5-minute interval stream gauging using automated equipment. Streamwater grab samples have been collected at least biweekly for full chemical analysis; automated ISCO samplers, triggered by discharge events, have been used since 2000 to capture episodes. We have measured throughfall at approximately 40 sites in each watershed. Throughfall collectors are located in study plots in which soils have been sampled for chemical characterization, and in selected landscape positions to provide a representative sample of the topography and vegetation. Although not part of the original design and not paid for by USGS, we are also operating an Aerochem Metrics wet-only precipitation collector in each watershed during the non-freezing seasons for comparison to the NADP data collected near ANP headquarters.

The expected results will provide new information for Acadia and the New England region on the ecological consequences of high N deposition at Acadia. This research will provide key information about these important natural resource issues at Acadia. Moreover, Acadia's forests are generally representative of forests in the New England region, including both mixed hardwood and spruce-fir types. Combined with the fire history, also typical of the New England region, the range of landscape characteristics included in our experimental design will provide information for these issues at the regional scale.

Site selection

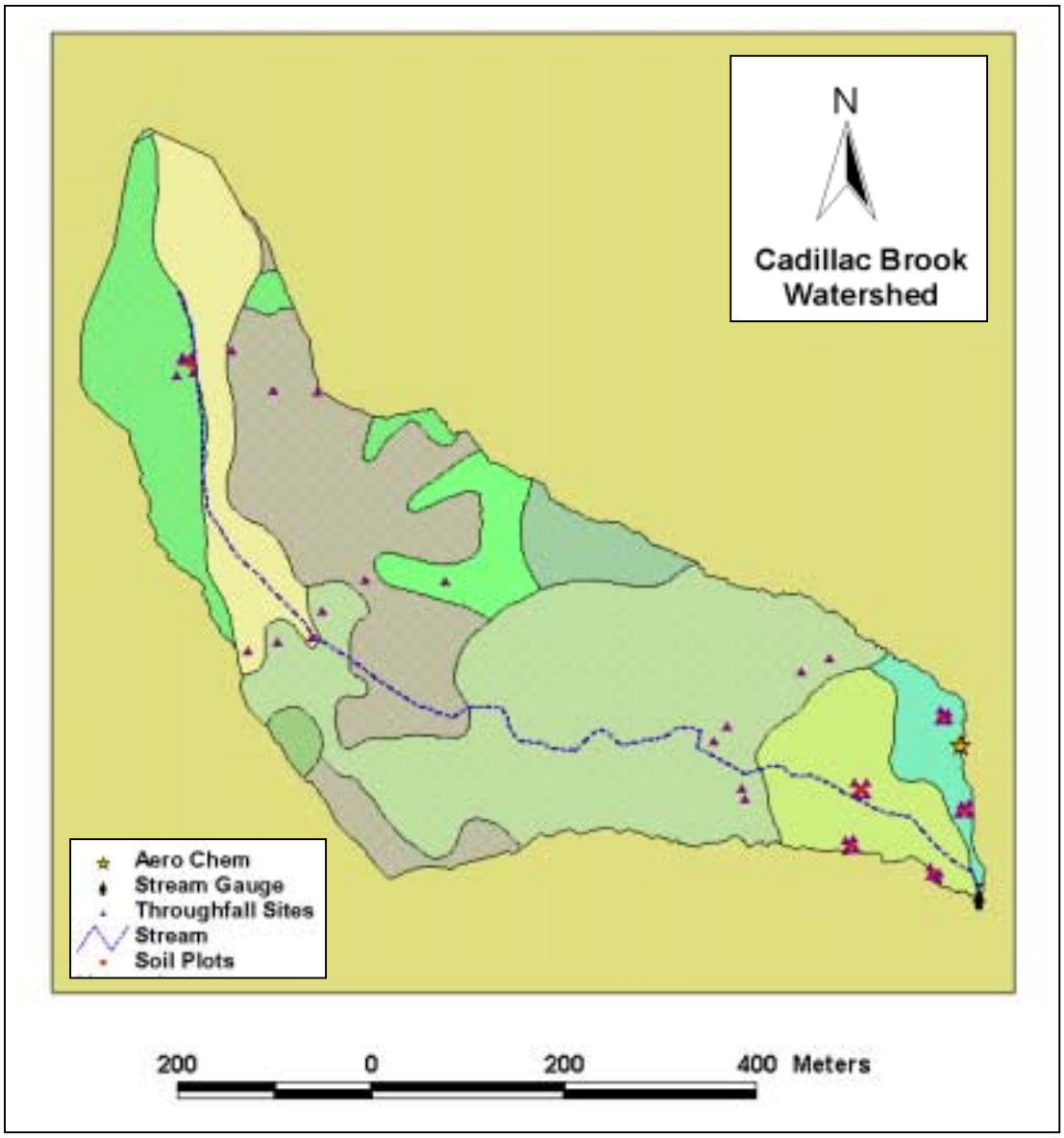
Site selection began upon receipt of EPA funding in June 1998, prior to BRD funding of this portion of the program. The PIs had an excellent baseline of headwater stream chemistry dating from 1982-84 (Kahl *et al*., 1985), and a detailed evaluation of short-term mass balances (Heath *et al.*, 1993) and episodic acidification (Kahl *et al*., 1992; Heath *et al*., 1992). We also had excellent data on deposition loading to the park (Norton *et al*., 1997; Norton and Kahl, 1987), to underscore the suitability of Acadia for this research. However, no data existed for the past 14



Vegetation Types

- Blueberry-Mtn. Ash Scrub
- Sparse Blueberry-Mtn. Ash Scrub
- Mixed Summit Shrubland
- Red Spruce Woodland
- Red Spruce-Grey Birch Summits
- Northern White Cedar Wooded Fen
- Spruce-Fir
- Successional Spruce-Fir

Figure 1a. Hadlock Brook watershed (47.2 hectares), undisturbed. Vegetation classification provided by the USGS-NPS Vegetation Mapping Project, Upper Midwest Environmental Services Center, 1999. Beta map.



Vegetation Types

- Early Successional Northern Hardwood
- Blueberry-Mtn. Ash Scrub
- Mixed Summit Shrubland
- Conifer-Hardwood Woodland Mess
- Pitch Pine Rocky Summit
- Red Spruce Woodland
- Red Spruce-Grey Birch Summits
- Spruce-Fir
- Utilities/Bare Rock
- White Pine-Northern Hardwood

Figure 1b. Cadillac Brook watershed (31.6 hectares), much of which burned in 1947. Vegetation classification provided by the USGS-NPS Vegetation Mapping Project, Upper Midwest Environmental Services Center, 1999. Beta map.

years on small streams in the park, so the first task was to sample several streams from the 1985 work, plus several others, to ensure that our choices were as inclusive as possible.

Due to the very dry conditions that existed by June of 1998, final site selection was delayed until November in order to collect several samples from each candidate site. PI Kahl spent 18 days in the field for site selection and sampling, and the entire group of PIs, USGS cooperators, and key UM staff visited the sites twice prior to final site selection. Beginning in November 1998, regular sampling began at the two final sites (Table 1).

Equipment installation and field sampling

Stream gauging was not feasible in November, so USGS installed their equipment in May 1999 and regular discharge measurements began soon thereafter. An example of comparative discharge is included in Figure 2. Automated water samplers were deployed in late fall of 1999. The samplers have been operated regularly in the spring, summer, and fall; samplers have been operated in winter when it has been feasible to power sites by solar panels in the field.

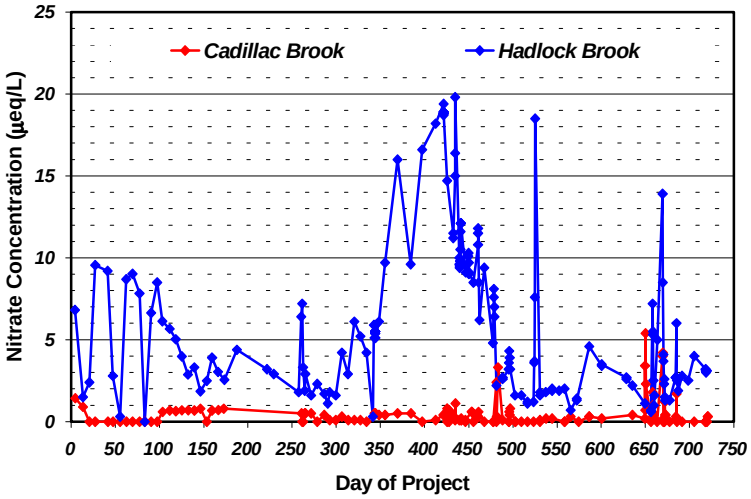


Figure 2. Comparative nitrate concentrations in PRIMENet streams, 1999 – 2000.

During the field season of 1999 we established six 15 x 15 m plots in each of Hadlock and Cadillac watersheds as the basis for the long-term soil and throughfall measurement program at Acadia National Park. Permanent plots were distributed throughout the watershed to intentionally capture the range of forested conditions in these watersheds, but did not include portions of the watersheds that were not forested. At each plot, five soil sampling stations were established and excavated by depth increment to include the O horizon, the upper 5 cm of the mineral B horizon, and the next increment of B horizon to the top of the C horizon.

Soils were returned to the laboratory at the University of Maine for processing and are currently being analyzed. In addition, at each of the soil sampling locations in situ N mineralization was measured by the buried bag technique with four buried bags at each of four plot stations (total 20 buried bags per plot). They were installed in the field in mid summer, incubated in situ until the fall, and samples were collected and extracted in the fall of 1999.

Throughfall collectors for major ion chemistry and total mercury were constructed and deployed in the summer and fall of 1999. Full deployment was dependent on the locations of soil plots, which was completed in late summer, 1999. Winter throughfall was collected using snow buckets and a more restricted matrix to ease the logistics of collection.

Table 2. Overview of progress.

Project Activity	1998 Q3	1998 Q4	1999 Q1	1999 Q2	1999 Q3	1999 Q4	2000 Q1	2000 Q2	2000 Q3	2000 Q4	2001 Q1	2001 Q2	2001 Q3	2001 Q4	2002 Q1	2002 Q2
funding status				■	■	■	■	■	■	■	■	■	■	■	■	
site selection					■	■										
equipment installation				■	■	■										
stream sampling		■	■	■	■	■	■	■	■	■	■	■	■	■		
stream gauging				■	■	■										
throughfall sampling						■		■	■	■		■	■	■		
baseline soil sampling					■	■										
annual watershed mass balances								■				■				■
NPS staff participation						■	■	■	■	■	■	■	■	■		
sample analyses		■	■	■	■	■	■	■	■	■	■	■	■	■		
progress report							■				■					

■ = project plan ■ = in progress ■ = completed

Stream chemistry and watershed mass balances. Bi-weekly or more frequent stream samples have been taken since November 1999, except when streams are dry or heavily iced. 2001 was the driest year on record in Maine since 1984, which resulted in low flows and decreased numbers of precipitation and throughfall samples. The comparative nitrate response is included in Figure 2. The project hypothesis continues to be supported by the data, with Hadlock Brook watershed yielding much higher concentrations of nitrate in streamwater.

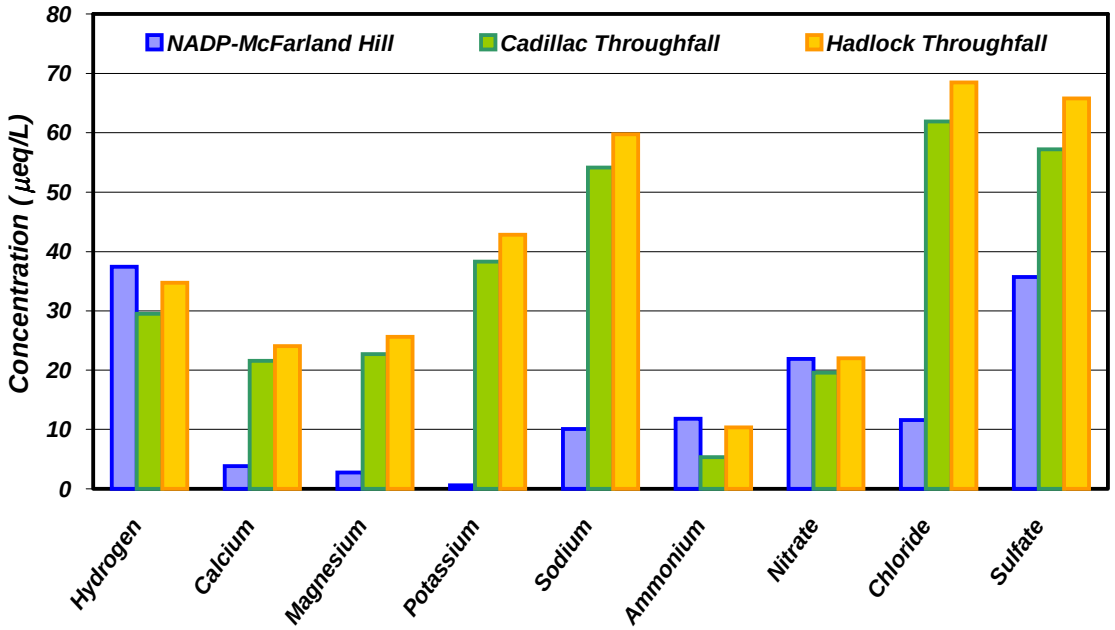


Figure 3. NADP wet-only concentrations and throughfall concentrations in the PRIMENet watersheds, May – November 2000.

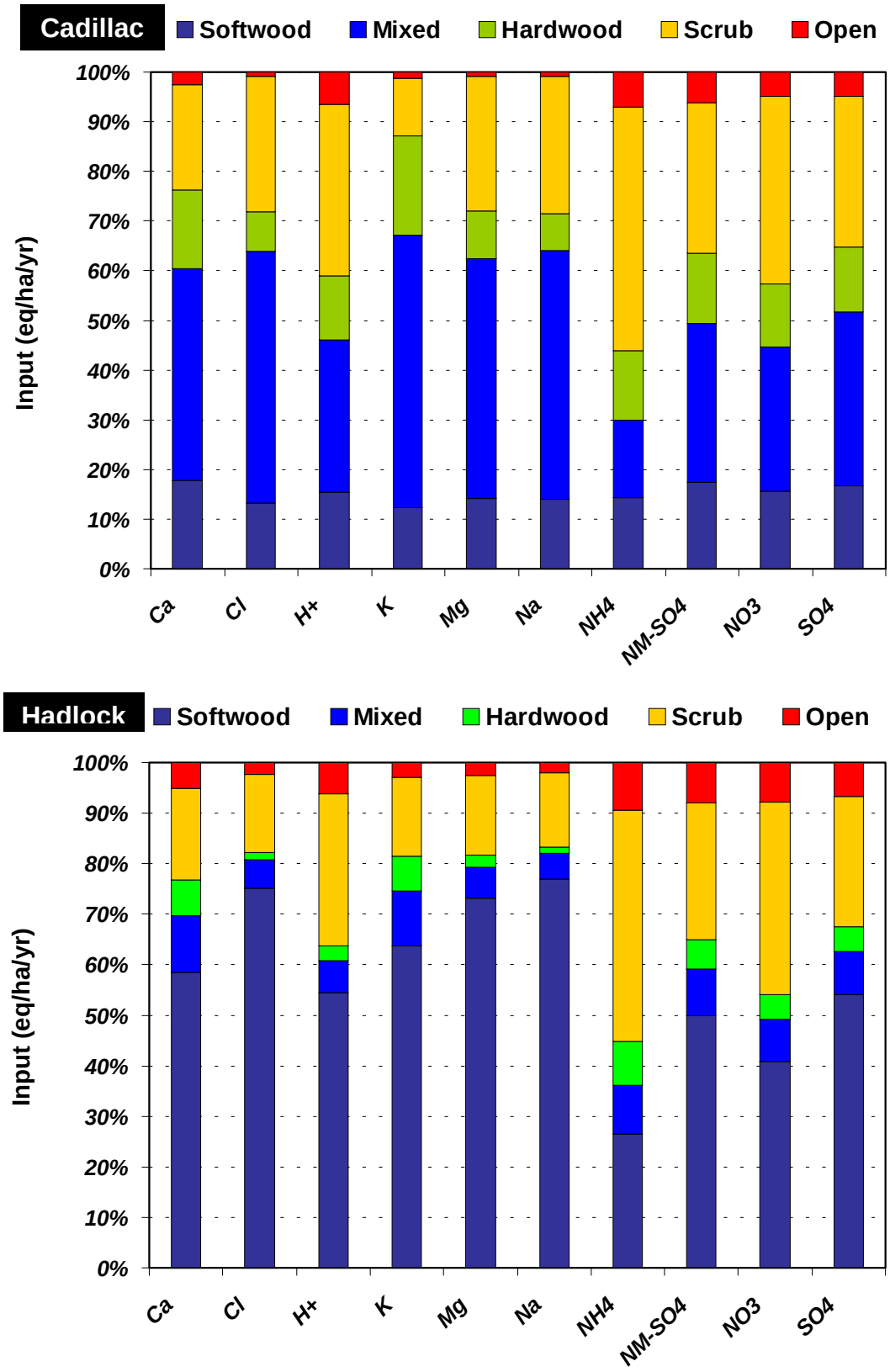


Figure 4. Percent of total mass input of major ions for each vegetation type at Cadillac Brook watershed and Hadlock Brook watershed for water year 2000. Each bar segment represents the contribution, in percent, of each respective vegetation type to the estimated deposition across the watershed area.

Throughfall collections in each watershed are based on precipitation amount and generally occur every three weeks. A summary of throughfall data compared to Aerochem Metrics NADP data is shown in Figure 3. As predicted, throughfall inputs to the watersheds are much higher than wet deposition. We hypothesized that the softwood canopy at Hadlock Brook watershed is more effective at scavenging substances from the atmosphere. Seasonal patterns and vegetation type (Figure 4) were found to be the primary drivers of differences in deposition across the landscape. We calculated enhancement ratios by comparing measured throughfall deposition to NADP wet-only deposition for synchronized time intervals in 1999 and 2000. These enhancement ratios compared favorably with other ratios calculated throughout the Northeast (Figure 5). Deposition input estimates were calculated for the two watersheds, based on measured throughfall inputs during the growing season; enhancement ratios were used to scale up NADP wet-only deposition during the dormant season (Figure 6).

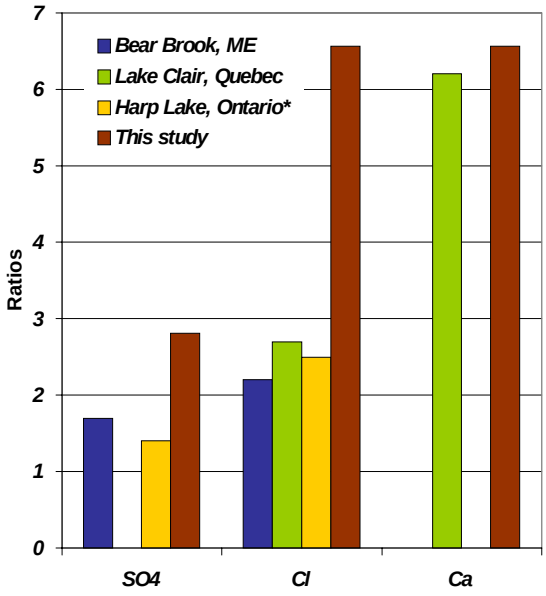


Figure 5. Throughfall enhancement for the growing season for Bear Brook, Maine (Rustad *et al.*, 1994); Lake Clair, Quebec (Houle *et al.*, 1999); Harp Lake, Ontario (Neary and Gizyn, 1992); and this study.

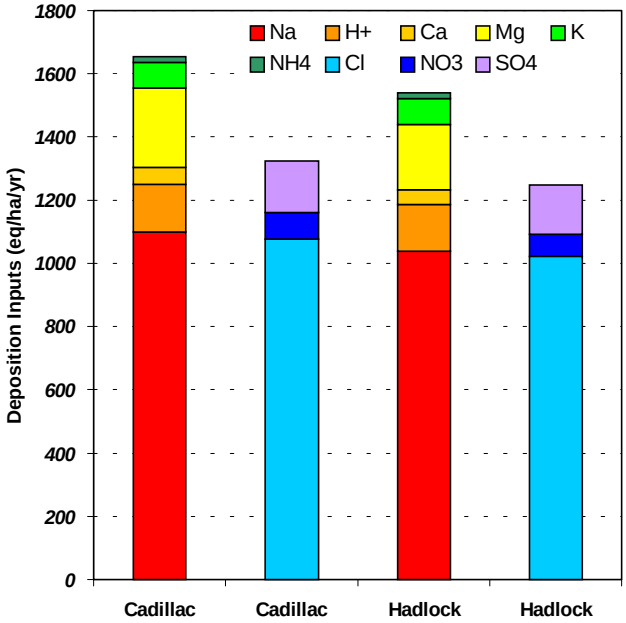


Figure 6. Inputs to the PRIMENet watersheds for water year 2000. Cations and anions in deposition were estimated using throughfall for the growing season and enhancement ratios in conjunction with NADP data for the dormant season.

We also collected throughfall and wet precipitation, streamwater, and litter samples from November 1999 to November 2000 and analyzed them for total mercury (Hg). Annual input estimates were compared to export estimates to determine Hg retention by watershed soils. The hypothesis was that Cadillac Brook would export less Hg than Hadlock Brook because the fire in 1947 depleted the soil Hg in Cadillac Brook watershed, allowing the soils to sequester a greater percentage of the Hg deposited on the burned watershed. This study supported the hypothesis. Another major finding was the magnitude of the contribution of Hg to the forest floor by leaf litter. Figure 7 shows the contribution of Hg by wet-only deposition (MDN), throughfall precipitation (TF), and litter as well as export by the streams for both watersheds. Litter contributes the most Hg to the forest floor in each watershed, but the residence time of that Hg in the watershed is largely unknown.

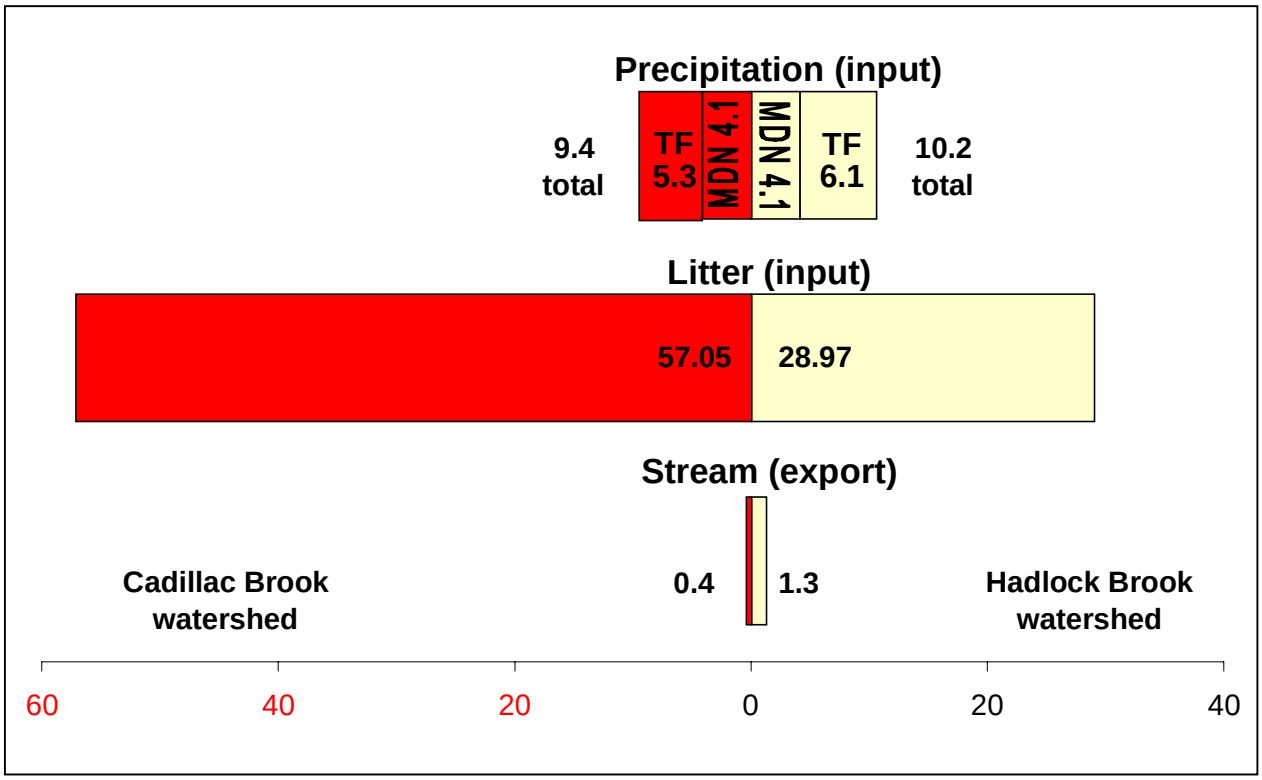


Figure 7. Hg dynamics stratified by vector and watershed.

Watershed soils. During the field season of 1998 a pilot study was conducted in the Hadlock and Cadillac watersheds to evaluate soil properties, particularly as they related to C and N in soils. These data suggested that the forest floor was depleted of both C and N, as might be expected due to loses through combustion and increased rates of mineralization due to litter quality changes, but that depletions in the forest floor were offset by higher accumulations in the mineral soil beneath. Preliminary results suggest a shift to greater light fraction than heavy fraction organic carbon in the burned watershed mineral soils, that could reflect (a) the presence of charcoal in the soil, and/or (b) a shift towards more rapidly mineralized C forms. Both density fractionation and particle size C fractionation methodologies suggest similar trends, but the density fractionation is better expressed yet more vulnerable to charcoal presence artifacts. Further work is being done to understand the differences between these soil systems that may be related to the natural history of the site. Antecedent conditions, wildfire, and forest composition all potentially play a role in these results.

Workshops and meetings

The first of planned annual Acadia Watershed meetings was held in Orono January 21, 1999. In addition to UM PIs, staff, and graduate students, attendees included NPS representatives from Acadia, Boston, and Denver, and USGS BRD staff from West Virginia. Ten talks were presented by PIs and staff at the day-long meeting.

The second in this planned annual series of research workshops was held March 13 in Orono. The meeting series was entitled 'Aquatic Research at Acadia (ARIA)'.

The third ARIA meeting was held March 27, 2001 at the College of the Atlantic. The agenda for the meeting is attached as Appendix 1.

The fourth in the series will be held at Schoodic Point on March 22, 2002. The agenda will expand beyond an aquatic focus to include coordination and planning for a wide variety of research in Acadia.

Presentations and abstracts based on data from this cooperative agreement:

Evans, J.L., I.J. Fernandez, and L.E. Rustad, 1999. *The response of soil C and N to forest ecosystem change.* Agron. Abstr. p. 296.

Jacobson, G. *et al*., 1999. *Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds*. PRIMENet annual review meeting at Sequoia NP, California (November 1999).

Johnson, K.J., T.A. Haines, J.S. Kahl, S. A. Norton. *Mercury and Methylmercury Budgets for a Pair of Watersheds in Acadia National Park.* Gordon Research Conference – Forested Catchments, Andover, New Hampshire (July 2001).

Johnson, K.J., T.A. Haines, J. S. Kahl, S. A. Norton, 2001. *Mercury and methylmercury dynamics in a pair of watersheds at Acadia National Park.* PRIMENet annual meeting at Hawaii-Volcanoes National Park, Hawaii (November 2001).

Kahl *et al*., 1998. *Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds*. Second annual DISPro review meeting, Pt. Reyes CA (November 1998).

Kahl, J.S., I. Fernandez, S. Norton, B. Wiersma, G. Jacobson, and T. Haines, 1999. *Patterns of N and Hg geochemistry in paired gauged watersheds at Acadia National Park.* (Invited abstract). Maine Biological and Medical Sciences Annual Symposium, Bar Harbor (May, 1999).

Kahl *et al*., 1999. *Patterns of N and Hg geochemistry in paired gauged watersheds at Acadia National Park.* (Invited abstract). Maine Biological and Medical Sciences Annual Symposium, Bar Harbor, Maine (May 1999).

Kahl, J.S., 2000. *Acid rain and Maine salmon: is there a link?* (Invited lecture). Forum on restoration of salmon, University of Maine, Machias, (October, 2000).

Kahl, J.S., 2000. *A regional assessment of aquatic effects from acidic deposition.* (Invited talk). Annual meeting of the Northeast Regional Air Quality Committee (November, 2000).

Kahl, J.S., 2000. *Maine and the Clean Air Act re-authorization.* (Invited keynote). Spring meeting, Maine Lakes Conservancy Institute (April 2000).

Kahl, J.S., J.M. Peckenham, and S.J. Vidito, 2000. *Developing harvester-defined water quality 'Best Management Practices' during forestry operations.* (Poster presentation). Forest Information Exchange annual meeting, Orono, Maine (October, 2000).

Kahl, J.S., S. Norton, I. Fernandez, 2000. *Biogeochemistry of mercury and nitrogen at Acadia N.P.* (Invited). PRIMENet annual meeting, Shenandoah N.P. (November, 2000).

Kahl, J.S., 2001. *Indicators of recovery from acidification (or not) in surface waters of the northeastern US.* (Invited plenary talk). Gordon Research Conference on Biogeochemistry of Forested Watersheds (July 2001).

Vidito, S., J. S. Kahl, I. Fernandez, S. Norton, Terry Haines, D. Manski, L. Rustad, C. Roman, R. Lent, 1999. *Mercury and Nitrogen Biogeochemistry in gauged watersheds at Acadia National Park.* (Poster presentation). Gordon Research Conference, Andover NH (May, 1999).

Vidito, S. J., J. S. Kahl, 2000. *The relative importance of landscape factors: linkages between atmospheric deposition and stream export in contrasting watersheds at Acadia National Park* (Poster presentation). Gordon Research Conference – Environmental Sciences, Holderness, New Hampshire (June 2000).

Vidito, S. J., 2001. *Coupling throughfall chemistry with landscape assessment.* (Oral presentation). Maine Water Conference, Augusta, Maine (May 2001).

Vidito, S. J., J. S. Kahl, I. J. Fernandez, C. S. Cronan, A. S. White, 2001. *Modification of atmospheric inputs at Acadia National Park, Maine.* (Poster presentation). Gordon Research Conference – Forested Catchments, Andover, New Hampshire (July 2001).

Vidito, S. J., J. S. Kahl, 2001. *Inferring regional patterns and responses in N and Hg biogeochemistry using gauged paired watersheds at Acadia National Park.* (Invited). PRIMENet annual meeting at Hawaii-Volcanoes National Park, Hawaii (November 2001).

Documents in review. Paleoecological assessment of forest-disturbance: linkage to watershed deposition and export of N and Hg. Can J. For. Research.

References cited

Heath, R.H., J.S. Kahl, S.A. Norton, and I.J. Fernandez, 1992. Episodic acidification caused by the sea-salt effect in coastal streams, USA. Water Resources Research 28:1081-1088.

Heath, R.H., J.S. Kahl, S.A. Norton, and W.F. Brutsaert, 1993. A calibrated watershed/long term monitoring sites at Acadia National Park, Maine. Final report, National Park Service, North Atlantic Region, Boston, MA. 115 p.

Houle, D., R. Oimet, R. Paquin, J. LaFlamme, 1999b. Interactions of atmospheric deposition with a mixed hardwood and a coniferous forest canopy at the Lake Clair Watershed (Duchesnay, Quebec). Canadian Journal of Forest Research 29: 1944-1957.

Kahl, J.S., J.L. Andersen, and S.A. Norton, 1985. Water resource baseline data and assessment of impacts from acidic precipitation, Acadia National Park, Maine. NPS Technical report #16, 123 p.

Kahl, J.S., S.A. Norton, T.A. Haines, E.A. Rochette, R.H. Heath, and S.C. Nodvin, 1992. Mechanisms of episodic acidification in low-order streams in Maine, USA. Environ. Pollut. 78:37-44.

Kahl, J.S., T.A. Haines, S.A. Norton, and R.B. Davis, 1993. Recent temporal trends in the acid-base chemistry of surface waters in Maine, USA. Water, Air, and Soil Pollution, 67:281-300 (and reply to comment by Mattson and Likens; WASP 83:101-104, 1995).

Neary, A. J., W. I. Gizyn, 1994. Throughfall and stemflow chemistry under deciduous and coniferous forest canopies in south-central Ontario. Canadian Journal of Forest Research 24: 1089-1100.

Norton, S.A., and J.S. Kahl, 1987. A comparison of lake sediments and ombrotrophic peat deposits as long term monitors of atmospheric pollution. In: New Approaches to Monitoring Aquatic Ecosystems, ASTM STP 940, T. Boyle, ed., Am. Soc. Testing and Materials, Philadelphia, pp. 40-57.

Norton, S.A., Evans, G.C., and Kahl, J.S., 1997. Comparison of Hg and Pb fluxes to hummocks and hollows of ombrotrophic Big Heath bog and to nearby Sargent Mt. Pond, Maine, USA: Water, Air, and Soil Pollut. 100:271-286.

Rustad, L.E., J.S. Kahl, S.A. Norton, and I.J. Fernandez, 1994. Under-estimation of dry deposition by throughfall in mixed northern hardwood forests. J. Hydrol. 162:319-336.

Appendix A. Agenda for 2001 Aquatic Research in Acadia Symposium

ARIA 2001 Aquatic Research in Acadia, March 27, 2001

Gates Center, College of the Atlantic, Bar Harbor, Maine

8:45	Manski	Introductions, goals of conference
8:55	Haertel	Welcome; Importance of research to Acadia; the Learning Center initiative
9:05	Manski	The role of research in management: the Acadia Water Resources Management Plan
9:15	Tonnessen	Research in National Parks: UV and watershed research in the US
9:30	Gawley	National Park Service-wide resource data management system
	PRIMENet WATERSHED-SCALE RESEARCH	
9:45	Kahl	The goals of PRIMENet watershed research at Acadia
10:00	Eckhoff	The vegetation module of PRIMENet research
10:35	Fernandez	Evidence of wildfire/vegetation on soil organic carbon and nutrients
10:50	Vidito	Atmospheric Inputs to PRIMENet watersheds
11:05	Weathers & Vidito	Atmospheric deposition in mountainous terrain: Scaling up to the landscape
11:15	Kahl	Chemical mass balances and trends for PRIMENet watersheds: comparison with long term regional respons
11:35	Haines	Sources and sinks of mercury in two contrasting watersheds
11:55	WORKING LUNCH	
12:40	Johnson	Mercury Budgets for Hadlock and Cadillac Brooks, paired PRIMENet Watersheds
12:55	Ruck	Cycling and Speciation of Mercury in Soils at Acadia National Park.
1:10	Norton	Should we really expect mercury to decrease in our lakes, streams, and fish?
	NUTRIENTS AND ESTUARIES	
1:30	M. Nielsen	Estimates of hydrologic nitrogen inputs and a preliminary water budget for the Northeast Creek/Fresh Mead
1:45	Culbertson & Good	Monitoring nutrient enrichment in Northeast Creek estuary: study design and results from first year field sea
2:00	Keats	The effect of nitrogen loading on estuarine ecosystems: a stable isotope approach in Northeast Creek Estua
	AQUATIC BIOLOGY RESEARCH	
2:25	Moring	Freshwater fishes of Acadia National Park
2:45	Attix	Developing a management plan for the Common Loon on Mount Desert Island, ME.
3:00	Longcore	Transfer of mercury and other trace metals from food to tissues of Tree Swallows at Acadia National Park
3:15	Guntenspergen & Ne	Developing indicators of freshwater emergent wetland integrity for monitoring and management
3:30	Cunningham	The effect of beaver disturbance on spatial and temporal patterns of amphibian breeding and wetland use
3:45	Kolozsvary	Hydroperiod and the reproductive success of wood frogs and spotted salamanders
3:55	Bank	Preliminary results from the 2-lined salamander mercury study
4:10	Loftin	Effects of landscape heterogeneity and environmental stressors on palustrine and lotic amphibian populatio
4:20	Jung	Amphibian Research and Monitoring Initiative (ARMI)
4:30	Fegley	Development of protocols for monitoring of organisms in intertidal sea caves
6:30	EVENING PLENARY TALK	
	Haines	Mercury in Acadia NP: where does it come from and what does it mean?