Great Basin Naturalist

Volume 37 | Number 1
Article 4

3-31-1977

Hydrological features of a California coastal fen

Don C. Erman
University of California, Berkeley

Kenneth B. Roby
U.S. Forest Service, San Francisco

Michael Eames
Department of Fisheries, State of Washington, Olympia, Washington

Recommended Citation

Erman, Don C.; Roby, Kenneth B.; and Eames, Michael (1977) "Hydrological features of a California coastal fen," *Great Basin Naturalist*: Vol. 37 : No. 1 , Article 4.
Available at: https://scholarsarchive.byu.edu/gbn/vol37/iss1/4

HYDROLOGICAL FEATURES OF A CALIFORNIA COASTAL FEN

Don C. Erman[1], Kenneth B. Roby[2], and Michael Eames[3]

Abstract.— A unique fen peatland, on the California coast, depends on six streams for its supply of flowing, mineral-rich water. About 25 percent of the water is supplied by surface streams that had average concentrations of Ca^{++} from 0.15 meq/l to 0.32 meq/l and of Mg^{++} from 0.25 meq/l to 0.47 meq/l. During the dry summer period oxygen concentration and pH were lower in the central area than in the fen margins. Water flow near the margins maintains high O_2, pH, and cation content. The fen ranges from 4 m to over 11 m in depth, but the thickest peat layer is made up of very liquid, unconsolidated peat. In one year, an estimated 19.3 metric tons of suspended sediment entered the 38.6 ha fen, which was equivalent to a 42 kg/ha loss from the total watershed.

Inglenook Fen near the coast of Fort Bragg, California, may be the southernmost example of a fen-type peatland on the Pacific coast and is the only recognized example on the California coast (Baker 1972). A fen is a physical land type that has distinctive flora and vegetation. It is often concave in cross section, has strong inflows of mineral-rich waters, has near-neutral pH, contains high amounts of Ca and Mg ions, and is productive (Heinselman 1970). To emphasize the source of minerals and water, this land type is referred to now as a minerotrophic (Heinselman 1970) or rheotrophic (Moore and Bellamy 1973) peatland.

Fens evolve naturally over time to become bogs. Bogs (ombrotrophic peatlands) are characterized as being isolated from mineral-rich water, often convex in cross section, acid in pH, and unproductive (Heinselman 1970). Numerous examples of bogs exist along the Pacific coast of North America (Rigg and Richardson 1938). Several are within a few km of Inglenook Fen in the "pygmy forest" on the upper coastal terraces (Rigg 1933, Jenny et al. 1969).

The peatland type and rate of change from fen to bog is strongly influenced by certain critical or controlling factors. Water sources are the key element in peatland evolution (Heinselman 1970, Moore and Bellamy 1973). Little information is available on the important hydrologic features of Inglenook Fen. Our objectives were to determine the sources and amounts of inflowing water, the nutrient status of the water, and the physical-chemical conditions in the fen.

Study Area

Inglenook Fen was described by Baker (1972), who included a floral list and some chemical conditions. The fen was formed by sand dunes blocking the stream outlet of a small valley on the second coastal terrace. A small 1.11 ha pond (Sandhill Lake) exists at the western edge, and radiating outward, especially to the east, are typical zones of marsh-fen vegetation—floating aquatics, emergents, sedge fen, and woody plants. The fen is 38.6 ha, of which about 4.6 ha are dominated by Cyperaceae fen and *Calamogrostis*-Cyperaceae-*Menyanthes* fen (cf. Baker 1972). The remainder is predominantly woody vegetation (fen carr).

Six streams drain five watersheds (A-E) into the fen (Fig. 1). The watersheds range from forest land (67 percent) and pasture to some residential development in Area C and part of Area D.

---

[1] Department of Forestry and Conservation, University of California at Berkeley, Berkeley, California 94720.

[2] U.S. Forest Service, San Francisco, California.

[3] Department of Fisheries, State of Washington, Olympia, Washington 98501.

Methods and Materials

Approximately twice a month from November 1972 to November 1973, we measured discharge, water temperature, pH, dissolved oxygen, calcium and magnesium ion content, total suspended sediments, orthophosphate, and nitrate in the fen streams. Silica was measured occasionally. Aerobic limit, peat depth, O_2, pH, and temperature were measured irregularly on the fen.

Flow was measured in two ways. The first involved catching stream flow in a container of predetermined volume. The time required to fill a container was measured with a stopwatch. All streams except A_{no}, A_{so}, and the outlet were measured this way as they emptied from culverts that passed beneath Highway 1 (Fig. 1). Flows of other streams that did not empty from culverts were determined by measuring a section for width, average depth, length, and average velocity. Velocity was determined by timing a float over a measured distance.

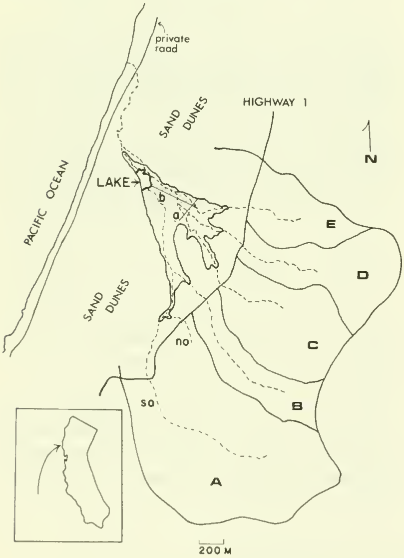

Fig. 1. Map of Inglenook Fen showing inlet streams (dashed lines) and their watersheds (A to E). Lines *a* and *b* are transects for peat depth cores. The dotted area in the central fen region is predominantly sedge vegetation.

Water temperature was determined with a thermistor or mercury thermometer, and oxygen concentration was determined with a YSI Model 51A O_2-temperature meter or by the Winkler method.

Small samples were taken for water pH determinations. Shortly after collection of the sample, pH was measured with a LaMotte colorimetric comparator (wide range pH 3–10, narrow range pH 5–8).

Other water samples were taken for Ca-Mg ions and PO_4-NO_3 analysis. Samples for Ca-Mg analysis were preserved by addition of perchloric acid, filtered qualitatively before analysis, and brought to a concentration of 0.5 meq/l of strontium chloride to reduce interference. Analysis was performed on a Perkin-Elmer Model 303 atomic absorption flame spectrophotometer.

Separate glass bottles were used for PO_4-NO_3 samples; they were stored for one to three weeks in a refrigerator prior to analysis. Determinations were made on a Hach #640 Direct Reading Colorimeter. Orthophosphate was measured by the Hach-Stannaver Method and nitrate (after nitrite adjustment) by the cadmium reduction method.

An additional water sample was vacuum-filtered through a preweighed glass fiber filter (approximately 0.3 μm pore size). The filter was then oven dried and reweighed to determine total suspended sediments.

Silica was measured with a LaMotte colorimetric comparator. The depth to which oxygen was present in the fen (aerobic limit) was determined by measuring the stain that developed on implanted redwood stakes (Erman 1973). The distance from fen surface to where staining begins (absence of oxygen causes stain) is the aerobic limit. To determine peat depth, we made cores along two transects, A and B (Fig. 1), of the fen with a Hiller-type peat borer.

Results and Discussion

Stream Flows

Mean surface flows are given in Table 1. Large seasonal fluctuations occurred in dis-

TABLE 1. Yearly average (and standard deviations) of environmental conditions of outlet and inlets to Inglenook Fen, Mendocino Co., California.

Environmental Factor	Stream A_{so}	A_{no}	B	C	D	E	Outlet
Discharge (1/sec)	4.93	3.26	14.6	9.17	9.03	4.25	179.8
(S.D.)	(3.97)	(4.93)	(14.1)	(17.7)	(14.8)	(11.5)	(278)
O_2 (mg/l)	10.1	10.0	10.5	10.1	11.3	10.3	7.43
(S.D.)	(1.24)	(2.13)	(0.94)	(1.31)	(1.66)	(1.01)	(1.92)
O_2 saturation (%)	94.4	89.3	101.2	95.1	101.5	95.8	70.5
(S.D.)	(9.47)	(16.8)	(5.56)	(6.3)	(10.7)	(7.64)	(24.4)
Temperature (°C)	12.7	12.0	12.8	12.7	11.3	12.9	13.4
(S.D.)	(3.3)	(3.4)	(3.7)	(4.4)	(4.0)	(4.9)	(5.3)
Median pH	6.5	5.6	6.7	6.8	6.8	6.3	6.6
Ca^{+2} (me/l)	.16	.14	.18	.28	.32	.15	.62
(S.D.)	(.09)	(.08)	(.08)	(.14)	(.15)	(.07)	(.25)
Mg^{+2} (me/l)	.27	.26	.33	.47	.47	.25	.47
(S.D.)	(.06)	(.06)	(.09)	(.14)	(.14)	(.06)	(.10)
Sediments (mg/l)	19.9	11.4	16.0	12.5	16.9	4.24	4.41
(S.D.)	(22.9)	(12.6)	(20.8)	(11.6)	(18.6)	(3.50)	(5.59)
PO_4 -P (mg/l)	.09	.09	.08	.09	.09	.07	.13
(S.D.)	(.08)	(.07)	(.05)	(.08)	(.08)	(.07)	(.08)
NO_3 – N (mg/l)	.60	.23	.28	.13	.28	.06	.12
(S.D.)	(.29)	(.26)	(.07)	(.07)	(.16)	(.03)	(.10)
Conductivity[a] (uMhos @ 25°C)	109	216	154	222	203	92	366

[a] Data from November only.

charge with minimum flows from May to October. Stream B consistently had the highest flow (avg. 14.6 l/sec). The total outflow from May to October (the dry season) averaged 47.6 l/sec (28–68 l/sec) and was more than twice the combined inflow (15.9 l/sec). Mean monthly discharge of the combined inlets and of the outlet are shown in Fig. 2.

One of the most interesting results of this work is the relationship between inlet and outlet flows. R. Jackson (pers. comm.), who surveyed the fen for the Nature Conservancy, surmised that the predominantly sandy soils of the watershed would result in much subsurface flow. For the entire sampling period the measurable surface inflow averaged only 25.2 percent (13.8–66.3 percent) of the measurable surface outflow. With one exception, during a rainstorm on 21 September 1973, measurable inflow never exceeded 50 percent of outflow. Thus subsurface flow appears more important than surface flow in this area. Water, of course, also enters the fen from surrounding sand dunes and direct precipitation on the fen, and it leaves via evaporation and evapotranspiration. These sources were not measured.

By expanding the mean discharge value we estimated the total annual volume of water carried by each stream (Table 2). The estimated yearly inflow of all surface water was 1.43 million m^3, compared to about

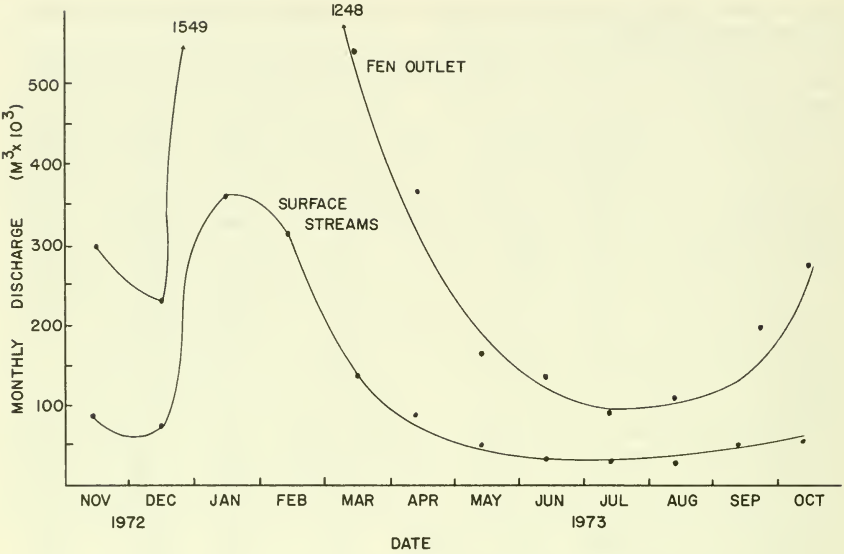

Fig. 2. Estimated total discharge by month of all inlet streams combined and of the outlet.

5.67 million m^3 of outflow. In Table 2 the discharge of each inflowing stream is shown as a percentage of the total inflow, and this value is compared with the percentage of the total watershed area for each of the streams. These results indicate differences between size of watershed and amount of surface flow. For example, based on surface flow, Watershed A accounted for 18.1 percent of the water volume while it included 42.7 percent of the total watershed. Watershed B contained 12.4 percent of the area, but accounted for 32.3 percent of the total flow. Differences shown in these figures may be due to differences in vegetative cover, soil type, and slope gradient in the five watersheds. Preliminary soil maps of the fen watershed show streams A to C drain Empire Sandy Loam, while streams D to E drain Hugo Sandy Loam. We have no data on subsurface flow, but it may be that when subsurface flow is added to surface flow, the total contribution of each stream is closer to its percentage of the total watershed.

Mean monthly discharge of the combined inlets and of the outlet are shown in Fig. 2.

Table 2. Comparison of surface stream inflow and area of watershed of Inglenook Fen.

Stream	Total Annual Flow ($M^3 \times 10^3$)	% of Total Flow	Area of Watershed (Hectares)	% of Total Watershed Area
A (No + So)	258	18.1	196.3	42.7
B	460	32.3	86.7	12.4
C	289	20.2	33.8	18.3
D	285	20.0	77.7	16.9
E	134	9.4	44.9	1.7
Total	1430		459.4	

Jackson (pers. comm.) has suggested that only Stream E is seasonal. Stream A_{no} was the only intermittent stream during the present study, although Stream E carried less than 0.3 l/sec from June to September.

Temperature and Oxygen

It was impossible to sample the streams at the same time of day on the various dates. Daily fluctuations in temperature are unknown for these streams. As expected, the winter water temperature (5–12 C) was lower than the summer water temperature (15–20 C), although temperatures below 10 C are unusual. High daytime air temperatures are uncommon in summer because of frequent fog along the coast, and thus even small streams are not particularly warm.

In general, oxygen concentration in inlet streams was near air saturation (average 95–101 percent except for A_{no}, which had low O_2 (5.7–7.3 mg/l) at low flows (Table 1). Warmer water temperatures during low flows resulted in lower oxygen concentrations, as shown for Stream B in Fig. 3, than at other times of the year, although oxygen was still near air saturation. For most of the year, the outlet had significantly lower O_2 content than the inlets. The outlet is compared to Stream B in Fig. 3. This result is expected because the fen has a tremendous amount of decaying material that would consume oxygen as water flowed through its length. Much of the inflow water also eventually passes through the small lake near the outlet. Lake O_2 levels were consistently below saturation, especially at lower depths. The outlet stream generally was below 60 percent saturation (less than 7 mg/l) during the wet months; but from June to September, when outflows were less than 50 l/sec, the oxygen levels were at their highest (89–111 percent saturation, 8.4–11.2 mg/l). Higher oxygen content in the outlet during low water periods probably reflects less contact of inflowing water with fen peats. During the winter months water is obviously moving across much of the fen surface. But when inflows diminish to some minimum level (probably at least 50 l/sec combined surface and subsurface), the water tends to move only through the marginal channels ("moats," e.g. Rigg 1940) of the

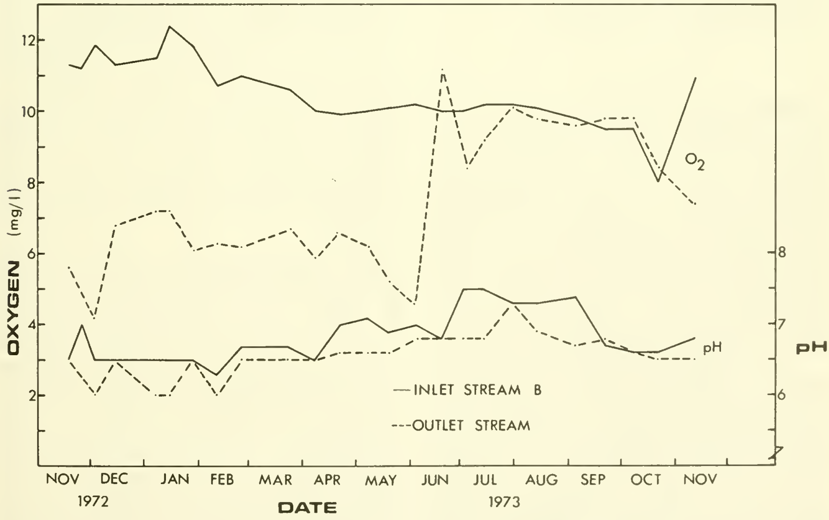

Fig. 3. Seasonal changes in oxygen concentration and pH in the outlet compared to the major inlet stream (B).

fen. We observed that the central sedge area was noticeably drier during the period from June to September, and this observation supports the idea of the sedge area's reduced contact with flowing water and of lower water levels. As long as this oxygen-rich (and relatively mineral-rich) water flows through the central fen, the rate of peat accumulation will be slower than if water flow is confined to the margins. As peat and living plants in the center of a fen become isolated from flowing water, characteristic changes occur (Gorham 1957, Deevey 1958, Heinselman 1970, Moore and Bellamy 1973): the rate of peat accumulation accelerates with a consequent rising of the surface; and the peaty soils become progressively less rich in nutrients, more acid in pH and more bog than fen. Recent work in Manitoba, Canada, showed that about 74 percent of the net primary production of a bog remained after one year, whereas 52 percent remained in a marginal fen (Reader and Stewart 1972). Changes in the biota accompany such changes in physical-chemical conditions. There is, then, a very important influence of the quantity of water and its oxygen and mineral conditions on the rate of succession of Inglenook Fen.

Acidity (pH)

Median pH of the inlet and the outlet streams is given in Table 1. There was a general trend of streams with lower discharge to have lower pH. From May through August, when inflows were derived almost entirely from aquafer rather than run-off, pH was generally above neutral (7.0–7.7) or, in the case of A_{no} and E, was higher than at other periods, although it was less than 7.0. In contrast, streams had lower pH in months when flows were high.

Tests of oxygen, temperature, and pH in the fen were made generally along Transect A. Average values from these collections are given in Table 3. Samples were taken near the fen edge, where moving water occurred all year, as well as toward the center, where water was low in summer and had little flow. These average values showed seasonal changes in oxygen, temperature, and pH that were the opposite of the incoming streams (*see* Stream B in Fig. 3). In winter months high water flushes the entire fen and elevates oxygen and pH (especially in the central region). During drier periods, oxygen and pH decline in the fen except near the marginal channels. Oxygen, pH, and aerobic limit (to be discussed later) are increased relatively close to a region of moving water (Lahde 1969, Heinselman 1970, Erman 1973). Recent studies on a raised bog-system in Germany (Lotschert and Gies 1973, Gies and Lotschert 1973) showed that the marginal fen areas were consistently higher in pH and cation content than the raised, central portion of the peatland.

TABLE 3. Average selected chemical conditions in Inglenook Fen.

Date	Number of Samples	Oxygen (mg/l)	Temp. (°C)	pH
Dec. 2, 1972	7	4.9	9.2	6.0
Jan. 1, 1973	4	5.8	7.1	–
Feb. 10	4	5.8	11.2	6.2
Feb. 24	4	8.7	10.0	6.2
Mar. 24	6	6.2	13.9	6.0
Apr. 7	6	3.5	16.8	6.0
Apr. 21	5	3.5	16.8	5.9
May 10	3	2.6	13.3	6.0
May 19	3	3.0	17.2	5.8
June 19	8	2.5	14.6	5.8
July 2	3	3.3	16.0	5.7
July 14	6	0.7	18.3	5.8
Aug. 1	6	3.0	18.0	5.9
Aug. 13	2	0.6	18.7	5.6
Sept. 4	5	3.0	18.8	5.6
Sept. 21	3	3.4	20.0	6.6
Nov. 3	5	5.0	9.2	5.8

The pH of the outflow stream also indicates isolation of water from the central fen region during dry periods. Instead of pH decreasing—a condition that would occur if the water were in contact with the more acid central area—the pH of the outflow increases (Fig. 3). The studies by Lotschert and Gies (1973) also showed a summer increase in pH and cations in the marginal fen of Schwarze Moor. This change in pH in Inglenook Fen could result from additions of water that drain the alkaline dunes and that are less diluted by stream inflows at this time.

Gorham (1975) suggests a pH of 4.2 as a lower limit of fen conditions, and Lotschert and Gies (1973) give ranges of 4.9 to 6.3 for typical fen conditions. Previous work (Baker 1972) and our present samples from the sedge-fen region indicate pH levels of 5.4 to 6.6, depending on season (more acidic during dry periods).

Calcium-Magnesium ions

Calcium ions averaged 0.15 meq/liter (3 mg/l) at Stream E to 0.32 meq/l (6.4 mg/l) at Stream D (Table 1). These values are lower than observed on one occasion by Baker (1972), who found 0.40 meq/l in Stream E. The outlet was consistently higher in Ca ions (average 0.62 meq/l) than the inlets, and probably reflects the influence of dunes that were found to have higher Ca ion concentration than inflow water (Baker 1972). As a further check on the possibility of the dunes influencing the outlet water, a test for silica was made 7 October 1973. If dune water is important, then silica should be much higher in the outlet than in the inlet streams. The average for the six inlets was 3.5 mg/l, compared to 8.5 mg/l for the outlet. These results further indicate the relative importance of direct drainage from the dunes into the fen margins.

Magnesium ions varied similarly to calcium in all inlet streams (Table 1), and ranged from 0.25 meq/l (E) to 0.47 meq/l (C and D) or 3.5 to 5.7 mg/l. The outlet, however, contained about the same as the inlets (0.47 meq/l), which is in contrast to the situation for calcium as noted previously by Baker (1972).

Sea water spraying directly onto the fen may also contribute to the concentration of various ions in the outflow, as was suggested by Baker (1972).

Heinselman (1970:245) stated that "accumulating evidence indicates that the ionic balance and cation content of peatland waters in relation to water sources and hydrotopography are key factors influencing floristics, vegetation types, and ultimately peatland evolution." He used pH, Ca, and Mg and specific conductivity of peatland waters to relate peatland types and vegetation. We used overall averages of the six inlet streams for these factors and obtained these figures: pH = 6.5, Ca = .205 meq/l (4.1 mg/l), Mg = .342 meq/l (4.16 mg/l), and specific conductivity (measured in November only) = 166. These values indicate minerotrophic to weakly minerotrophic waters in Heinselman's classification (1970), and they are typical also for European fen conditions (Lotschert and Gies 1973).

Sediments

Mean sediment concentrations in the six inlet streams and the outlet are given in Table 1. Stream A_{so} had the greatest average sediment load (19.9 mg/liter), and Stream E had the lowest (42. mg/liter). The average from all inlets was considerably higher than the outlet (13.5 mg/l inlets, 4.4 mg/l outlet). On an annual basis this sediment influx is approximately 19.3 metric tons entering the fen and 25 metric tons leaving. The greater amount of sediments leaving than entering results partly from the influx of dune material near the outlet, where dunes encroach directly on the stream. Natural dune shifting, in addition to disturbance from off-road vehicles on the dunes, causes sands to be mobile in the vicinity of the fen. The small existing housing development consisting of 13 houses in Watershed C and part of Watershed D and occasional plowing of some pastures as yet show little impact on stream-suspended sediments.

One of the major factors that influences the rate of fen-bog succession is the rate of basin filling. This filling occurs from peat accumulation, dune shifting, and sedimentation from the watershed. Soil disturbance in the watershed can rapidly increase the amount of sediments reaching the inlet streams and, subsequently, the fen.

Most of the incoming sediments no doubt accumulate in the fen, but our methods cannot distinguish the net change. The rate of sediment loss from the entire watershed (459.4 ha) amounts to 42 kg/ha per year. In a study of the Hubbard Brook Watershed in New Hampshire, Bormann et al. (1969) found that particulate losses from a forested watershed were 25 kg/ha per year, and a summary of studies on small, undisturbed forested watersheds gave a range from 25 to 53 kg/ha (Likens and Bormann 1974).

Phosphate and Nitrate

Soluble phosphate-phosphorus (Table 1) was very similar in most of the inlet streams (.07–.09 mg/l) and was slightly higher in the outlet streams (.13 mg/l). This result suggests that PO_4-P is being released by decomposition in the fen. Occasionally, every stream contained three to five times the average PO_4-P found in other streams, but these higher levels occurred in no consistent pattern. They may have resulted from agricultural activities, since pastureland is occasionally fertilized, but the intermittent nature of the higher readings does not suggest sewage contamination.

Nitrates seem to be retained in the fen (Table 1). The average amount of NO_3-N in the outlet (0.12 mg/l) was considerably lower than in most of the inlets. Nitrates were also occasionally high in each stream, although A_{so} was consistently higher in NO_3, and this result suggests some basic difference in the immediate vicinity of A_{so} because A_{no} did not appear similarly influenced. A yellow color in A_{so} water may have interfered with colorometric determinations.

The few homes on Watershed C and Watershed D apparently had no major effect on PO_4 or NO_3 in those streams. The levels of these nutrients in the six streams may serve as a baseline in case of later development.

Peat Depth and Aerobic Limit of the Fen

Two series of cores to determine peat depth were taken along the transects shown in Fig. 1. Transect A was taken across the fen at 30 m intervals (Fig. 4). Maximum peat depth was 8.2 m along this transect. The peat was composed of three distinct layers: a narrow surface layer of dense living plant roots and organic matter; a layer

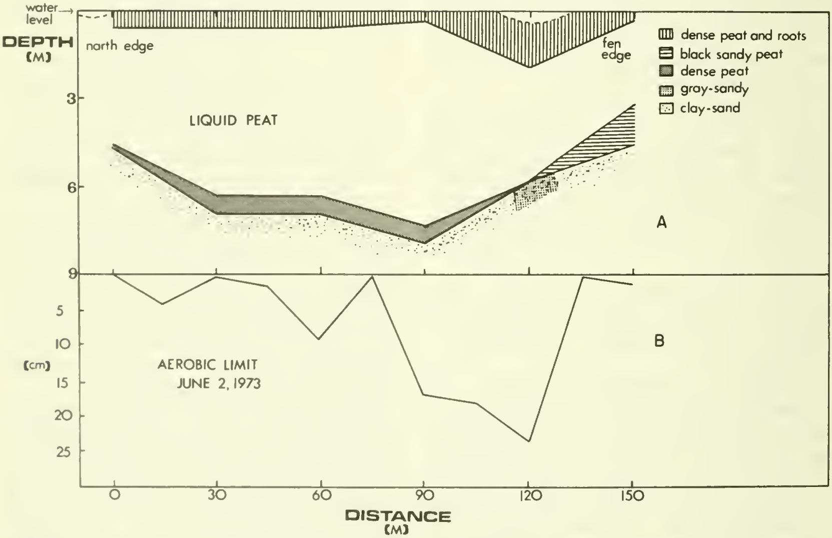

Fig. 4. Peat depth profile (A) along transect *a* at 30 m intervals and aerobic limits (B) along the same transect at 15 m intervals. Dotted lines near surface of A indicate approximate location of stream channels.

underlying the surface made up of loose, soft brown peat that was very liquid; and a basal layer of dense peat in the central fen region. When the peat borer cut through the surface layer of dense fibrous peat, water squirted up through the hole, especially on the southern edge. The corer then passed freely through the next layer without effort until the bottom peat layer was reached. It appeared that the entire surface was floating over the liquid middle layer, and exerted a pressure on the watery fluid below.

Beneath the peat was a dark clay layer, except on the southeastern edge (0–30 m), where black organic ooze overlaid the dark clay layer directly below the surface channel.

Along this same transect, a series of measures of aerobic limit were taken (2 June 1973) every 15 m. The influence of moving water is apparent in the aerobic limit measures; the limits tend to be deeper where moving water maintains higher O_2 levels, and hence maintains deep O_2 penetration (Fig. 4). Mean aerobic limit for the 11 samples was 7.1 cm.

A second transect to determine peat depth was taken along the east-west axis of the fen (Fig. 5) and ended at Sandhill Lake. The layers of peat are similar to those in Fig. 4. Fen depth increased toward the lake, where depths exceeded 11 m, the limit of our coring device. This transect halfway along its length also revealed a ridge covered with dark sand on the bottom. The higher sand-topped ridge may be the remnant of a former dune now submerged by the fen.

Depth measures of Sandhill Lake showed that it had vertical sides that drop off rapidly to about 6 m. The peat beneath the lake was of the same loose, watery texture as the similar layer in the fen and extended beyond the 11 m limit of our device. Peat profiles of bogs along the Pacific coast made by Rigg and Richardson (1938) showed some bogs with lakes that had similar steep sides and were relatively deep in comparison to the total bog depth. Heinselman (1970) showed that even small lakes surrounded by peat may persist for long periods. Early workers on bog lakes believed that the lakes were in terminal stages of succession and would soon fill. While this conclusion may still be valid over a very long time period, Heinselman (1970) showed that Myrtle Lake in Minnesota had maintained its size and depth and had even risen, rather than filled, with the height increase of the surrounding peat.

Under existing conditions Inglenook Fen

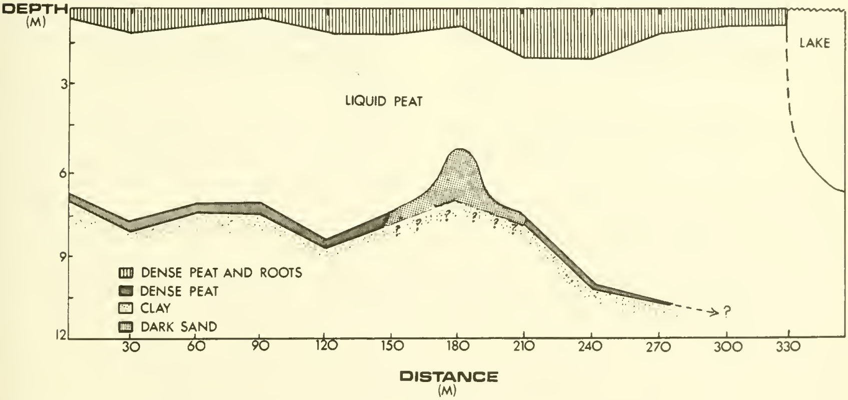

Fig. 5. Peat depth profile along transect *b*. Note sandy ridge at 180 m that may be a remnant sand dune. Coring device could not extend beyond 11 m near the lake.

is slowly filling, and during low flows it shows signs of succession toward bog (ombrotrophic peatland). The process of change from minerotrophic to ombrotrophic would still require a very long time. But as recent studies of lake eutrophication have shown, a natural successional change in productive status can be tremendously increased by man's activities. The data in this report provide baseline information on some of the key elements essential to maintenance of a minerotrophic peatland.

ACKNOWLEDGMENTS

We thank Ken McDonald and Dick Sander for field assistance and Clarence Johnson for analysis of Ca and Mg. The Nature Conservancy and the state of California contributed financial support for the work. We thank Evert Schlinger and Herbert Baker for criticizing an earlier draft of the manuscript and Mr. Ralston Ross for his permission to visit the fen on his land.

LITERATURE CITED

BAKER, H. G. 1972. A fen on the northern California coast. Madrono 21:405-416.

BORMANN, F. H., G. E. LIKENS, AND J. S. EATON. 1969. Biotic regulation of particulate and solution losses from a forested ecosystem. BioScience 19(7):600-610.

DEEVEY, E. S., JR. 1958. Bogs. Scient. Amer. Reprint #840 (October 1958), 8 pp.

ERMAN, D. C. 1973. Invertebrate movements and some diel and seasonal changes in a Sierra Nevada peatland. Oikos 24:85-93.

GIES, T., AND W. LOTSCHERT. 1973. Untersuchungen uben den Kationengehalt im Hochmoor. II. Jahreszeitliche Veranderungen und Einfluss der Sphagnen-Vegetation. Flora 162:244-268.

GORHAM, E. 1957. The development of peatlands. Quart. Rev. Biol. 32:145-166.

HEINSELMAN, M. L. 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecol. Monogr. 40:235-261.

JENNY, H., R. J. ARKLEY, AND A. M. SCHULTZ. 1969. The pygmy forest podsol ecosystem and its dune associates of the Mendocino Coast. Madrono 20:60-70.

LAHDE, E. 1969. Biological activity in some natural and drained peat soils with special reference to oxidation reduction conditions. Acta. For. Fenn. 94:1-68.

LIKENS, G. E., AND F. H. BORMANN. 1974. Linkages between terrestrial and aquatic ecosystems. Bio Science 24:447-456.

LOTSCHERT, W., AND T. GIES. 1973. Untersuchungen uber den Kationengehalt im Hochmoor. I. Abstufengen in den Vegetationskomplexen. Flora 162:215-243.

MOORE, P. D., AND D. J. BELLAMY. 1973. Peatlands. Springer-Verlag, New York. 221 pp.

READER, R. J., AND J. M. STEWART. 1972. The relationships between net primary production and accumulation for a peatland in southeastern Manitoba. Ecology 53(6):1024-1037.

RIGG, G. B. 1933. Notes on a sphagnum bog at Fort Bragg, California. Science 77:535-536.

______. 1940. Comparisons of the development of some sphagnum bogs of the Atlantic coast, the interior, and the Pacific coast. Amer. J. Bot. 27:1-14.

RIGG, G. B., AND C. T. RICHARDSON. 1938. Profiles of some sphagnum bogs of the Pacific coast of North America. Ecology 19:408-434.