The Search for New Industrial Crops IV. Prospectus of *Limnanthes*

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Introduction

The Limnanthaceae, a small family of flowering plants native to North America, has but two genera. *Floerkia,* monotypic with *F. proserpinacoides* Willd., is widespread across northern United States and Canada and does not concern this report. *Limnanthes* is endemic to the Pacific Coast and, according to Mason's monograph (7), consists of eight species with eleven varieties. They are all winter-spring annuals, many of them forming showy "banks" or masses of white flowers along the streams and swales of the meadowlands, whence the common name "meadow foam" (Fig. 1). Generally they are low, diffuse herbs with several to many stems from the base (Fig. 2). In open stands, they are low and spreading; but when bunched in dense stands, they are erect on longer stems with interlacing crowns. Two of them, *L. floccosa* var. *pumila* (Howell) C. T. Mason and *L. floccosa* var. *bellingeriana* (Peck) C. T. Mason, are rare endemics, each known from single small localities in southern Oregon. *L. macounii* Trel. of Vancouver Island, British Colombia, is thought to be extinct. Many populations of other species play a conspicuous part in the California natural wild flower display; but as the warm, dry spring advances they fade away, overtopped by grasses and other herbs, going to seed inconspicuously.

The Limnanthaceae, according to Hutchinson (5; p. 496) and other systematists, belongs in the order Geraniales and is distinguished from the Geraniaceae by lack of stipules. Other distinguishing characters of the Limnanthaceae are annual habit, dissected leaves, 3–5-merous perianth, 6–10 free stamens, superior gynoecium of 3–5 distinct ovaries which mature as 3-5 one-seeded nutlets. *Limnanthes* and *Floerkia* can be distinguished by the 5- (rarely 4-) merous flowers of the former and the 3-merous flowers of the latter.

Fig. 1. *L. douglasii* var. *nivea* near Calistoga, California, May 1, 1962.

This family of plants first came to the attention of botanists during 1831 and 1832, when David Douglas visited the California coast. He took collections to England, and Robert Brown named the first *Limnanthes* after Douglas in 1833. Plantings of seeds were successful, and *Limnanthes douglasii* R. Br. was subsequently widely disseminated as an ornamental in northwestern Europe and North America. It is still offered in seed catalogues from horticultural stocks apparently originating with Douglas' original introduction. The wide dissemination of this species, one of the most hydrophytic in the genus, demonstrates its suitability to cultivation. *L. douglasii* is more vigorous in gardens than in its native marshes and meadows.

The systematics and nomenclature pro-

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posed by Mason (7) are followed in this paper. A list of his taxa is provided below to simplify and clarify the following text. However, it is the writers' opinion that future investigations would modify Mason's concept of species and varieties. For instance, *Limnanthes gracilis* var. *parishii* appears more like a sibling species with *L. gracilis* var. *gracilis,* rather than a variety of the latter. Mason's treatment, however, is consistent with the criteria he developed and represents a most useful clarification over treatments accorded the genus in earlier regional floras.

Mason recognizes the following taxa:

Section *Reflexae*

- *Limnanthes douglasii* R. Br. var. *douglasii*
- *Limnanthes douglasii* var. *sulphurea* C. T. Mason
- *Limnanthes douglasii* var. *nivea* C. T. Mason
- *Limnanthes douglasii* var. *rosea* (Benth.) C. T. Mason
- *Limnanthes striata* Jepson
- *Limnanthes bakeri* J. T. Howell
- *Limnanthes macounii* Trel.

Section *Inflexae*

- *Limnanthes gracilis* Howell var. *gracilis*
- *Limnanthes gracilis* var. *parishii* (Jepson) C. T. Mason
- *Limnanthes montana* Jepson
- *Limnanthes alba* Benth. var. *alba*
- *Limnanthes alba* var. *versicolor* (Greene) C. T. Mason
- *Limnanthes floccosa* Howell var. *floccosa*
- *Limnanthes floccosa* var. *bellingeriana* (Peck) C. T. Mason
- *Limnanthes floccosa* var. *pumila* (Howell) C. T. Mason

Chemistry and Industrial Uses

Oil from seed of *Limnanthes* is unique. Essentially all of its constituent fatty acids are of higher molecular weight than the acids of the common domestic vegetable oils, and the acids, when unsaturated, are unsaturated at an unusual location in the molecule. Such oils as those from cottonseed and soybeans are almost entirely triglyceride esters of fatty acids that contain 16 or 18 carbon atoms. The unsaturation occurring in these oils is at the 9th; 9th and 12th, or 9th, 12th and 15th carbon atoms, counting from the carboxyl end of the molecule.

Fig. 2. *L. douglasii* var. *nivea* (By permission of C. T. Mason from Univ. of Calif. Publ. Bot. **25**: 478, 1952).

Rapeseed and mustard oils are exceptions to this almost exclusive occurrence of 16- and 18-carbon acids and contain, in addition to the common acids, up to 50% of a 22-carbon acid, erucic acid, unsaturated at the 13th carbon atom. In Limnanthes oil, however, at least 95% of the acids present are 20- and 22-carbon acids, and the unsaturation is primarily at the 5th carbon atom and also, in some instances, at the 13th carbon atom.

Three of the four fatty acids that comprise the major portion of Limnanthes oil were unknown before the recent chemical investigations at the Northern Regional Research Laboratory on oil from *L. douglasii* (1, 3, 10). The unique character of the oil and the three new acids prompted this botanical survey of the genus and the expanded chemical research now in progress at the Southern Regional Research Laboratory at New Orleans on utilization of *Limnanthes* as a new oil seed.

In all of the Limnanthes species obtained for testing, the seed oil comprised the same fatty acids but in varying proportions. The major component, a 20-carbon acid unsaturated at carbon 5, ranged in amount from 52 to 77% of the total acids. A second new component, a 23-carbon acid also unsaturated at carbon 5, was not separated from erucic acid by the chromatographic equipment used for analysis; the sum of the two ranged from 8 to 29%. The third new acid, a 22-carbon acid unsaturated at both the 5th and the 13th carbon atom, ranged from 7 to 22%. In Fig. 3, the structures of the three new acids are illustrated.

The only comparable source of such a high concentration of 20- and 22-carbon straight-chain compounds is the liquid wax from seed of "jojoba" (*Simmondsia chinensis*). This material is not a true glyceride oil, in which three fatty acid molecules are combined with one molecule of glycerol, but consists of molecules in which one fatty acid is combined with one long-chain fatty alcohol. By using well known chemical reactions already commercially practiced, Limnanthes oil can be converted in good yield to a product substantially identical to liquid jojoba wax (9). Thus, all the proposed uses, about which some investigators have been enthusiastic (2, 4, 6), for jojoba wax are equally applicable to derivatives that can be prepared from Limnanthes oil. Catalytic hydrogenation of the oil or liquid wax derived from it provides solid waxes that have good hardness and rather high melting points and may prove useful in wax formulations similar to those employing carnaúba and candelilla waxes or in conjunction with them. Limnanthes oil may also find special application in the preparation of such products as lubricants, detergents, and plasticizers.

The unique location of unsaturated bonds in the Limnanthes acids affords another focus for chemical research. Not only may this structural isomerism contribute different physical properties to Limnanthes derivatives, but the location of this double bond so close to the acid grouping in the molecule may make possible the synthesis of chemical derivatives otherwise impossible or at least much more difficult of accomplishment.

The Limnanthes seed contains 20 to 33% oil and 15 to 25% crude protein. Lysine and methionine are present in the protein of *L. douglasii* (11) in amounts comparable to those in legumes, so the meal may find use as a feed component. Sulfur-containing glucosides similar to those found in the Cruciferae occur in all samples analyzed, and should be investigated to determine their effect on nutritional quality of the meal. Details of the chemical compositional investigations of the various species described in this paper will be reported elsewhere (8).

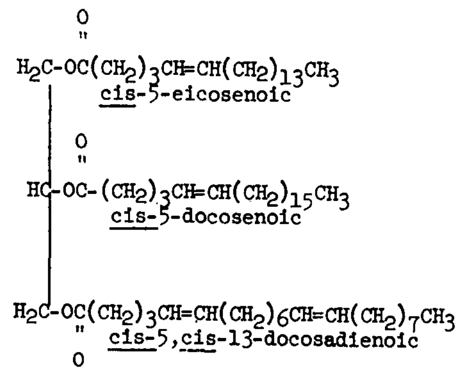

Fig. 3. Hypothetical glyceride molecule of *Limnanthes* oil showing its three new constituent fatty acids in ester form.

Distribution and Ecology

The natural area or range of *Limnanthes* is confined to the coastal side of the Cascade-Sierra Nevada Range (Fig. 4). The annual average precipitation is from 15 inches in the drier parts of the central valley to about 50 inches on the forested slopes of the Coast Ranges. Eighty percent or more of the rain falls during the cool seasons. Several of the varieties at higher elevations may be topped with snow during their early stages. Thus, *Limnanthes* germinates and grows through the cool moist portion of the year and rapidly matures and dries out during the drought of late spring and early summer. Mason (7) reports that lengthening days rapidly promote flowering on even young plants.

All species and varieties of *Limnanthes* appear to require abundant moisture for germination and wet to moist soils throughout their growth period. However, the sundry varieties occupy a wide range of sites and soil types. Those in the wet meadows, such as *L. douglasii*, are hydrophytes, where-

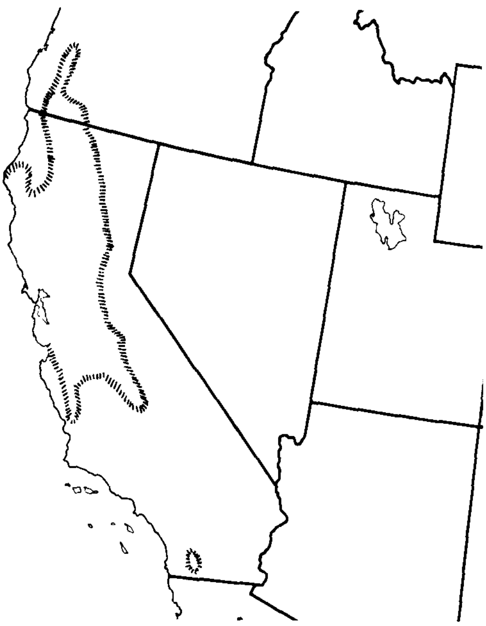

Fig. 4. The natural range of *Limnanthes*, excluding *L. macounii* on Vancouver Island, British Columbia.

as others on porous, quick-drying soils, such as *L. floccosa* and *L. alba*, are relatively xerophytic, flowering and setting seed on the last of the seasonal soil and stem moisture. These latter appear to have about the same water requirements as dry-farmed winter grains.

The soils in which *Limnanthes* grows are usually acid with pH ranging from 5.5 to 6.7, as determined with a portable field kit. One exception is the Oregon population of *L. gracilis* var. *gracilis* found growing in coarse alluvial soil with a pH of 7.2. *L. douglasii* var. *rosea* grows about the vernal pools of the Sacramento Valley. The soil is alkaline probably because of the salt accumulation in such basins, but no pH tests were made. The relative acidities of soils where species of *Limnanthes* grow are shown in Table 1 together with other environmental factors. In general, the relative moisture requirements are indicated by grading the series from top to bottom as hydrophytic to xerophytic.

During field work, the senior author was impressed by the correlation of varieties with narrow habitats. Mason's work did not consider the micro-ecology involved, so a brief summary of observation is given here.

Swampy meadow plants are well represented by *L. bakeri*, known only from Willets Valley, California, and the wide-ranging varieties of *L. douglasii*, (*douglasii*, *sulphurea*, *rosea*, and *nivea*.). The last is represented by at least two ecotypes. One is abundant in Napa County as a hydrophyte with long stems and reflexed sepals, spilling nutlets early. The other ecotype is a mesophyte prolific in the fields of Willets Valley with shorter stems, more diffused branching, and inflexed sepals tending to retain the nutlets.

L. douglasii var *rosea* is another striking example of genetic tailoring for a tight environmental fit. This plant meets the requirements of a short growing season with a minimal rainfall, about 15 inches, by growing at the edge of vernal pools. It achieved this adaptation not by increasing drought tolerance, but by escaping drought with early maturation of seed.

Other communities of *Limnanthes* occupy the banks and gravel bars of the small intermittent streams of the Sierra Nevada foothills. They consist mainly of *L. striata* and *L. alba* var. *versicolor*. The ranges of these taxa overlap, but being in different sections of the genus, they do not hybridize. As the small streams dry in the late spring, growth is terminated, and the plants rapidly mature their nutlets or, in drier seasons and sites, wither away in flower without seed. Placer mining and local diversion of streams appear to have eliminated many former populations of these two plants.

L. gracilis var. *gracilis* of southern Oregon is a mesophyte found on a variety of sandy loams and alluviums of the open meadows and fields of the valleys. It has also been reported on serpentine by Mason (7). It appeared to receive about the same amount of precipitation and to occupy the same kind of sites as the northern ecotype of *L. douglasii* var. *nivea* in Willets Valley.

The several montane varieties include *L. gracilis* var. *parishii* of the Cuyamaca Mountains in southern California, *L. montana* of the middle Sierra Nevada area, and *L. floccosa* var. *bellingeriana* of southern Oregon. *L. gracilis* var. *parishii* was observed only upon the open sandy loams of the highland pastures about Lake Cuyamaca. Because of the cool highland, this variety has a rather long growing season, does not mature much seed until June, and often flowers diffusely in moist swales up to June 1. A prostrate late-blooming form and a more erect early-flowering form were noted.

L. montana was observed only on the moist shady slopes and shady stream banks in the rather open oak-pine transition zone. It is unusual in the genus in frequenting shady situations.

L. floccosa var. *pumila* and *L. floccosa* var. *bellingeriana* both grow on open clay

Table 1
Some ecologic features of Limnanthes varieties

Species or Variety	Site Preferences	Soil pH	Altitude, ft.	Seeding Dates 1962
douglasii	Wet, heavy, meadowland clay loams	5.8 6.8	50-1000	May 20-30 Cal. June 1-10 Ore.
sulphurea	Wet, dark, meadow clays	6.0	50-200	May 25-June 10
bakeri	Wet to moist meadows with heavy to light clay loams	6.2	1500	May 20-30
nivea (Napa Co.)	Wet clay loams and alluviums of bottomlands	6.6 6.8	50-500	May 15-25
rosea	Heavy clays of vernal pool margins; pasture bogs		50-300	April 15-25
striata	Wet to moist riparian gravels		500-1500	May 1-10
versicolor	Wet to moist riparian sands and gravels	6.0	500-1000	May 15-20
nivea (Willets)	Moist loamy slope and fallow fields		1200-1500	May 15-30
montana	Moist rocky shade slopes and riparian sands and gravels	6.4 6.4	2500-4000	May 20-June 10
gracilis	Sandy and alluvial loams in meadow slopes and fields	6.4 7.2	1000-1500	June 1-10
parishii	Moist sandy loams on meadow slopes and swales	6.0	2000 4500	June 1-20
pumila	About vernal pools on volcanic meadow	5.8	2000	May 5-20
bellingeriana	Open volcanic pineland	6.0	4000 4500	June 1-15
alba	Sandy and silty loams on slopes and cultivated fields	6.2	50-500	May 5-30
floccosa	Sandy upland slopes and alluviums	5.5	300-1000	April 25-30

soils derived from volcanic rocks. They are very rare, small plants 3 to 5 inches tall with balled calyces, growing scattered in very limited localities. The latter is known only from a colony scattered over about two acres between Mountain View and Lincoln, Oregon.

L. floccosa var. *floccosa* and *L. alba* var. *alba* appear to require less moisture than other species of *Limnanthes*. The former was observed only upon the open slope soils derived from sandstone and volcanic rocks. These soils dried rapidly, bringing on cessation of plant growth in late April.

L. alba var. *alba* was abundant over the rolling valley bench lands from about Sacramento to Chico. These bench lands have light sandy soils and are frequently planted to dry-farmed grains. Although the colonies were thickest and rankest through the swales, this ecotype showed a strong successful response on the slopes, especially where grain was thin (Fig. 5). Growth and seeding periods closely approximated those of oats and barley. As these cultivated lands are a new habitat scarcely 100 years old, *L. alba* var. *alba* appears to represent a contemporary case of rapid evolution. This adaptive potential suggests that *L. alba* var. *alba* would perform well under cultivation.

Seed Production

Contrary to expectations, seed production in the wild was heavy or copious. Seeds produced on individual plants varied by

Fig. 5. *L. alba* var. *alba* on a fallow grain field, Sacramento County, California, April, 1962.

count from 20 to 50 on depauperate and closely colonial plants to as many as 1000 per plant on large diffuse uncrowded individuals. Some of the heavier yielding or denser stands of *Limnanthes* were noted quantitatively from measured quadrats.

45 sq. ft. of *L. Bakeri*	1.75 lb
300 sq. ft. of *L. d. nivea* (Willets)	5.0 lb
200 sq. ft. of *L. d. nivea* (Calistoga)	4.5 lb
72 sq. ft. of *L. d. rosea*	1.5 lb

Extrapolated to an acre basis these yields would be respectively, 1700, 725, 980, and 900 lb per acre.

Although five nutlets to a flower is the full complement, two, three, or four occur just as frequently. Reduction of the full complement apparently is due ordinarily to lack of pollination. With fewer nutlets, the nutlet size increases, and this appeared to be the main factor in relative seed size within a given variety. However, the seeds of *L. douglasii* var. *douglasii* average considerably larger than those of most other varieties, and there are presumably genetic factors controlling seed size.

Seed retention on the maturing plants is of prime importance in considering harvest. In most members of the section *Inflexae*, the seed is retained indefinitely on the drying plants; whereas members of the *Reflexae* drop their seeds early and late during maturation. In members of the former section, the seed may be retained by adherence of the nutlet to the receptacle or by the incurved perianth segments. Seed retention is especially pronounced in the fuzzy-headed *L. alba* var. *alba* and *L. floccosa* var. *floccosa*, and the nutlets were difficult to separate from the heads by hand methods. However, in *L. floccosa* var. *floccosa* the heads are highly caducous because of an abscission layer below the heads, so that seed retention by the receptacle is negated by early head-fall. In other varieties of the *Inflexae* group, however, seed retention is good and one could wait for complete nutlet maturation before harvesting. The members of this section, therefore, are to be preferred as new crop prospects.

In members of the *Reflexae*, seed retention is poor. Nutlets from the first-formed flowers fall while later flowers are still developing. In collecting seed, it was necessary to pull the maturing plants and let them dry out on canvases, where the falling seeds accumulated. It is estimated that 10 to 20% of yield was lost or curtailed in collecting seed of the *Reflexae*.

Seeding characteristics and habits of these plants as they pertain to ease of harvesting are compared in Table 2.

Summary

A season of observation and note-taking on *Limnanthes* from flowering to seeding, or mid-April through June, found nothing to discourage economic interest in this group of plants. The environments of the species and varieties, although correlatively variable, all indicate the genus requires a cool, moist growing season and maturation during the lengthening days of spring. While incipient difficulties are to be expected in such areas as germination and weed control, *Limnanthes* shows many features of hopeful character for new crop research.

1) Its annual nature makes it suitable for cash crop manipulation. In crop regimes, its growth and harvest period coincides closely with the winter grains, and it may be considered as a potential replacement for surpluses in this commodity field.

2) The wide dissemination of *Limnanthes douglasii* in garden culture and local adventism on disturbed soils by other members of the genus indicate adaptability to culture.

3) Short life cycle and genetic pliability indicate that plant breeding could rapidly develop selections with high oil yields suitable

Table 2
Relative qualifications of species and varieties of Limnanthes as seed crop prospects

Species or Variety	Habit	H_2O Requirement	Yield	Seed Retention	% Oil
gracilis	Good	Medium	Good	Fair	28.8
alba	Good	Light	Good	Excellent	26.8
nivea (Willets)	Good	Medium	Good	Fair	30.4-33.2
montana	Good	Medium	Good	Fair	25.8
nivea (Calist.)	Good	Heavy	Good	Poor	26.1
bakeri	Good	Heavy	Good	Poor	25.6
douglasii	Good	Heavy	Good	Poor	24.0-29.8
versicolor	Fair	Heavy	Fair	Poor	30.9
parishii	Poor	Medium	Good	Good	33.3
floccosa	Good	Light	Light	Poor	28.3
rosea	Fair	Heavy	Good	Poor	20.0-21.7
pumila	Fair	Medium	Light	Good	
striata	Fair	Heavy	Light	Poor	29.0
bellingeriana	Poor	Medium	Light	Good	

to a wide range of soils. Inter-sectional crossing has already been demonstrated.

4) Production in wild populations shows a very high ratio of seed bulk to plant bulk, or a high efficiency in the synthesis of hydrocarbons. Total seed yield in wild stands was generally found to be good.

5) Most of the preferred characters in the genus are found in members of the *Inflexae*: better seed retention, lower water requirements, pre-adaptation to cultivated lands, and slightly higher oil content. None of these varieties have yet been tried in cultivation.

6) The chemical structure of the oil indicates a large potential use in several industrial markets.

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