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DISTRIBUTION OF NATURALIZED *CARDUUS NUTANS* (COMPOSITAE) MAPPED IN RELATION TO GEOLOGY IN NORTHWESTERN OHIO[1,2]

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ABSTRACT

Within recent years the nodding thistle or musk thistle (*Carduus nutans* L.) has become naturalized and abundant in northwestern Ohio in at least two areas, the Castalia-Bellevue-Sandusky area and the Carey area. In the summers of 1967 and 1968, the total detailed distribution of *Carduus nutans* in these two areas was mapped by noting its occurrence and abundance in relation to the general geologic conditions, topographic features, and habitats. The thistle was most abundant in moderately grazed pasture fields, hay fields, and along grassy roadsides on high, dry ridges and hillsides where the limestone or dolomite bedrock was less than six feet below the surface. Plants were rare or infrequent where the bedrock was deeper, in flatter terrain, in cultivated fields, and along railroad tracks. Detailed maps of the two areas depict, by the use of three different sizes of dots, the aproximate abundance of the plants at each site and the correlation of this distribution with the geologic substrate. Expansion of the plant's local range by natural means is slow, because many of the heads do not have fully developed achenes, the achenes do not readily become separated from the head, and the heads tend to drop to the ground directly beneath the parent plant.

These data, although limited, may allow botanists to predict locations where *Carduus nutans* might be expected to invade in the future, and geologists to infer, from reported occurrences of the plant in Ohio, the presence of limestone or dolomite bedrock at shallow depths.

For some time it has been known that certain native species of plants tend to have distributions which are more or less correlated with certain substrates. In Ohio, for example, *Cercis canadensis* (redbud), *Juniperus virginiana* (red cedar), *Fraxinus quadrangulata* (blue ash), and *Thuja occidentalis* (white cedar) are known to occur more commonly on calcareous substrates (Braun, 1961); *Trillium nivale* (snowy trillium) (Braun, 1967) and *Plantago cordata* (cordate-leaved plantain) (Tessene, 1969) are limited to outcrops of limestone or dolomite. The relationships of most of Ohio's native flora to the substrate, however, are poorly known and little understood. And, with reference to introduced (non-indigenous) species, knowledge of such relationships is almost nonexistent.

Carduus nutans is an example of an introduced species whose distribution originally appeared to be strikingly erratic. Therefore, in an attempt to learn more about any possible relationships between the distribution of this plant and

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the associated geologic substrate, we conducted field investigations in northwestern Ohio, during the summers of 1967 and 1968, mapping the distribution of this naturalized plant in relation to the substrate.

THE PLANT

Carduus nutans L., the nodding thistle or musk thistle (fig. 1), is a species introduced (or non-indigenous) from Europe, which is either adventive or naturalized in many widely scattered places throughout the United States and parts of Canada. This thistle occurs in pasture fields, roadsides, and waste places, blooming in late June and throughout July in Ohio. The plants commonly grow singly, are herbaceous and much branched, and range in height from three to five feet in fully

FIGURE 1. Photograph of *Carduus nutans* growing along Billings Road, one mile southeast of Castalia, 12 July 1967.

developed individuals. The large, showy, bright pink-purple heads, which are mostly solitary, usually nodding, and occur at the tips of the partly naked peduncles, are very striking. These prominent features make the plants readily recognized in the field, even from a moving car, making this thistle a particularly easy plant to map.

The achenes are oblong or slightly curved, have a glossy surface with obscure alternating transverse yellow and brown stripes, and measure about 3½ mm long and 1½ mm wide. A cone-shaped style, 5-lobed at the base, is persistent at the apex of the achene. The achenes appear to become readily detached from the pappus, and therefore are probably not blown for long distances.

Other common roadside and pasture-field thistles with which *Carduus nutans* might be confused are *Cirsium arvense* (L.) Scop. (Canada thistle) and *Cirsium vulgare* (Savi) Tenore (bull thistle). The Canada thistle is generally a shorter, less-branched plant, with smaller, lavender-purple, erect heads at the ends of leafy peduncles. In addition, the Canada thistle is clonal and may form extensive patches of very closely spaced stalks. The bull thistle is characterized by tall single plants, with large purple heads which are held erect and occur in clusters at the ends of leafy peduncles. It is the bull thistle with which *Carduus nutans* is most likely to be confused in the field, for both are tall, solitary thistles with large, showy heads. However, *C. nutans* has a head that is more pink, and involucral bracts that are broader and less spiny, and the peak of its blooming is in late June and throughout July, at a time when the bull thistle is still mostly in the vegetative condition. The bull thistle reaches its blooming peak in late July and throughout August.

Carduus nutans was apparently introduced, late in the 1800's, on the east coast of North America, where some of the early collections of the plants come from ballast dumps. Dates and locations (rather generally stated) of the earliest known records for selected locations in northeastern and central North America are given in Table 1.

TABLE 1

Summary of earliest known records of Carduus nutans *from selected locations in northeastern North America, compiled from the literature and from examination of herbarium specimens at MICH, MO, OS, PH, and US. (Herbarium abbreviations according to Lanjouw and Stafleu, 1964, except SEN, which represents the collection at the Seney Wildlife Refuge, Seney, Michigan.)*

Date	Location	Reference
	Pennsylvania:	
1853–1866	Harrisburg	Porter, 1898
1869	Harrisburg	*T. Porter s.n.*, US
	New Brunswick:	
1871	spread from ballast, Chatam	*J. Fowler s.n.*, MO
1874	Bass River	*J. Fowler s.n.*, MICH
	New York:	
1879	Hoboken, New York City area	Brown, 1879
	New Jersey:	
1880, 1882	ballast, Camden	*I. Martindale s.n.*, US, PH; Britton, 1889
	Rhode Island:	
Since 1890	Providence	Collins, 1893
	Washington, D.C.:	
1897	waste ground in southwest Washington, D.C.	Hitchcock & Standley, 1919
	Island of St. Pierre:	
1902	town of St. Pierre	Arsène, 1927
	Quebec:	
1903	in pasture on the Peche River, Wakefield, Gatineau County	*Macoun 60,636* CAN; Mulligan & Frankton, 1954; Rousseau, 1968
	North Dakota:	
1904	Milton, Chavalier County	Stevens, 1950
	New York:	
1912–1913	a weed in dry gravelly pastures, rare, Dryden and Cornell University Campus; of recent introduction but well established	*Miss L. J. Sutherland*, CU, and *E. Dean & A. J. E[ames]*, CU; Eames, 1926

TABLE 1—(*Continued*)

Date	Location	Reference
	Connecticut:	
Before 1917	spontaneous in garden, Ledyand	Harger *et al.*, 1917
	Ontario:	
1920	Travistock, Oxford County	Collector unknown, DAO; Mulligan & Frankton, 1954
	Indiana:	
1924	established in fields a few miles east of Elkhart	*Hansen*, PUL; Hansen, 1925
	Ohio:	
1925	West Jefferson, Madison County	*H. D. Folmer s.n.*, OS
	Illinois:	
1930	pasture three miles south and one mile west of Seymour, Piatt County	*L. R. Tehon;* Jones & Fuller, 1955
	Missouri:	
1935	pasture, Independence	*B. F. Bush s.n.*, MO
	Iowa:	
1937	along fence along Hwy. 69 and in a cornfield about 2 miles south of Little Wall Lake, Hamilton County	*A. Hayden 10848*, MO
	Delaware:	
1938	one collection from cultivated ground 1¼ mile north of Millington	*R. R. Tatnall 3829;* Tatnall, 1946
	Kansas:	
Before 1940	roadsides and cultivated ground, Washington County	Gates, 1940
	Missouri:	
1941	weed in a field near Palmyra, Marion County	*C. G. Tarleton*, UMO; Drew, 1942
	Kentucky:	
1945	common in pasture fields and roadsides; six miles north of Bowling Green, Warren County	*F. T. McFarland & G. Campbell 100*, MICH, MO, US
	West Virginia:	
1945	on dry roadside bank near cabins, Grant County	*Mr. & Mrs. Davis 7270*, WVA; Core & Davis, 1947
	Wisconsin:	
1947	Waukesha County	Johnson & Iltis, 1963
	Newfoundland:	
1949	occasional on clay soil over rock along roadside, near Heart's Content, east side of Trinity Bay	*Bassett 617*, DAO; Mulligan & Frankton, 1954
	Manitoba:	
1950	a single plant growing in the grassy sod on broad highway allowance, 2 miles west of Heywood	*Dore & Breitung 12727*, DAO; Mulligan & Frankton, 1954
	Michigan:	
1956	along dikes, roads, just east of headquarters, Seney Wildlife Refuge, Schoolcraft County	*D. McGlauchlin s.n.*, SEN
1958	locally common, grassy roadside, about 5 miles south of Manchester, Washtenaw County	*E. G. Voss 6265*, MICH

In Ohio, *Carduus nutans* was first discovered on 17 July 1925 at West Jefferson, Madison County, as verified by a specimen collected by H. D. Folmer and deposited in the Herbarium of the Ohio Agricultural Experiment Station (now in

The Ohio State University Herbarium). Thirty years passed before the next record for an occurrence of *Carduus nutans* was made on 11 June 1955 along a roadside in southeastern Adams Township, Darke County, by Dr. Clara G. Weishaupt and Mr. Leslie Canup. A year later, 8 July 1956, they obtained a second collection from the same locality, the plants being recorded as having come from a pasture field. A few plants were still persisting at the Darke County locality when it was checked on 17 September 1967 (*Stuckey 6055*). Before our field work in 1967, verified specimens of *C. nutans* (in The Ohio State University Herbarium) had been collected in Ohio from only two other counties: Seneca (23 June 1963, *E. M. Herrick s.n.*) and Erie (22 Aug. 1966, *G. T. Jones, s.n.*).

Additional data are available concerning the arrival time of *Carduus nutans* in the two areas studied by us—Castalia-Bellevue-Sandusky and north of Carey. Both of these areas had been intensively studied floristically earlier, the Sandusky area by Moseley (1899) and the Carey area by Bonser (1903). Moseley's work represents one of the most complete and detailed studies of a local flora in Ohio. Bonser's study deals primarily with the flora of the Big Spring Prairie (on low land north of Carey), although he also discusses the floristic composition of the dolomite ridges, where *Carduus nutans* now occurs, to either side of this prairie. Because neither work mentions the nodding thistle, its arrival in both areas is considered to have been subsequent to the times of both men's studies. Farmers near Castalia, southwest of Sandusky, report first noticing *Carduus nutans* in their fields about 15 years ago (L. E. Beerbower, S.C.S. District Conservationist, personal communication, 1969). Early information on the thistle in the Carey area appears in a letter dated 22 July 1957 from Mr. Glen J. Vollmar, then Associate County Agent of Wyandot County (letter on file in The Ohio State University Herbarium), and reveals that *C. nutans* was known at that time from a pasture field on the Earl Brown farm on the ridge northwest of Carey. Mr. Brown is reported to have stated that he had noticed the plant only in the past few years. From these records, it appears that *C. nutans* was becoming established in these northwestern Ohio areas about the middle of the 1950's.

The present known distribution of this species in Ohio, including data provided by our work in the Castalia-Bellevue-Sandusky area and in the area north of Carey, is shown in Figure 2.

THE GEOLOGICAL SETTING

Much of the bedrock underlying northwestern Ohio is composed of limestone and dolomite (fig. 3). Only in far northwestern Ohio and east of Bellevue is the carbonate rock replaced by shale or sandstone. Despite the great extent of limestone and dolomite in northwestern Ohio, these rocks occur close to the surface in only a very few restricted areas, such as in the Castalia-Bellevue-Sandusky and Carey areas, and farther west, near Fremont, Fostoria, Woodville, and Bowling Green (fig. 3). Throughout most of the region, glacial and lacustrine surficial deposits are so thick that the underlying bedrock surface is, in places, more than 100 feet deep.

Most of the glacial material in northwestern Ohio is till of late Wisconsin age (approximately 15,000 years old—Goldthwait, 1958). Lacustrine materials, in the form both of lake-deposited silt and clay and of sand bars and beaches, are present in many places on top of the till. The lacustrine silt and clay are most common in the areas of lowest elevations, near the shores of present Lake Erie, such as on the low flats north of Castalia and near Sandusky. Deposits of sand, on the other hand, generally occur farther away from the present Lake Erie shore, forming low ridges along the southern margins of those ancient ice-dammed lakes (on the north side of the Defiance End Moraine), and low isolated accumulations, or ring-shaped deposits, wherever a preglacial bedrock hill projected high enough above the broad flat lake plain to have caused shoaling in the ancient lake. All

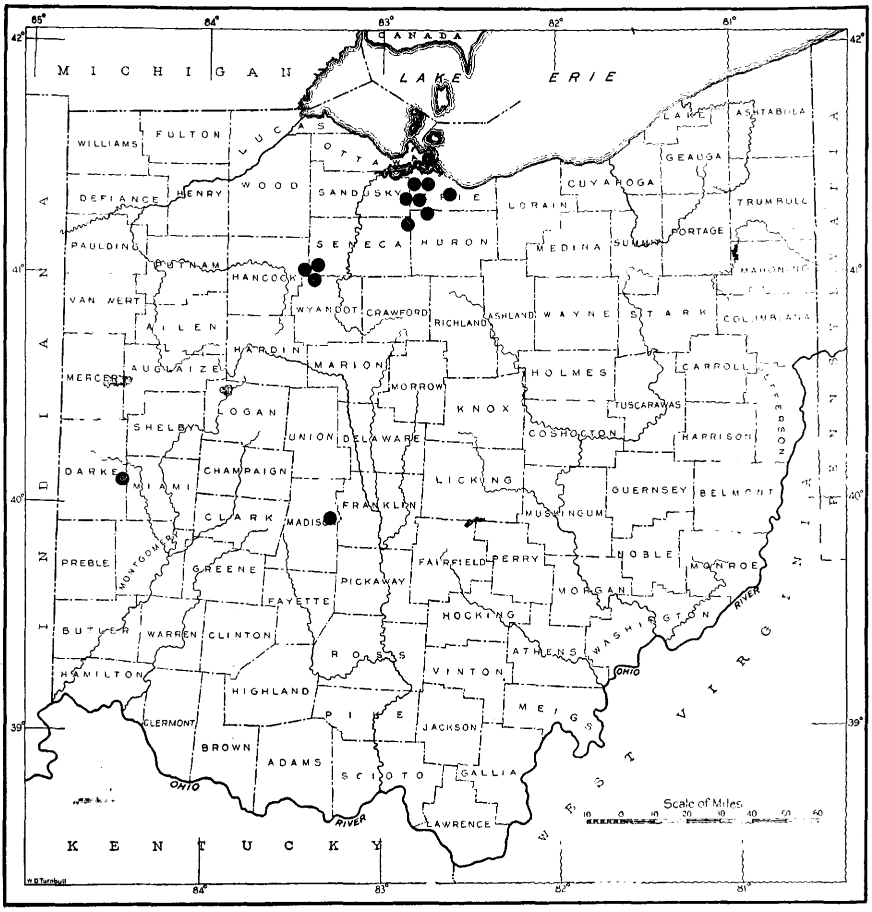

FIGURE 2. Known distribution of *Carduus nutans* in Ohio based on specimens in The Ohio State University Herbarium collected before 1968.

List of Specimens Used for Mapping in Figure 2

All specimens cited below are deposited in The Ohio State University Herbarium, Columbus. All were collected by R. L. Stuckey, unless otherwise noted. Duplicate specimens have been deposited in other herbaria, whose identities are noted according to the abbreviations in Lanjouw and Stafleu (1964), except for FTSL, which represents the herbarium of The Franz Theodore Stone Laboratory.

OHIO: DARKE CO.: Roadside, road between Red River community and Greenville Creek, southeastern Adams Twp., 11 Jun 1955, *Leslie Canup & Clara Weishaupt s.n.;* pasture field, southeast part of Adams Twp., 8 Jul 1956, *Leslie Canup & Clara Weishaupt s.n.;* two plants under tree along w side of Smith Road, NE ¼ Sec. 32, Adams Twp., just s of Greenville Creek, ca. 2 mi e Gettysburg. These specimens taken from lower branches that grew after the old plants had been mowed off by highway department. One plant was seen in a pasture field on e side of the road, 17 Sep 1967, *6055*. ERIE CO.: Occasional along roadside, Cement Road, Resthaven Wildlife Area, Margaretta Twp., ca. 1 mi w of Castalia, 29 Jun 1966, *2956* (FTSL); locally common at marsh along Sandusky Bay at e end of new bridge over the Bay, at the s city limits of Bay View, 27 Jul 1966, *3130* (SMU); overgrazed pasture on limestone hill, n Groton Twp., 22 Aug 1966, *G. T. Jones s.n.;* locally abundant in disturbed soil about the upper edge of limestone quarry just sw of junction of state highways 2 and 101, Margaretta Twp., ca. 3 mi ne of Castalia, 8 Jul 1967, *4268* (CAN, MICH, SMU, VDB); one plant in wheat field along Mud Brook Road just n of Mason Road, Milan Twp., ca. 3.5 mi n of the town of Milan, 8 Jul 1967, *4273*; one plant along roadside, Resthaven Wildlife Area, Heywood Road of these lacustrine deposits were formed during the early postglacial stages of Lake Erie (Glacial Lakes Maumee, Whittlesey, and Warren), when the lake waters, blocked by the dam of glacial ice in the eastern end of the Lake Erie basin, were so high that much of northwestern Ohio (including most of the Castalia region, but not the Carey area) was flooded (Forsyth, 1959). When ice recession exposed new, lower outlets, permitting the water levels in these ancient lakes to lower, the sand composing the beaches and sand bars became dried out and, where it was fairly thick, was blown into dunes (e.g. west of Bellevue).

The thickness of the glacial-lacustrine cover over the bedrock varies considerably. Where valleys were cut deepest into the buried bedrock surface by preglacial streams, the glacial mantle, beneath the flat modern land surface, is thickest. The glacial cover is thinner where preglacial hills are present on the buried bedrock surface, and is completely absent where these preglacial hills project up through the glacial till, forming low rises, or bedrock highs.

In the Castalia-Bellevue-Sandusky area, the rock forming the shallow bedrock is the Devonian Columbus Limestone (Carman, 1946). Its surface has the form of a cuesta, or eroded edge of a gently dipping resistant rock layer, now partly buried by glacial till and by lacustrine and eolian sand and silt. Along most of the cuesta's crest, which forms the rugged ridge extending from north of Bellevue north-northeast to Castalia, the bedrock is very shallow; elsewhere beach and dune sand and glacial till bury the bedrock more deeply.

In the Carey area, there are two relatively high bedrock hills of Silurian Niagaran Dolomite (Stein, 1966). These hills, which are preglacial bedrock hills now protruding more than fifty feet above the glacial plain around them, probably owe their height to the combination of the resistance of the Niagaran Dolomite composing them and to a divide position on that ancient preglacial landscape, far from the major streams that produced the buried topography. On the slopes and the adjoining crests of the present landscape, rock is very shallow and locally exposed. On the broad expanses across the tops of the hills, though, especially on the more western of the two hills, a cover of till is present which in places is so thick that, even here on top of these bedrock hills, the substrate characteristics are those of the till rather than of the bedrock. Between the two hills is a low flat area where bedrock is also somewhat shallow (20 feet—Stein, 1966), but where, because of its extreme levelness, drainage is so poor that the land is wet and marshy. As a result, the original vegetation was wet calcareous prairie, hence the name, Big Spring Prairie (Bonser, 1903; Gordon, 1969).

METHODS

Initial field observations suggested that the distribution of the nodding thistle might be related to geological substrate. To obtain more detailed information, almost every road in the areas studied was driven, and the distribution of the

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just w of state route 269, ca. 1 mi n of Castalia, 18 Jul 1967, *4470*. HANCOCK CO.: Locally common along roadside, SE ¼ Sec. 28, T1N, R12E, Biglick Twp., ca. 5 mi s of West Independence. Depth to dolomite bedrock, ca. 4 ft., 25 Jul 1967, *4634* (MICH). HURON CO.: A few plants in pasture field, ne corner of Lyme Twp., just s of Erie County line, ca. 5 mi e of Bellevue, 14 Jul 1967, *Jane L. Forsyth s.n.* MADISON CO.: West Jefferson, 17 Jul 1925, *H. D. Folmer s.n.* OTTAWA CO.: A few plants along w side of road (Alexander Pike) in limestone quarry, se portion of Marblehead Peninsula, Danbury Twp., ca. 1 mi s of the town of Marblehead. Last year's plants represented apparently only by one large, much-branched dead individual, 14 Jul 1967, *4359*. SANDUSKY CO.: Locally common in old pasture field along county road 175, NE ¼ Sec. 1, T4N, R17E, York Twp., ca. 4.5 mi n of Bellevue, 8 Jul 1967, *4274*. SENECA CO.: Along railroad, county road 32, 1.7 mi w of Huron County Line, Thompson Twp., 23 Jun 1963, *E. M. Herrick s.n.;* one plant seen by fence along New Haven Road, SW ¼ Sec. 20, T1N, R13E, Big Spring Twp., ca. 1½ mi s of Alvada, 25 Jul 1967, *4633*. WYANDOT CO.: Locally abundant in pasture field, NW ¼ Sec. 1, T1S, R12E, Ridge Twp., ca. 4 mi nw of Carey. Depth to dolomite bedrock, ca. 5 ft, 25 Jul 1967, *4635*.

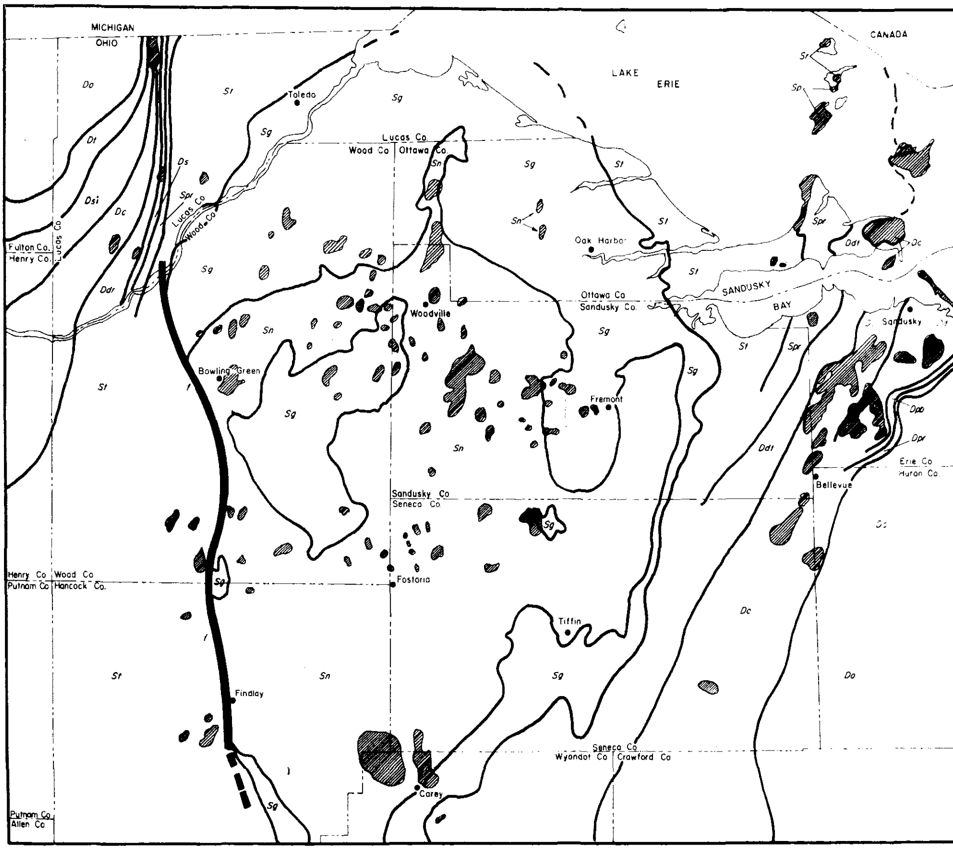

FIGURE 3. Map showing bedrock geology of a part of northwestern Ohio and the areas of shallow bedrock (shaded) within that area. Depth of bedrock in these areas varies, but in all cases is shallow enough either to be exposed (in natural or in man-made cuts, including quarries) or to affect the landscape, producing hills with characteristically smooth rounded forms. In only some of these areas is limestone or dolomite bedrock so shallow as to constitute likely locations for future colonization by *Carduus nutans*. Castalia-Bellevue-Sandusky area lies in east-central part of map, and Carey is in south-central part.

Letter symbols identify different bedrock units:

Devonian Do —Ohio Shale (Antrim in Lucas County)

Devonian Do —Ten Mile Creek Dolomite (not present in Erie, Huron, or Seneca Counties)

Dpr—Prout Limestone (reported only in Huron and Erie Counties)

Ds —Silica Shale (not present in Erie, Huron, or Seneca Counties)

Dpb—Plum Brook Shale (reported only in Huron County)

Dc —Columbus Limestone (Dundee Limestone in Lucas County; includes the Delaware Limestone in Seneca and Crawford Counties)

Ddr—Detroit River Group (in Ottawa, Erie, and Sandusky Counties, represents Lucas Dolomite, the only Detroit River formation present; in Lucas County, represents the Anderdon, Lucas, and Amherstberg Dolomites, but the basal formation of the Detroit River, the Sylvania Sandstone (Ds), is mapped separately)

Silurian Spr —Put-in-Bay and Raisin River Dolomites of the Bass Islands Group (mapped separately as Sp and Sr on the Erie islands)

St —Tymochtee Dolomite (Salina) of the Bass Islands Group

Sg —Greenfield Dolomite of the Bass Islands Group

Sn —Niagaran Dolomite (Lockport; Guelph)

Sources: Carman, 1946; Carman *in* Coash, Bernhagen, and Forsyth, 1957; Core, 1948; Farnsworth, Donald, Unpublished data (as of 1961) ;Forsyth, 1968; Sparling, 1965; State of Ohio, 1962; Stein, 1966.

plants, both as to location and abundance and as to associated geology and topography, was carefully noted. By combining, in the field, the observations of both a plant taxonomist and a geologist acquainted with the details of the distribution of both the bedrock and the glacial materials, the relationships between the occurrence and abundance of the nodding thistle and the geologic substrate readily became apparent.

In the Castalia-Bellevue-Sandusky area (fig. 4), mapping, most of which was done jointly, took place between July 1 and 15, 1967. In the Carey area (fig. 5), the distribution of the thistle was mapped on 25 July 1967 by the senior author alone. In both areas, surveys were extended beyond the limits of the plant's occurrence, so as to be certain that the full extent of the species' total local range at this time had been determined.

On the resulting maps (figs. 4 and 5), each locality where these thistle plants were observed is represented by a dot whose size indicates the relative abundance of the thistle at that site. In localities where plants were numerous (.e.g. consisting of a field nearly covered with plants, with perhaps several hundred or more individuals), a large-sized dot is used. Where the plants were fewer (several plants in a whole field or for a similar distance along the side of the road), the site is marked by a medium-sized dot. Where only one or two plants occurred at a locality, a small-sized dot is used. Because of the large, showy nature of the inflorescence, it was possible in many places to use field glasses to check occurrences of the plant from the automobile, thus increasing the efficiency of the mapping without any apparent loss of accuracy.

The geologic information appearing on both maps was compiled without reference to the recorded field distribution of the thistle. Depth-to-rock data in the Castalia-Bellevue-Sandusky area were taken from well records made available by the Division of Water, Ohio Department of Natural Resources, Columbus. In the Carey area, depth-to-rock data were obtained from Stein (1966, and personal communication, 1968).

RESULTS AND DISCUSSION

From our initial field observations, it was clear that the distribution of *Carduus nutans* was limited and that the occurrence of this species in any significant abundance was always in areas where limestone or dolomite bedrock was at or very close to the surface. In places where the transition from thick surface deposits of till or silt on flat plains to areas of very shallow limestone or dolomite on a bedrock high was abrupt, as southward along Ohio route 99 northeast of Castalia, the equally abrupt appearance of the plant in abundance, once the area of shallow bedrock was reached, was very striking. Systematic mapping confirmed the fact that these original inferences were consistently dependable.

When the maps showing the distribution of the plant, made in the field, and the maps of the depth-to-rock data, prepared independently in the office, were compared, it was apparent that only where limestone or dolomite bedrock was shallower than six feet, a depth which appeared to be the same throughout both areas studied, was the thistle present in any significant numbers. The heavy solid black lines in Figures 4 and 5 enclose areas where bedrock is six feet or less in depth, in contrast to areas outside the lines where bedrock is deeper (note that, north of Carey (fig. 5), areas of shallow dolomite bedrock occur only on the slopes and upland margins; in both the surrounding land and more centrally located areas on top of the uplands, till is thicker and the thistle occurs there infrequent). In all cases, the areas of shallow bedrock are also areas which stand somewhat higher than the surrounding plains and are thus very well drained. Drainage does not appear to be the main controlling factor, though, for whenever higher, better drained land lacking shallow calcareous bedrock was investigated, no thistle plants were observed.

On the low, clayey flats surrounding the bedrock hills, where the bedrock is deeper, the thistle was virtually absent. Where the thistle did occur in these places, only a few plants were present, as indicated by the widely scattered small-sized dots on the maps (figs. 4 and 5). A particularly interesting site is located on the fill along the south approach to the Thomas Edison Memorial Bridge, along Ohio route 2 at Bay View west of Sandusky, a site marked by two medium-sized dots in Figure 4. Bedrock here is much deeper than in the area of abundant

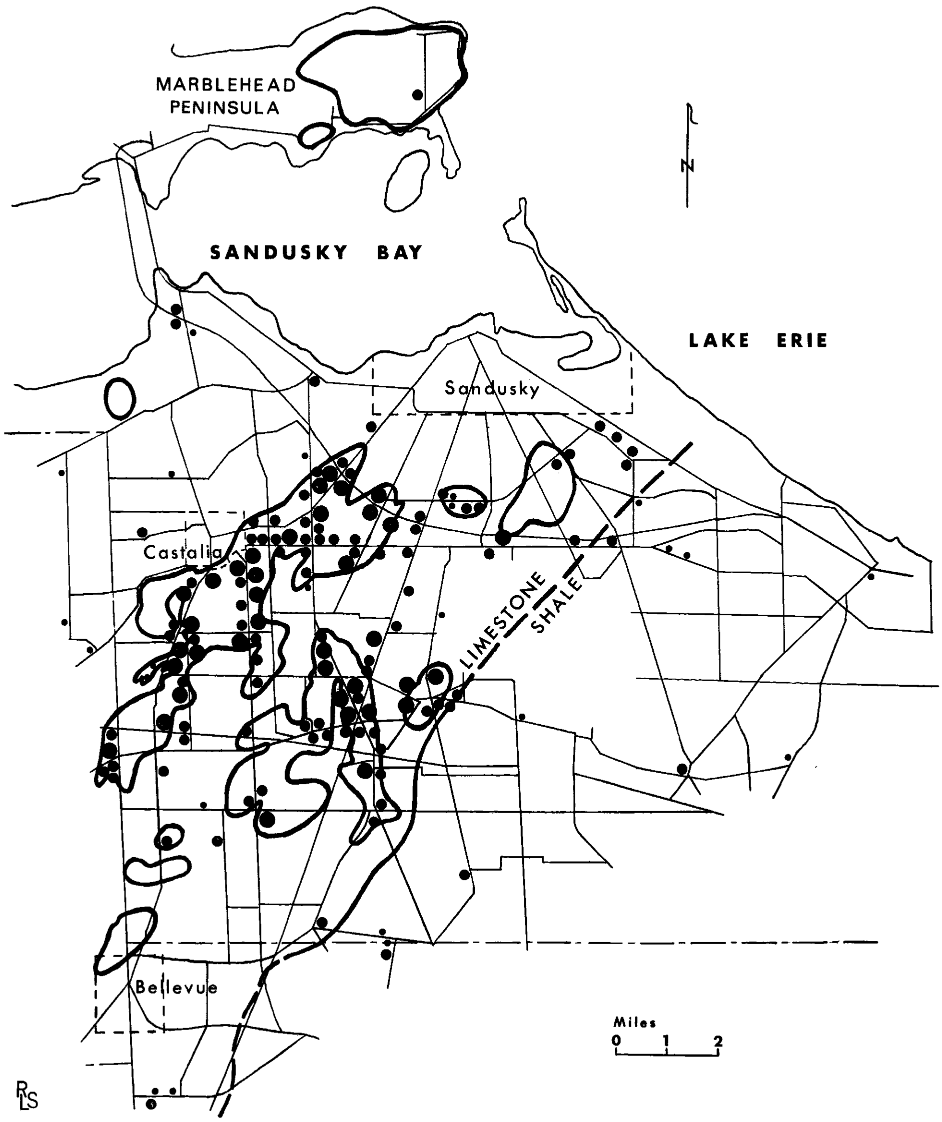

FIGURE 4. Detailed distribution of *Carduus nutans* in the Castalia-Bellevue-Sandusky area. Large dots = numerous plants, medium-sized dots = several plants, small dots = one or two plants. The heavy solid black lines enclose areas where limestone bedrock is at a depth of six feet or less from the surface.

thistles to the south, near Castalia. However, the source of the road fill was to the east, southwest of Sandusky, in an area of shallow limestone bedrock, where the thistle is abundant. It seems logical to suggest that achenes of *Carduus nutans* were moved, by road-construction equipment, from this site to the place along the bridge approach where the plants were observed.

Because the achenes of this thistle are not readily released, but remain enclosed in the dried head, natural expansion of the plant's local range is not as readily accomplished as it is for other thistles, which have readily released propagules that are blown by the wind. An example of the slow rate of the extension of its local range is borne out by our observations of the nodding thistle plants in the Marblehead limestone quarry, about one mile south of the town of Marblehead, Ottawa County. On 14 July 1967, an estimated 30 plants were seen in one place, about 20 feet in length, along the west shoulder of Alexander Pike at the southeast

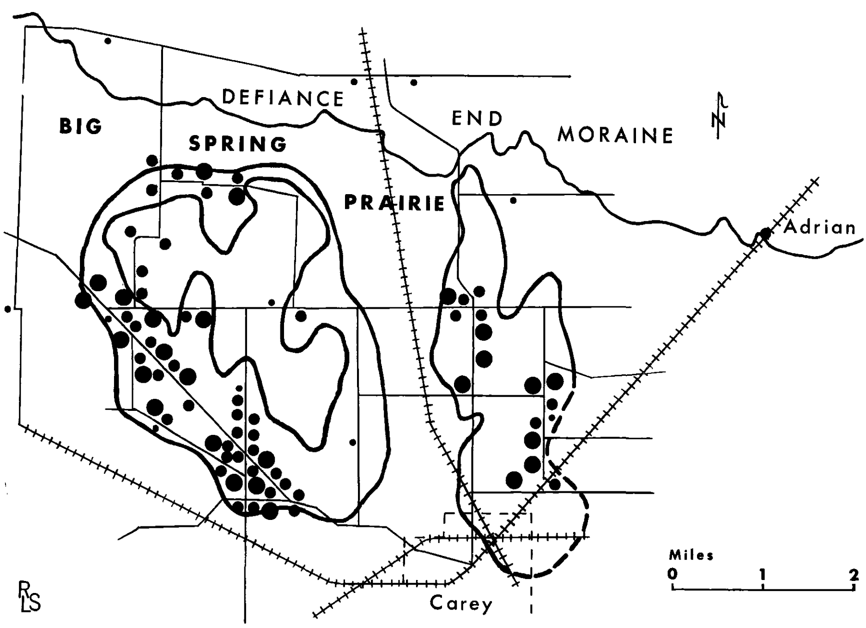

FIGURE 5. Detailed distribution of *Carduus nutans* in the Carey area. Large dots = numerous plants, medium-sized dots = several plants, small dots = one or two plants. The heavy solid black lines enclose areas where dolomite bedrock is at a depth of six feet or less from the surface. Note that, in the large area to the west, it is only on the outer slopes where the bedrock is sufficiently shallow for the plant to be present. In the center, even though this is a dolomite bedrock high, the till cover is too thick for any significant occurrence of *Carduus nutans*.

corner of the quarry. One plant was in flower, several were in bud, and many were in the young rosette stage. With these plants was one large, mature, dead thistle plant remaining from the 1966 season, from which we inferred the entire 1967 population must have been derived. By September, 1967, the plants formerly in the rosette stage had aerial stems, and most were in full bloom or fruit. Nodding thistle plants were totally absent from the shoulder along the east side of Alexander Pike, as well as from the southeast portion of the quarry floor on the east side of Alexander Pike (the flora of this part of the quarry was thoroughly studied during that summer).

By 31 May 1968, thistle plants were observed growing on the east shoulder of

Alexander Pike, with about 15 plants just beginning to bloom, while the total number of plants on the west shoulder of the road had increased considerably. Thistle plants, however, were still absent from the quarry floor on both sides of the road. A few plants were noticed in the quarry on high ground about half-way between the original site and the town of Marblehead on the east side of Alexander Pike. During the summer of 1969, a few plants appeared at another location still closer to the town of Marblehead, and on 11 October 1969, one small flowering thistle plant was seen on a pile of waste gravel on the quarry floor about 10 feet to the east of the population of plants on the east shoulder of Alexander Pike. Thus it had taken two years for the species to begin to invade the quarry floor, despite the favorable substrate there. Our explanation for this slow migration into habitats that appear to be as favorable for its growth as along the shoulder of the road is based on the observations (1) that many of the heads do not have fully developed achenes, (2) that achenes do not readily become separated from the head, and (3) that the heads either remain on the parent plant or drop to the ground beneath the parent plant. Our observations on local dispersal are in agreement with those reported by Doing, Biddiscombe, and Knedlhans (1969). The entire plant, when dead and dry, is more easily knocked to the ground than are most thistles; thus, dispersal by wind appears to be of little consequence. Based on these observations, we would predict that this species would eventually occupy the entire area of favorable substrate on Marblehead Peninsula (fig. 3), but that this expansion of the plant's occurrence would be extremely slow. Nodding thistle plants have not yet been seen on Kelleys Island, where there are extensive favorable sites—abundant limestone exposures, including those in several quarries—nor on Catawaba Island or the Bass Islands.

In northeastern United States as a whole, the migration of *Carduus nutans* has been quite slow over the past 120 years, as shown in Table 1. Furthermore, its present distribution in northeastern United States, as gleaned from the floristic literature and an examination of the specimens in several herbaria, is rather sporadic. This sporadic distribution is related in large part to the very restricted dispersal of the propagules of this plant. In marked contrast is the Canada thistle, *Cirsium arvense*, which is spread by air-borne seeds and perennial running roots. In a similar length of time, dating from the Revolutionary War until 1900, the introduced Canada thistle has become a common widespread weed of cultivated and pasture fields throughout northeastern United States (Dewey, 1901).

In both the Castalia-Bellevue-Sandusky and Carey areas, the plants occurred most frequently and abundantly in pasture fields moderately to heavily grazed by cattle or sheep; in hayfields of red clover, sweet clover, and/or timothy; in fields abandoned from one to several years; and along quarry margins, or along grassy roadsides, but always where calcareous bedrock lay only a few feet below the surface. A few plants were found in fields of oats or wheat, but not in fields of corn or soybeans. Although other thistle plants normally occur rather frequently along railroad embankments, *Carduus nutans* was generally rare in such sites. In places where extensive mowing had taken place, as on Billings Road southeast of Castalia, offshoots from the bases of cut thistles produced small plants which bloomed long after this thistle's normal time of flowering.

A close correlation between the frequency and abundance of *Carduus nutans* and the depth of the underlying carbonate bedrock has been demonstrated by our detailed field mapping in two areas in northwestern Ohio. The reason for this relationship is not well understood. Certainly carbonate rock should provide higher pH values for the soil, but attempts to test substrate pH at field sites located inside and outside of the solid lines on the maps (fig. 4 and 5) did not reveal any major critical differences. We have not attempted to grow the plants under uniform environmental conditions, where the single factor of pH could be varied, though such studies might have provided more evidence as to the significance of this factor in controlling the distribution of the thistle. Papers discussing the relationship of plants to soil pH do exist, but in the case of *Carduus nutans*, only meager information on this relationship is available. Turner (1928) studied the relationship between the distribution of certain Compositae (growing in soil derived from well-drained glacial lake clay, along roadsides, in oldfields, and in hillside pastures) to the hydrogen-ion concentration of the soil. He found that, out of 20 determinations in the field, 100 percent of the samples of soil in which *Carduus nutans* was growing gave a slightly alkaline reaction, or a pH of 7.1 to 7.3. Values for the upper few inches of the A horizon in the Castalia-Bellevue-Sandusky area, measured by us in the summer of 1968 at 18 stations, were comparable, varying between 7.0 and 7.3, but with the greatest proportion of readings at 7.3.

SUMMARY

Present knowledge about the relationship between most floras and the geologic substrate of the areas where they occur is still very inadequate. In order to begin to understand the dynamics of any flora, it is essential to investigate both the plants that are present and their relationship to the underlying geologic substrate. Certain generalizations about such investigations that emerged from the present study are listed below.

1. Detailed mapping of the distributions of plant species, either on a local or a wider regional basis, is essential, if any progress is to be made toward an understanding of the total present-day dynamic and changing flora. In the case of *Carduus nutans*, careful field observations of the plant's distribution revealed that its occurrence, in northwestern Ohio, is generally limited to limestone and dolomite highs where the bedrock is less than six feet deep. The reason for this restriction was not determined.

2. Botanists, by knowing something about a plant's behavior or distribution in relation to geologic phenomena, are in a better position to predict where certain plants may be found. Despite the limitations of the data in this study, we can predict, with some degree of accuracy, locations in northwestern Ohio where *Carduus nutans* should be expected to invade (though very slowly, owing to the fact that achenes are not readily released from the head) and to become common—on limestone or dolomite highs—and where it should be infrequent or lacking—away from this kind of substrate.

3. Geologists, by knowing some key plants, which can act as geological indicators (particularly plants which are readily distinguished from all other species), can use this tool to better infer both the nature of the geologic material beneath the surface and the landscape at the surface. Thus, any report of the presence of *Carduus nutans* in abundance anywhere in Ohio should lead any geologist acquainted with this plant to infer that the bedrock of that area is limestone or dolomite, and that it lies less than six feet below the surface.

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