A GIS-Based Model for Assessing Conservation Focal Areas for the Redwood Ecosystem

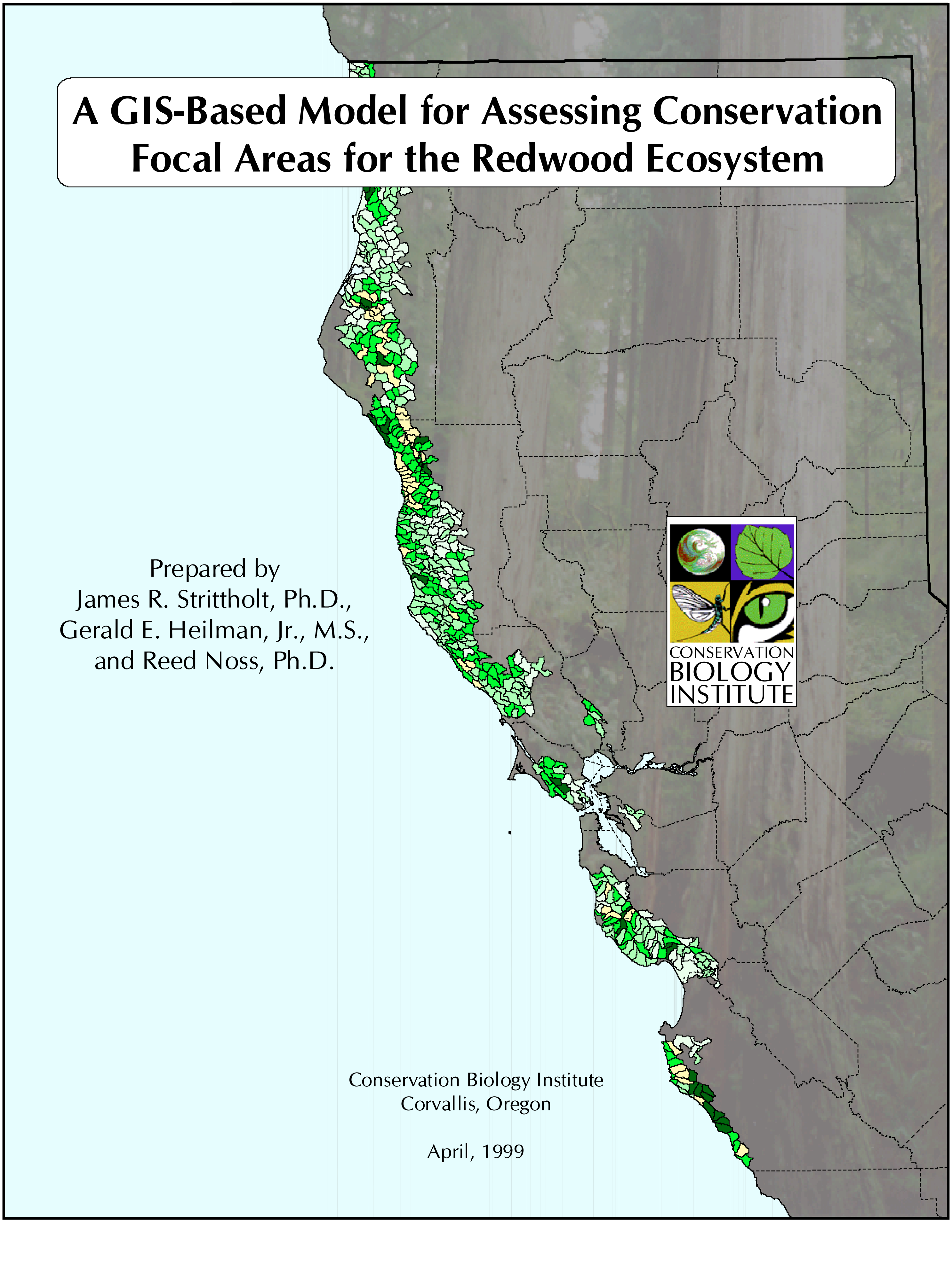

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Table of Contents

List of Tables	ii
List of Figures	iii
Acknowledgements	vi
The Model Design	1
The Data	5
Criterion #1—Location of Largest Late-Successional Patches [Patch Function]	5
Criterion #2—Concentration of Late-Successional Patches [Neighborhood Function]	5
Criterion #3—Road Density [Neighborhood Function]	11
Criterion #4—Location of Imperiled Species [Patch Function]	12
Criterion #5—Forest Neighborhood Age [Neighborhood Function]	17
Criterion #6—Forest Fragmentation [Neighborhood Function]	21
Criterion #7—Potential Connectivity to Existing Protected Areas [Neighborhood Function]	29
Criterion #8—Road/Stream Intersections [Watershed Function]	34
Criterions #9—Forested Riparian Zones [Watershed Function]	38
Discussion	45
The Composite Results	50
Literature Cited	65
List of Plates	66

List of Tables

Table 1. Data layers used in the GIS-based focal areas modeling. 5

Table 2. Protection status for old growth for each section based on the current old-growth forest data from Pacific Biodiversity institute. 7

Table 3. Fragmentation results for the northern section. 31

Table 4. Fragmentation results for the central section. 32

Table 5. Fragmentation results for the southern section. 33

Table 6. Spearman's Rank Correlation Coefficient summaries for the focal areas model. 45

Table 7. Ordinal classes for mean forest age along riparian zones per watershed for each of the three redwood sections. 46

Table 8. Actual model scores for classes depicted for the cumulative model score (criteria 1-9) organized by 1-hectare ha cell size (Figure 31) and organized by subwatershed basin (Figure 32) for the northern section. 51

Table 9. Actual model scores for classes depicted for the cumulative model score (criteria 2-9) organized by 1-hectare ha cell size (Figure 33) and organized by subwatershed basic (Figure 34) for the northern section. 51

Table 10. Actual model scores for classes depicted for the cumulative model score (criteria 2-9) organized by 1-hectare ha cell size (Figure 35) and organized by subwatershed basic (Figure 36) for the central section. 57

Table 11. Actual model scores for classes depicted for the cumulative model score (criteria 2-9) organized by 1-hectare ha cell size (Figure 37) and organized by subwatershed basin (Figure 38) for the southern section. 61

List of Figures

Figure 1. Three basic redwoods subregions: northern, central, and southern.	3
Figure 2. Focal areas model flowchart.	4
Figure 3. Old-growth redwood patch size for the northern section.	8
Figure 4. Old-growth redwood patch size for the central section.	9
Figure 5. Old-growth redwood patch size for the southern section.	10
Figure 6. Old-growth redwood patch concentration for the northern section.	13
Figure 7. Old-growth redwood patch concentration for the central section.	14
Figure 8. Old-growth redwood patch concentration for the southern section.	15
Figure 9. US Geological Survey and US Forest Service 1:24,000 scale digital data set coverage for the redwoods study area.	16
Figure 10. Road density for the northern section.	18
Figure 11. Road density for the central section.	19
Figure 12. Road density for the southern section.	20
Figure 13. Imperiled species concentration for the northern section.	22
Figure 14. Imperiled species concentration for the central section.	23
Figure 15. Imperiled species concentration for the southern section.	24
Figure 16. Mean forest age for the northern section.	26
Figure 17. Mean forest age for the central section.	27
Figure 18. Mean forest age for the southern section.	28
Figure 19. Cumulative forest fragmentation metrics for the northern section.	35
Figure 20. Cumulative forest fragmentation metrics for the central section.	36
Figure 21. Cumulative forest fragmentation metrics for the southern section.	37

Figure 22. Distance to existing protected areas for the northern section. 39

Figure 23. Distance to existing protected areas for the central section. 40

Figure 24. Distance to existing protected areas for the southern section. 41

Figure 25. Road and stream intersections for the northern section. 42

Figure 26. Road and stream intersections for the central section. 43

Figure 27. Road and stream intersections for the southern section. 44

Figure 28. Riparian zone forest composition the northern section. 47

Figure 29. Riparian zone forest composition the central section. 48

Figure 30. Riparian zone forest composition the southern section. 49

Figure 31. Composite model ranking by 1 hectare cell using criteria one through nine for the northern section. 52

Figure 32. Composite model ranking by watershed using criteria one through nine for the northern section. 53

Figure 33. Composite model ranking by 1 hectare cell using criteria two through nine for the northern section. 54

Figure 34. Composite model ranking by watershed using criteria two through nine for the northern section. 55

Figure 35. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the northern section. 56

Figure 36. Composite model ranking by 1 hectare cell using criteria two through nine for the central section. 58

Figure 37. Composite model ranking by watershed using criteria two through nine for the central section. 59

Figure 38. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the central section. 60

Figure 39. Composite model ranking by 1 hectare cell using criteria two through nine for the southern section. 62

Figure 40. Composite model ranking by watershed using criteria two through nine for the southern section. 63

Figure 41. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the southern section. 64

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A GIS-Based Model for Assessing Conservation Focal Areas for the Redwood Ecoregion

The purpose of this project was to create a GIS-based model that identifies specific focal areas throughout the range of the redwoods. Focal areas were defined as zones, organized by 6th order subwatersheds, that offer the best conservation opportunities for long-term protection and maintenance of the redwood ecosystem based on current conditions. GIS (geographic information system) is a computer-based mapping technology and was chosen because of its spatially explicit architecture and advanced analytical capability. For these and other reasons, GIS is rapidly becoming the cornerstone in modern conservation planning.

This model was produced for Save-the-Redwoods League as part of their overall Master Plan – an organizational blueprint for protecting the redwood ecosystem. More specifically, this model was intended to help the League target their future proactive conservation planning efforts more effectively as part of their overall conservation mission while supplying a broader organizational tool that could be shared with its conservation partners in the region.

The Model Design

The study area was initially defined by the historic range of redwood forests in California based on a data layer created by the Pacific Biodiversity Institute and modified to the nearest 6th order watershed from the file CALWATER obtained from the California Department of Fish and Game. Throughout this report the terms “file,” “data layer,” and “coverage” are synonymous and refer to spatially referenced computer records. Of course, the redwood range does cross into Oregon to a small extent, but due to data unavailability or gross data inconsistencies between Oregon and California, we elected to drop this small portion of the redwood range from the modeling exercise. That in no way diminishes the value of redwoods in Oregon, it was simply too difficult and expensive to add in the Oregon portion of the range for this project.

The analysis began by first dividing the redwoods region into three basic subregions: northern, central, and southern (Figure 1). Treating the three subregions individually has many practical benefits, but it is also important to have an appreciation that there are conservation issues and ecological processes that span these subregions. For example, the ranges of some species of concern (both aquatic and terrestrial) do not conform to subregions determined by the particular expression of redwood-dominated vegetation. For model reporting purposes, however, we have elected to generate map results for each subregion (from here on referred to as sections) individually. The method applied to create this model does not say anything specific about what conservation and management measures should be applied to each identified focal area – that task remains for a much more detailed assessment at the within-focal area and individual site level planning which is the logical next step in the development of proactive conservation plans for the region.

Our model was designed to use available spatially explicit data as much as possible at map scales ranging from 1:24,000 to 1:130,000. Larger scaled data for roads and streams (1:24,000) required some substantial database assembly before a number of the model criteria could be examined (e.g., criteria #3, #6, #8, and #9). All total, nine criteria were analyzed in each of the three sections with the ultimate goal of ranking subwatersheds in terms of current overall conservation value. The nine criteria were organized around three different types of descriptors (or functions): (1) **patches** – discrete, mappable units of a defined composition; (2) **neighborhoods** – the immediate surroundings of a patch or group of similar patches; and (3) **watersheds** – the landscape or hydrologic unit in which a group of patches exist (e.g., 6th order watersheds).

Each of the nine criteria was developed separately with individual results assigned ordinal scores numbering 1-5. These ordinal results were then added together to produce a final composite score and summarized by one hectare cells and subwatershed basin (see Figure 2 for model flowchart). Focal areas had no predetermined size – they could be a single subwatershed or clusters of many subwatersheds. A 10th criterion that considers management potential was not modeled, but was still included in the overall model design. This criterion can be assessed in a non-quantifiable way, but requires input from individuals who have knowledge about the current management of specific watersheds. It is difficult, if not impossible, to assign the same type of ordinal score to this criterion. It is best to therefore use it as a final filter to refine the focal areas selection process. For example, we might learn that two of the 15 highest scoring subwatersheds are going to be particularly difficult to work in because of existing management plans or conflicts. In these instances, it may be more effective to work in one or more of the remaining 13 subwatersheds that do not possess the same serious institutional barriers.

To a limited degree, we experimented with weighting the various criteria, and even dropped various criteria out of the model altogether to see what impact that would have on the final focal areas results. The model is easily manipulated to identify and emphasize different conservation objectives (e.g., the least impacted watersheds, the highest concentration of old forest, and the most permeable landscapes for wide-ranging, sensitive species). In addition, model transparency is an important attribute that will hopefully lead to future enhancements as better data become available and as additional scientific expertise is incorporated. We chose to focus this final report on the basic framework of the model with all criteria being equally weighted. Further refinements may prove useful in the future, but reporting on the basic design and use of the model is the fundamental focus of this report.

The GIS-based model was developed using Arc/Info™ (version 7.2.1) and ArcView™ (version 3.1) with the Spatial Analyst™ (version 1.1) extension and FRAGSTATS™ (version 2.0) a fragmentation analysis software package. Some support data layers were manipulated in ERDAS Imagine™ (version 8.3.1) and then imported into Arc/Info for inclusion into the model. Every effort was made to conduct as much of the model as possible in the ArcView/Spatial Analyst environment.

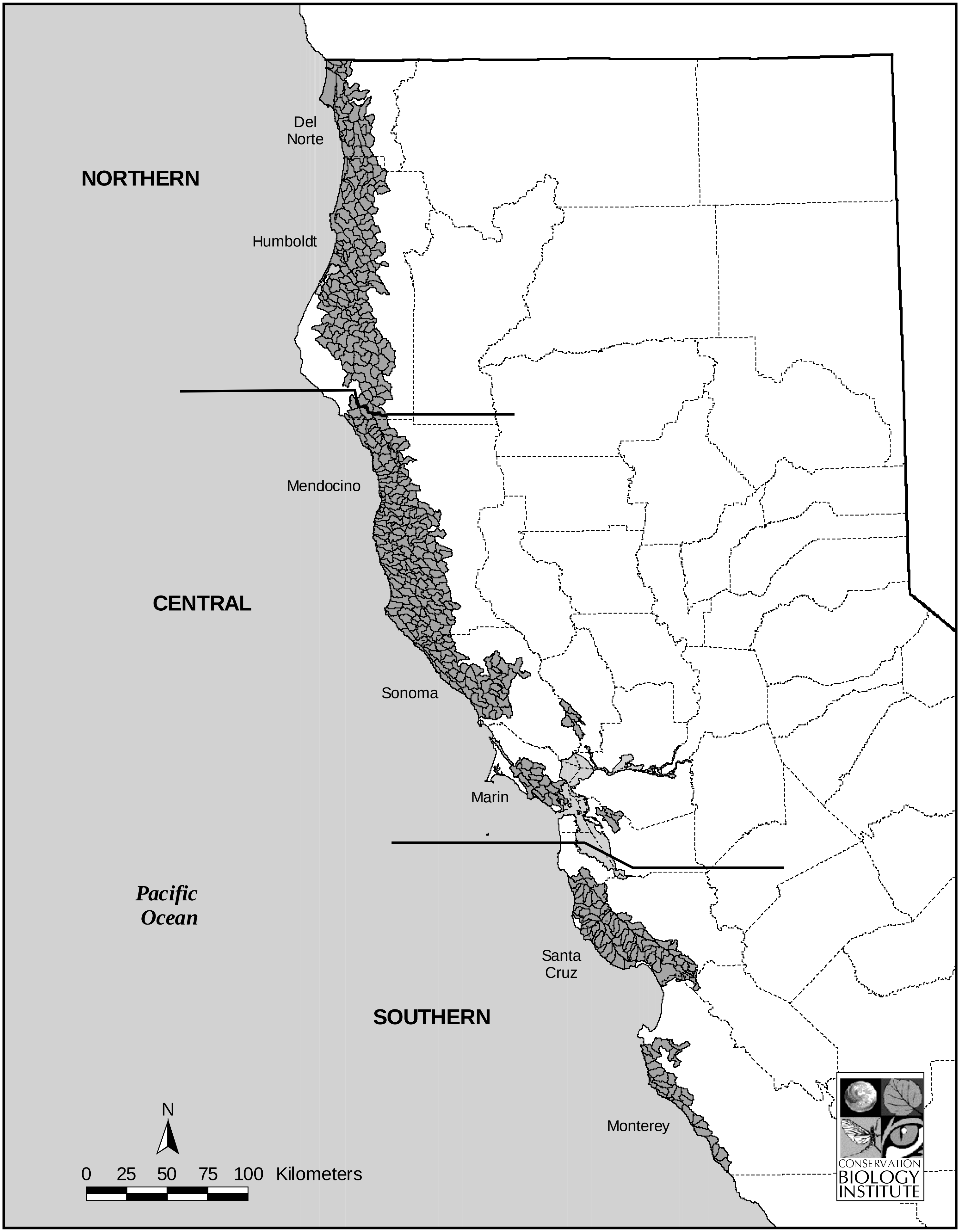

Figure 1. Three basic redwoods subregions: northern, central, and southern.

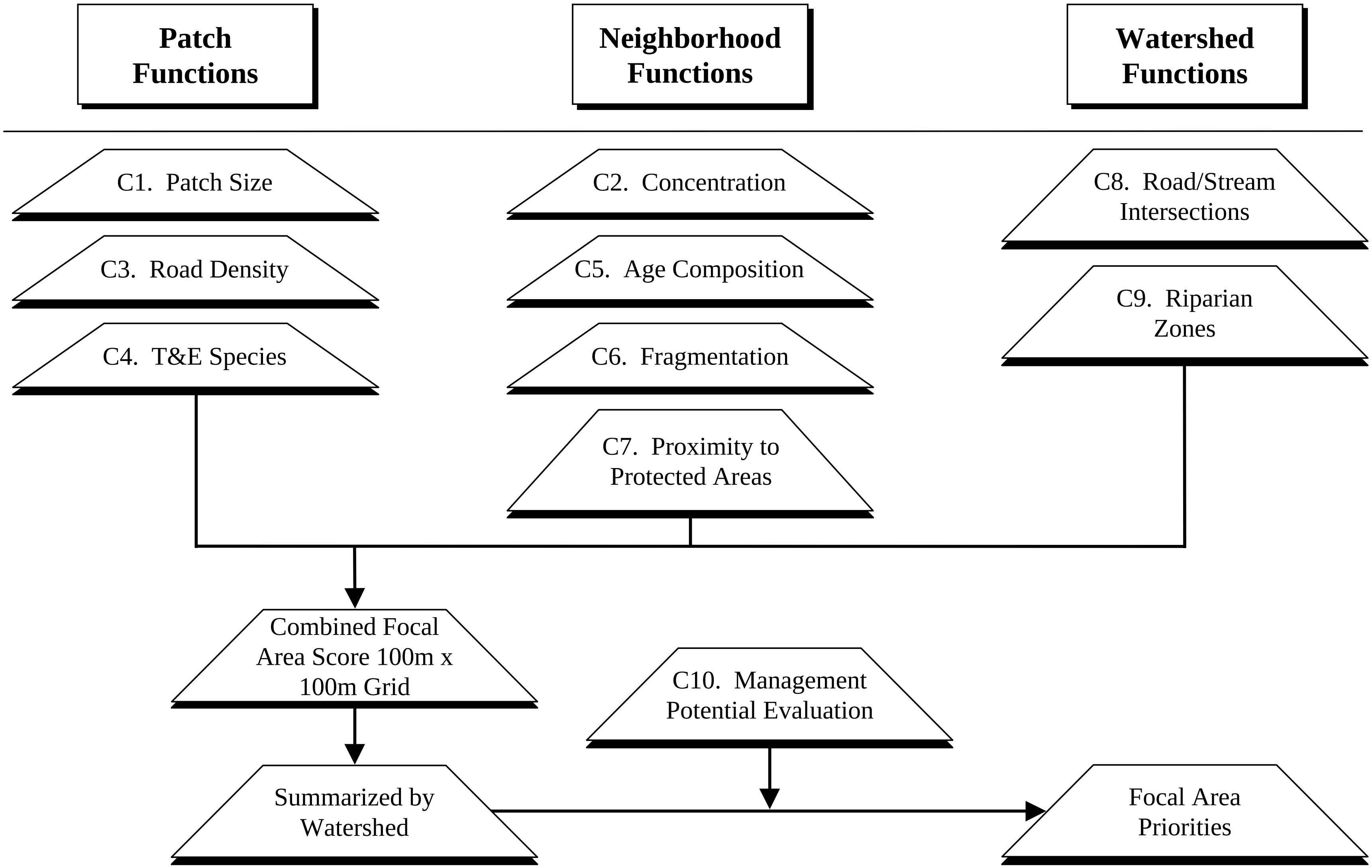

Figure 2. Focal areas model flowchart.

The Data

The data layers (or themes) used to create the model are summarized in Table 1.

Table 1. Data layers used in the GIS-based focal areas modeling.

Data Layer	Scale/ Resolution	Source
Historic extent of coastal redwoods	1:130,000	Pacific Biodiversity Institute
Current forest cover	1:130,000	CA Dept. of Forestry & Fire Protection
Current vegetation	30m x 30m	LEGACY
Current vegetation	50m x 50m	CA GAP
Current old-growth redwoods	30m x 30m	Pacific Biodiversity Institute
T&E element occurrences	1:24,000	CA Natural Diversity Data Base
Watershed subbasins	1:24,000	CA Fish & Game
Roads	1:24,000	USGS 7.5 minute quadrangles
Hydrography	1:24,000	USGS 7.5 minute quadrangles
Headwaters area lands	1:24,000	Pacific Lumber Company
Protected areas	1:100,000	CA GAP
Administrative boundaries	1:100,000	CA GAP
Private timberland boundaries	1:100,000	LEGACY

Assessment Criteria

Criterion #1 – Location of Largest Late-Successional Patches [Patch Function]

Rationale:

The first criterion was based on the conservation biology principle that, all else being equal, larger patches are better than smaller patches. In this case, we were most interested in late-successional (especially old-growth) stands of redwoods because late-successional stands and the species dependent on them have been reduced far more than early-successional stands since European settlement – hence, they are generally more endangered.

Data Sources:

We used the late seral data supplied by Peter Morrison from the Pacific Biodiversity Institute, which was a compilation of various data sources including satellite imagery, high altitude aerial photos, and stand mapping. This data layer contained information on both redwood and Douglas-fir forest patches in undisturbed and partial retention (residual) sites. Douglas-fir patch data was only mapped for a small portion of the northern subregion and was not considered in this assessment criterion. Patch size was easily obtained from the data layer and ranked using a natural breaks function. All sections used the same data layer for this criterion. The most recent protected areas layer was obtained from the California GAP program supplemented with Headwaters data from Pacific Lumber Company.

Methodology:

Before building Criterion #1 of the model, we first determined protection area and percentages of old-growth forests for each of the three sections. Ordinal forest patch size classes were then determined from the existing old growth data for each section using the natural breaks option in the ArcView software. The natural break formula used is called Jenks optimization, which identifies breakpoints between classes using a statistical formula that minimizes the sum of the variance within each of the classes to help find groupings and patterns inherent in the data.

Results:

Table 2 summarizes protection status for old growth for each section based on the current old-growth forest data from Pacific Biodiversity Institute. The summary statistics include the most recent Headwaters addition, which added approximately 2.6% more old-growth redwoods to the existing protected areas. Collectively, approximately 14% of the redwoods region with nearly 60% of the remaining old growth is currently protected.

Considering redwood forests in both intact groves and residual patches, old growth in the northern section was found to be most protected (GAP codes 1 and 2) for a total of 26,903 ha (69.61%) compared to the central section (4,399 ha, 37.64%) and southern section (6815 ha, 43.96%).

Ordering the existing old growth patch sizes using 5 distinct classes (white = lowest score of “1” – black = highest score of “5”) resulted in Figures 3 – 5. Note that the range of values is dependent upon the specific data for each section.

Discussion:

This criterion did not prove to be as powerful as originally anticipated. This is due to the fact that all three sections of the redwoods region contain so little existing late seral forest and a high percentage of that is already protected. We elected to run the model with and without this criterion, which resulted in only very minor changes observed in the final

Table 2. Protection status for old-growth for each section based on the current old-growth forest data from Pacific Biodiversity Institute.

	GAP Code									
	1		**2**		**3**		**4**		***Totals***	
Northern Section	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	***ha***	***%***
Redwood Grove	8716.95	32.25%	14008.05	51.82%	720.54	2.67%	3585.78	13.27%	*27031.32*	*100.00%*
Redwood Residual	326.25	2.81%	3851.82	33.16%	400.41	3.45%	7037.82	60.59%	*11616.30*	*100.00%*
Redwood Totals	*9043.20*	*23.40%*	*17859.87*	*46.21%*	*1120.95*	*2.90%*	*10623.60*	*27.49%*	*38647.62*	*100.00%*
Douglas-fir Grove	0.00	0.00%	8.19	1.90%	0.00	0.00%	417.69	98.10%	*425.88*	*100.00%*
Douglas-fir Residual	0.00	0.00%	454.32	25.00%	0.00	0.00%	1360.98	75.00%	*1815.30*	*100.00%*
Douglas-fir Totals	*0.00*	*0.00%*	*462.51*	*13.45%*	*0.00*	*0.00%*	*1778.67*	*86.55%*	*2241.18*	*100.00%*

	GAP Code									
	1		**2**		**3**		**4**		***Totals***	
Central Section	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	***ha***	***%***
Redwood Grove	633.26	7.74%	3272.53	40.02%	3.00	0.69%	4214.67	51.54%	*8123.46*	*100.00%*
Redwood Residual	188.65	5.40%	304.24	8.71%	56.30	0.00%	3001.89	85.90%	*3551.08*	*100.00%*
Redwood Totals	*821.91*	*7.04%*	*3576.77*	*30.64%*	*59.30*	*0.51%*	*7216.56*	*61.81%*	*11674.54*	*100.00%*

	GAP Code									
	1		**2**		**3**		**4**		***Total***	
Southern Section	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	***ha***	***%***
Redwood Grove	1397.48	12.28%	3181.45	27.95%	1357.08	11.92%	5448.42	47.86%	*11384.44*	*100.00%*
Redwood Residual	2166.42	52.61%	69.67	1.69%	332.24	8.07%	1549.20	37.62%	*4117.52*	*100.00%*
Redwood Totals	*3563.90*	*22.99%*	*3251.12*	*20.97%*	*1689.32*	*10.90%*	*6997.62*	*45.14%*	*15501.96*	*100.00%*

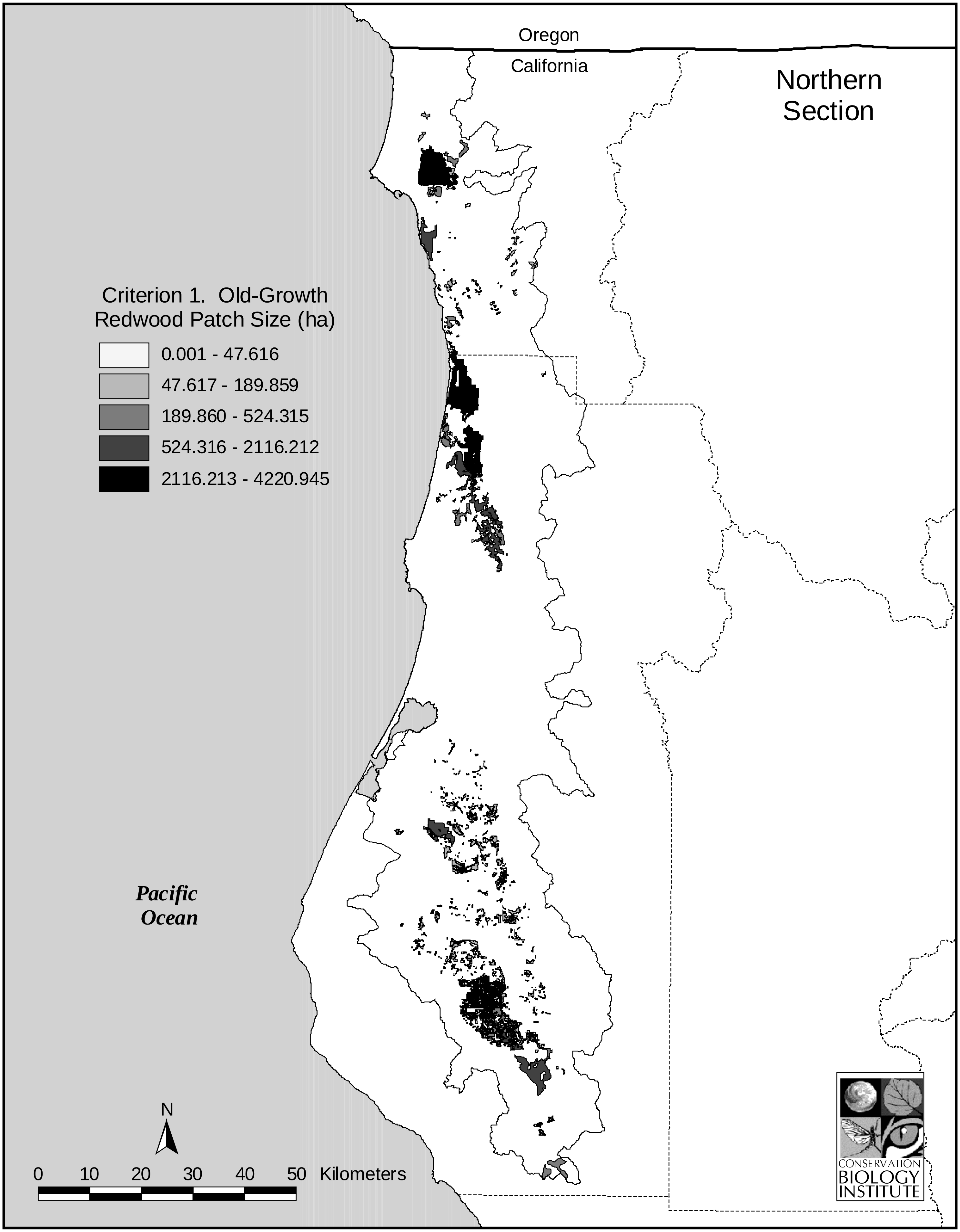

Figure 3. Old-growth redwood patch size for the northern section.

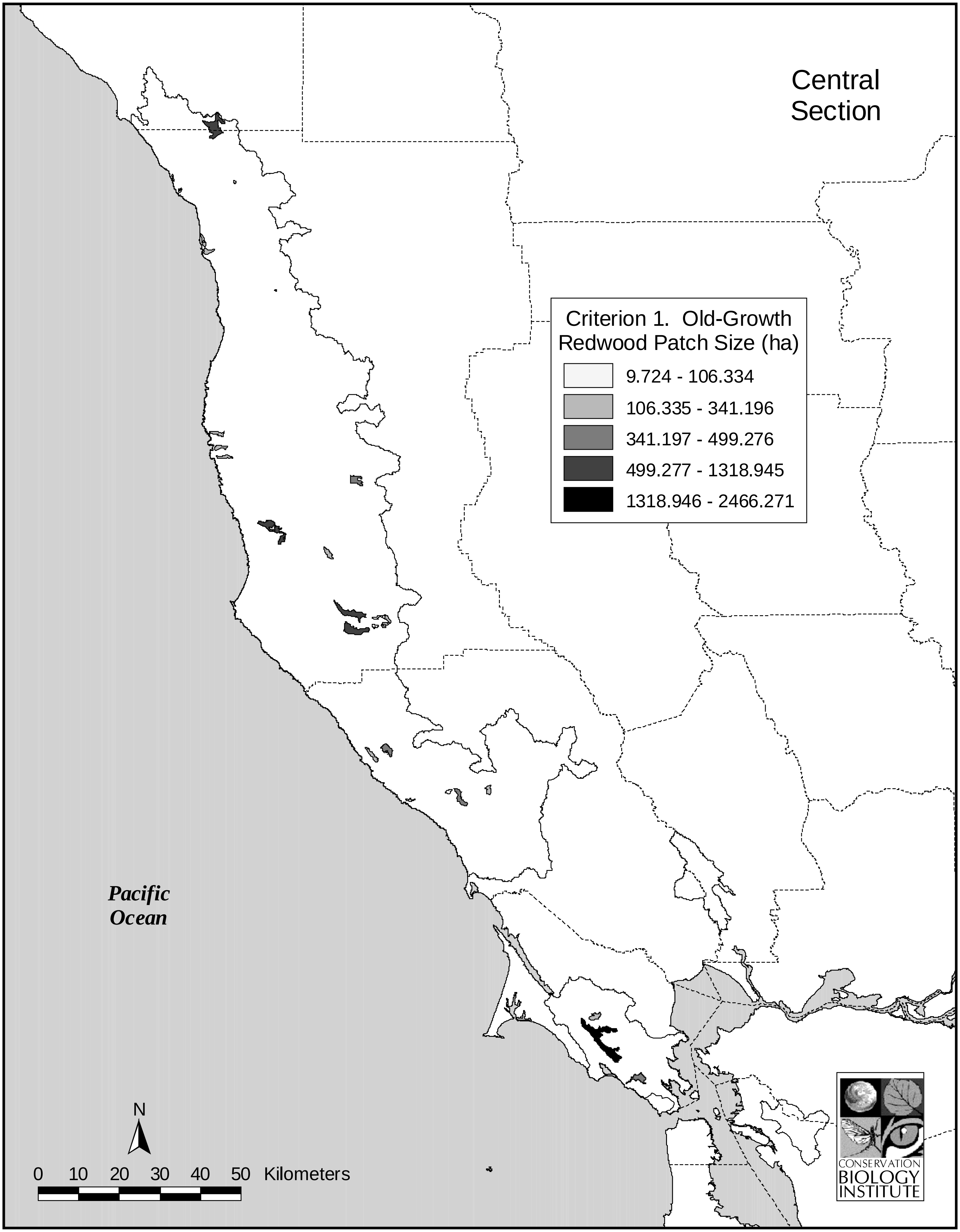

Figure 4. Old-growth redwood patch size for the central section.

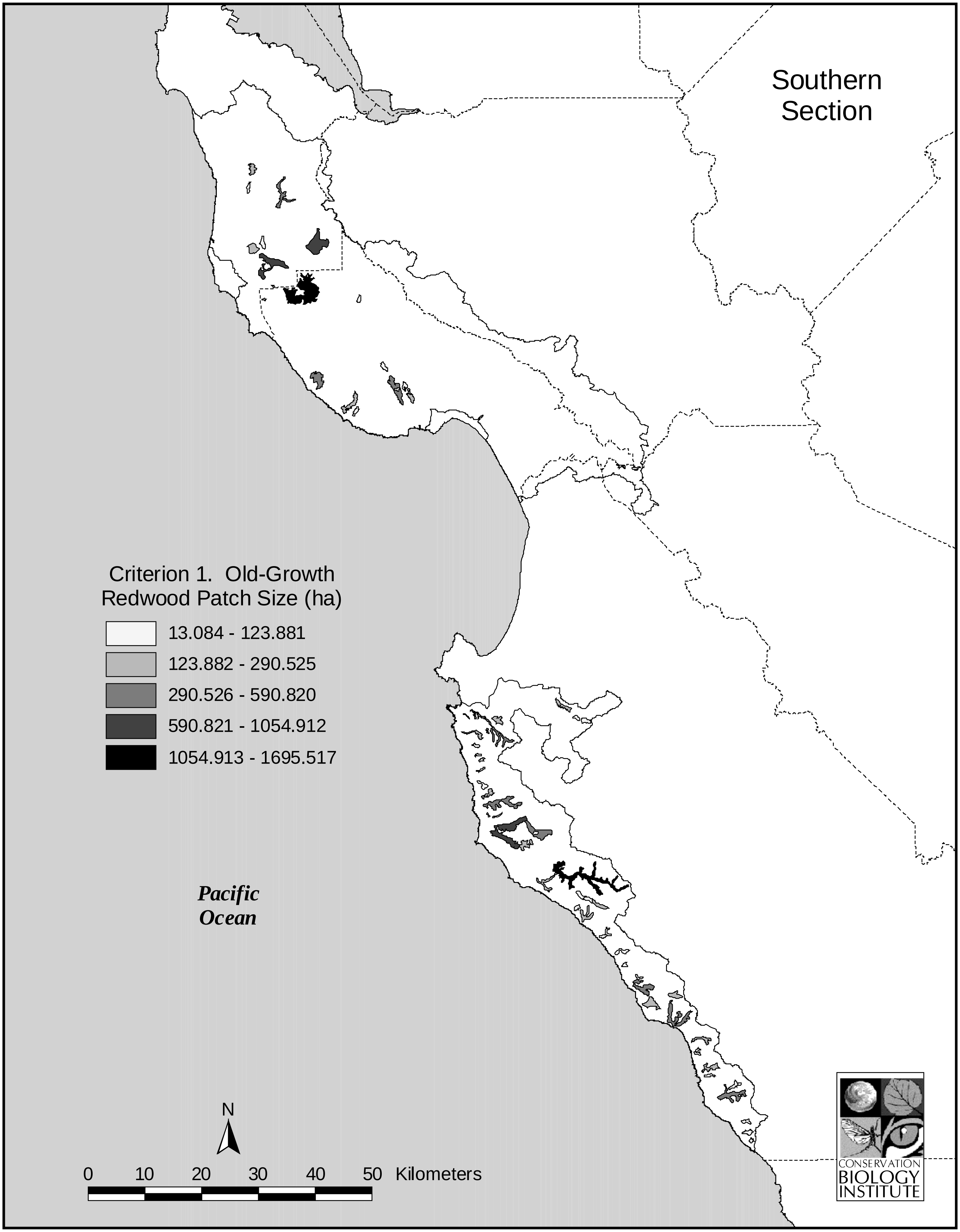

Figure 5. Old-growth redwood patch size for the southern section.

results. Dropping this criterion essentially tightened the results by pulling the highest scoring areas back closer to the mean cumulative criteria score. So little area was effected that the mean between the two treatments did not change. For these reasons, we removed this criterion from all three sections of the redwoods region focal areas model, but we anticipate this criterion will be more important in other forested ecosystems where old-growth patches are more widespread and less protected.

Criterion #2 – Concentration of Late-Successional Patches [Neighborhood Function]

Rationale:

The second criterion was based on the principle that patches close together are better than patches far apart (i.e., in that they combine to form a larger functional patch from the standpoint of organisms and ecological processes that move among patches; see Wilcove and Murphy 1991, Noss et al. 1997). A desirable patch density cannot be specified a priori; therefore, each circumstance needs to be evaluated individually.

Data Sources:

Same as for Criterion #1.

Methodology:

First, an appropriate neighborhood had to be determined for late seral forest patches. Using the "Find Distance" command in Spatial Analyst, we buffered away from each old-growth redwood forest patch out to the extent of the theme (grove and residual patches were treated the same). All cells <500 meters from existing patches were retained and used to define the various forest neighborhoods. Using the "Clump" command, each neighborhood was given its own unique identification number. FRAGSTATS was then run on each neighborhood. The mean nearest neighbor metric was then selected out of the FRAGSTATS results and linked back to the corresponding neighborhood.

For the original model, the neighborhoods were ordered into 5 classes using the natural break option with neighborhoods of one patch assigned an ordered score of "5." For the same reasons as explained under Criterion #1, we subsequently elected to assign all the neighborhoods with a value of "5" for the final version of the model.

Results:

Figures 6 – 8 show the initial ordinal scores for this criterion for each redwood section. For the final model, we used the same data layer but scored all of the polygons the same ("5").

Discussion:

When faced with such a limited distribution of old-growth redwoods throughout its region, we had a number of options. One of the options that we used was to assign the highest rank score to all old-growth redwood neighborhoods. This avoided a possible false distinction between neighborhoods when in reality they are so rare that they all become very valuable. Also, we could have dropped Criterion #2 and used Criterion #1 in the same way, but we elected to keep Criterion #2 instead. We felt that using the neighborhood rather than the actual patch data provided some room for positional error.

Criterion #3 – Road Density [Neighborhood Function]

Rationale:

The lower the road density, the more desirable an area is for conservation (in terms of protecting aquatic ecosystem integrity, reducing invasion potential of exotics, offering security to species sensitive to human disturbance, and other reasons; see Noss and Cooperrider 1994, pp. 54-57 for a review; also Lyon 1984, Megahan 1987). The application of this criterion depends on a comprehensive roads database, including unpaved logging roads, for each potential focal area.

Data Sources:

We acquired all the available electronic files of 1:24,000 roads from the U.S. Geological Survey and manually digitized those 7.5 minute quadrangles with no electronic file version. The only serious problem encountered that could impact the model results was the wide range of map completion dates encountered across the region. Dates ranged from the late 1960s to the present making the final data layer inconsistent temporally. It is still the best data available at the 1:24,000 map scale, but some caution is in order when interpreting the results. Figure 9 highlights the quadrangles involved in developing this data layer and indicates which ones were obtained electronically and which ones were manually digitized. For the manually digitized map sheets, we did not digitize high-density areas (e.g., within existing towns and cities). For these areas, we simply assigned the highest road density score of "1."

Methodology:

After exploring a couple of different techniques, we decided to calculate road density using a fixed 1km x 1km grid cell array making this criterion a discrete patch function. The 1km x 1km grid cell array is an arbitrary, but convenient, scale for landscape-level assessments. Road length, irrespective of road surface type, was totaled for each grid cell and road density calculated (km /sq. km). Classes included: 1 = >3.0 km/km^2, 2 = 2.0 – 3.0 km /km^2, 3 = 1.0 – 2.0 km / km^2, 4 = 0.5 – 1.0 km/km^2, and 5 = 0 – 0.5 km / km^2. These values were chosen based on a body of literature pertaining to approximate carnivore tolerances (e.g., Jensen et al. 1986, Mladenoff et al. 1995).

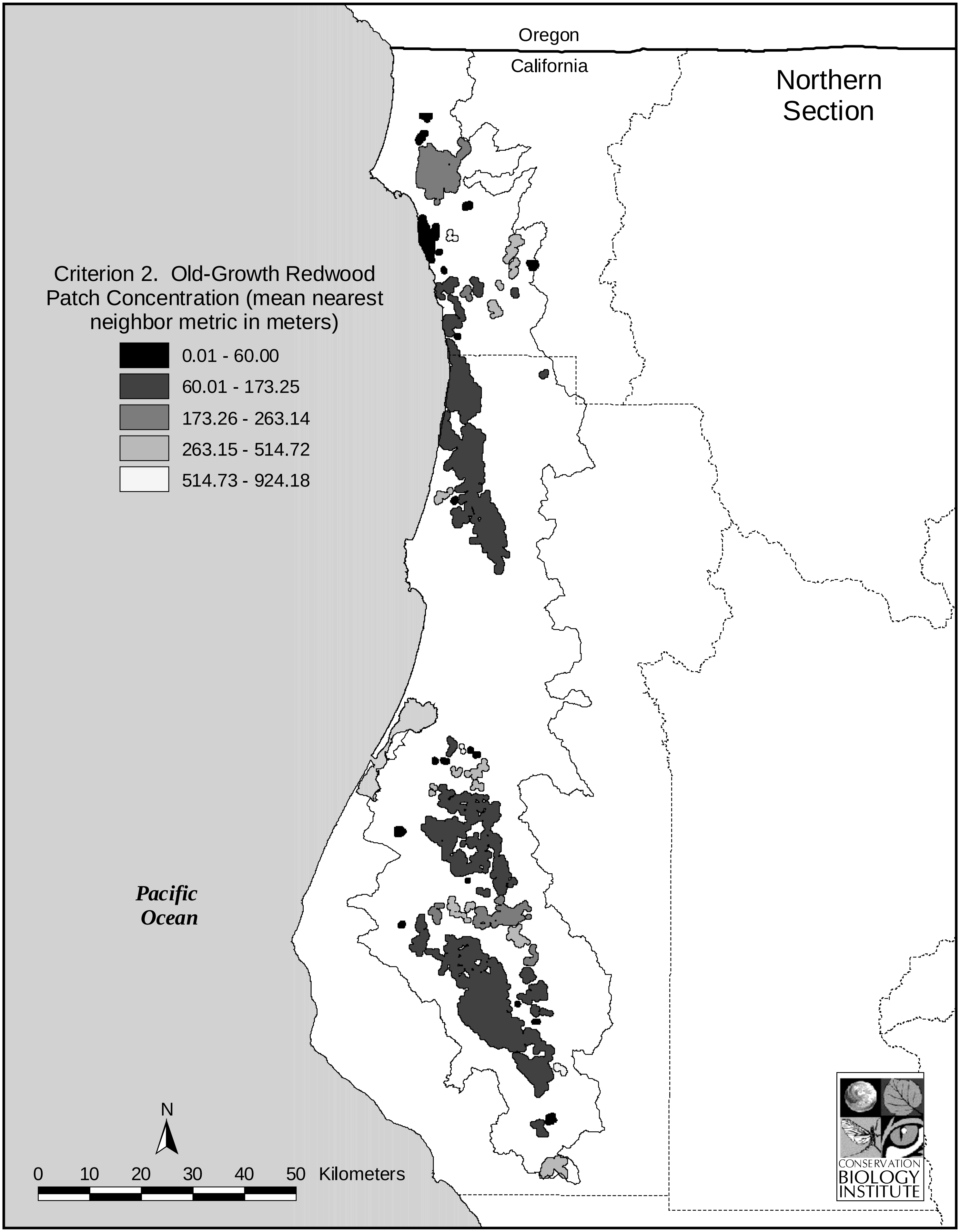

Figure 6. Old-growth redwood patch concentration for the northern section.

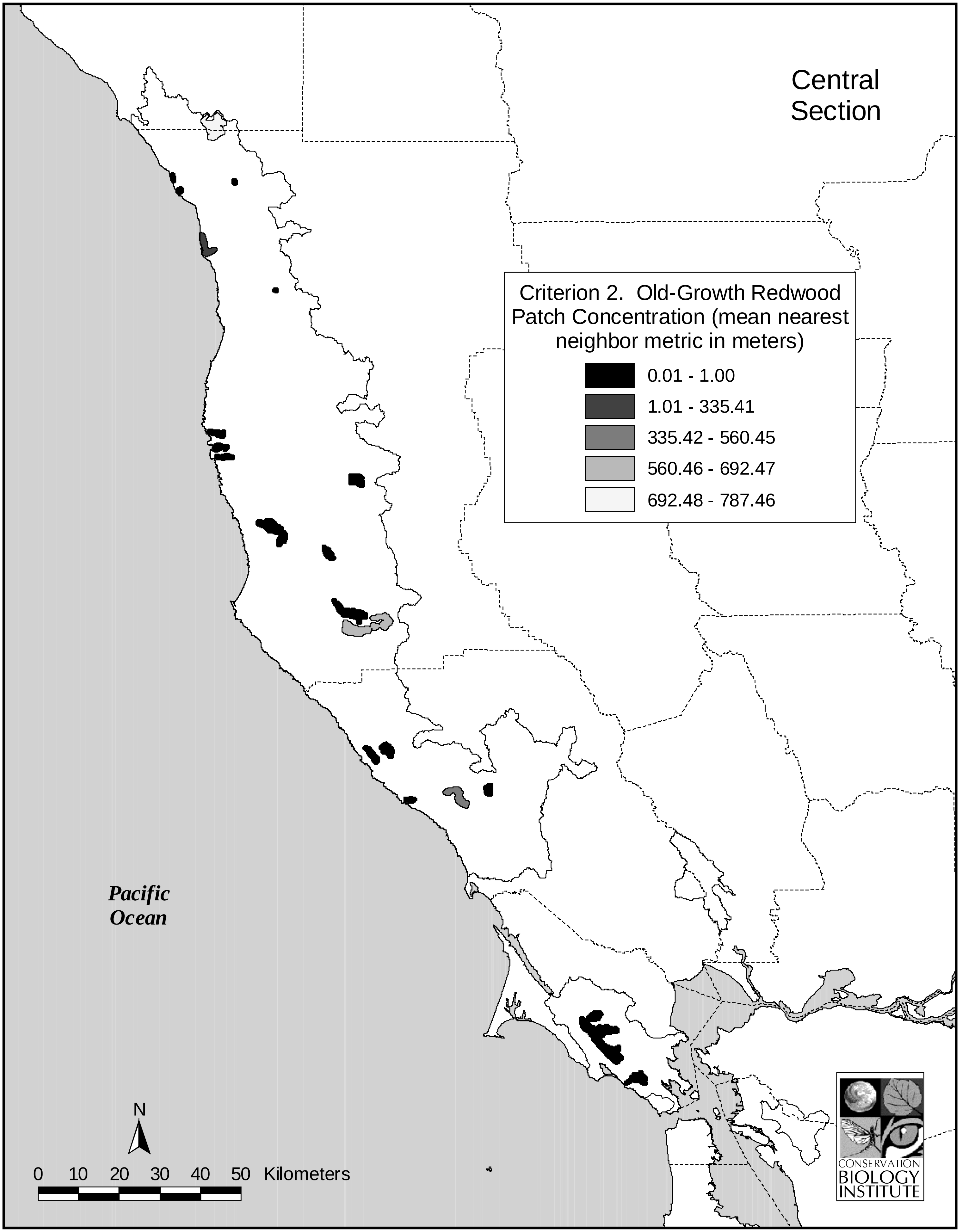

Figure 7. Old-growth redwood patch concentration for the central section.

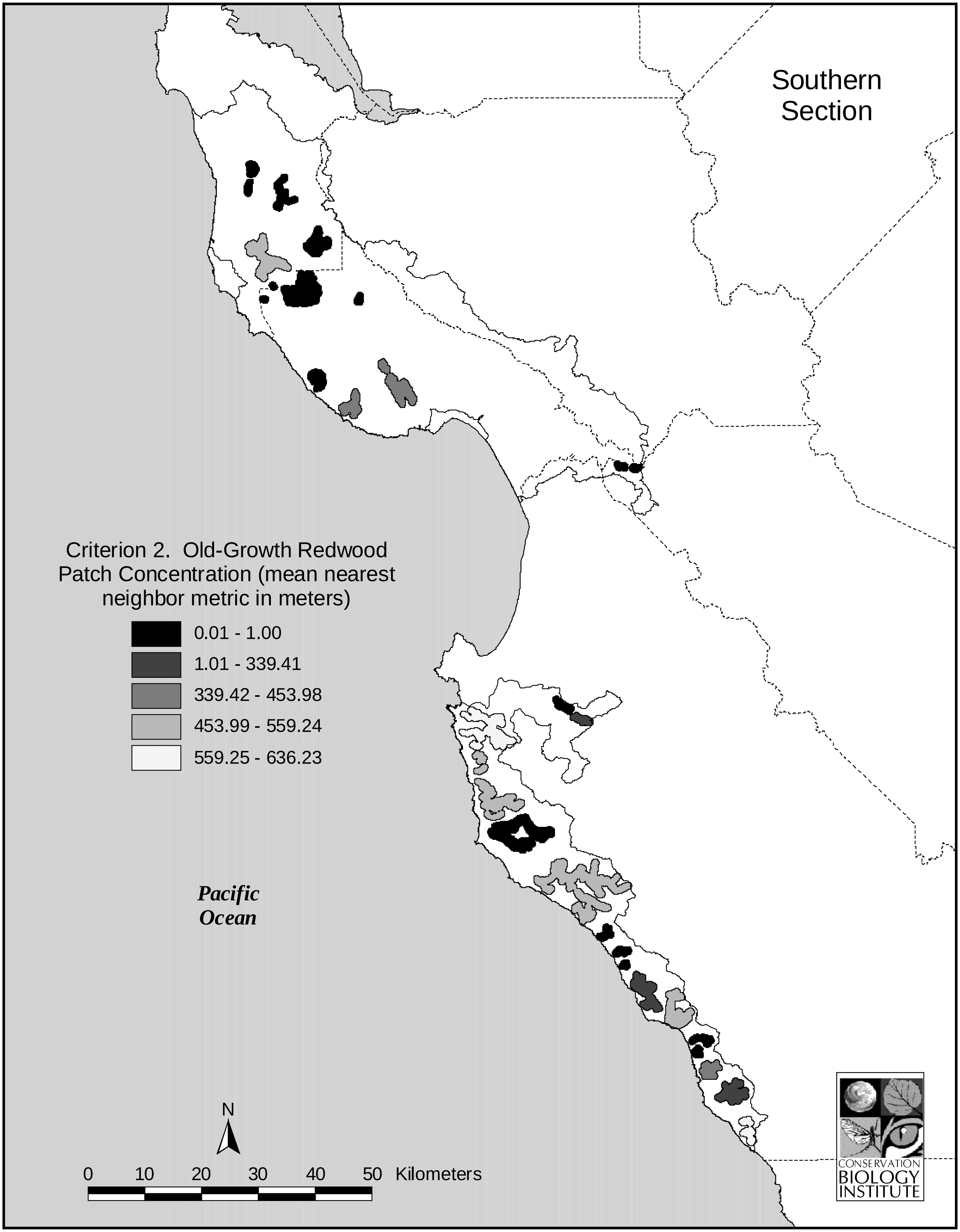

Figure 8. Old-growth redwood patch concentration for the southern section.

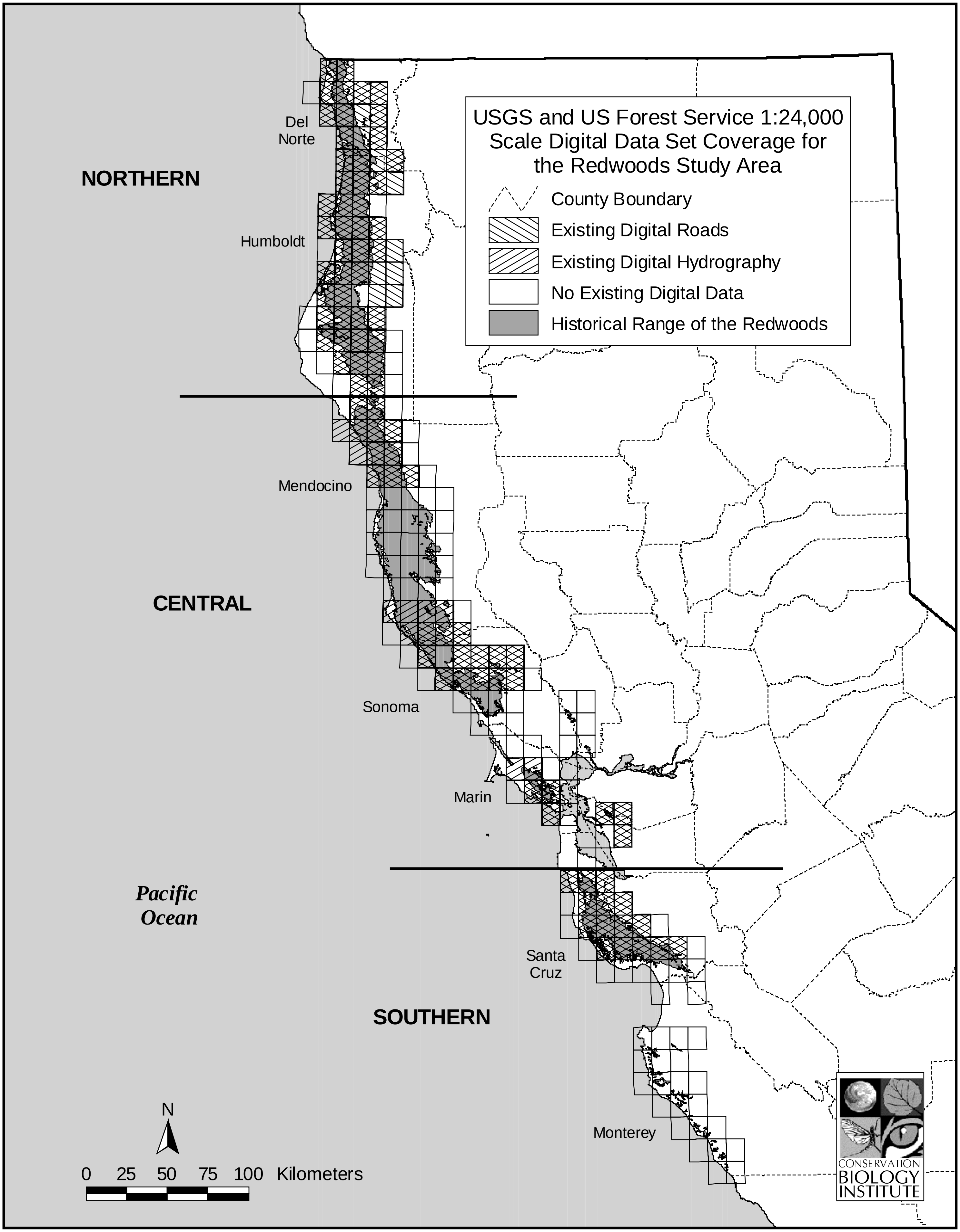

Figure 9. US Geological Survey and US Forest Service 1:24,00 scale digital data set coverage for the redwoods study area.

Results:

Figures 10 – 12 show the road density results for each of the sections. Note that the darker the color, the higher the conservation value. The ordinal numbering are therefore reversed for this criterion [black (0.0 – 0.5 km/ km^2) has an ordinal score of "5"]. Also note that the cell sizes appear different on the three maps – this is because the rendered scale for each section was different. The analysis grid cell size was identical (1km x 1km) for all sections.

Discussion:

This criterion worked very well keeping in mind that the data is not consistent temporally throughout the region. It appears that there are some roads missing from the 1:24,000 data that are currently present on the 1:100,000 road data, however, there are other areas where the 1:24,000 is significantly more detailed. This is due to the fact that the latter is updated more uniformly and regularly than the more detailed map series. Although it would seem reasonable to merge 1:100,000 scale data from areas with roads missing in the 1:24,000 scale data, merging data layers for the same feature using different map scales is not a technique normally considered valid. Thus, the 1:24,000 scale data layer was the only scale used.

Criterion #4 – Location of Imperiled Species [Patch Function]

Rationale:

Known locations of element occurrences of imperiled species are well accepted as areas for conservation emphasis (Noss and Cooperrider 1994), particularly for those sights that contain species that are endangered globally.

Data Sources:

The most recent copy (January 1999) of the California Natural Diversity Database was obtained from the California Department of Fish and Game.

Methodology:

For this application, we considered all known record locations (points) for threatened and endangered plant and animal species. As with the road density criterion, we first established a 1km x 1km grid cell array over each subregion (making this a patch function) then calculated a heritage record score for each cell. Heritage record scores assigned to each cell were based on the number of records encountered in each cell weighted by their degree of endangerment [the most globally endangered species (G1/G2) were given a weighted score of "50," state endangered species (S1/S2) were given a weighted score of "10," and all other records were counted as "1"]. No attempt was made to subdivide the heritage data into taxonomic group or by redwood dependent/independent species.

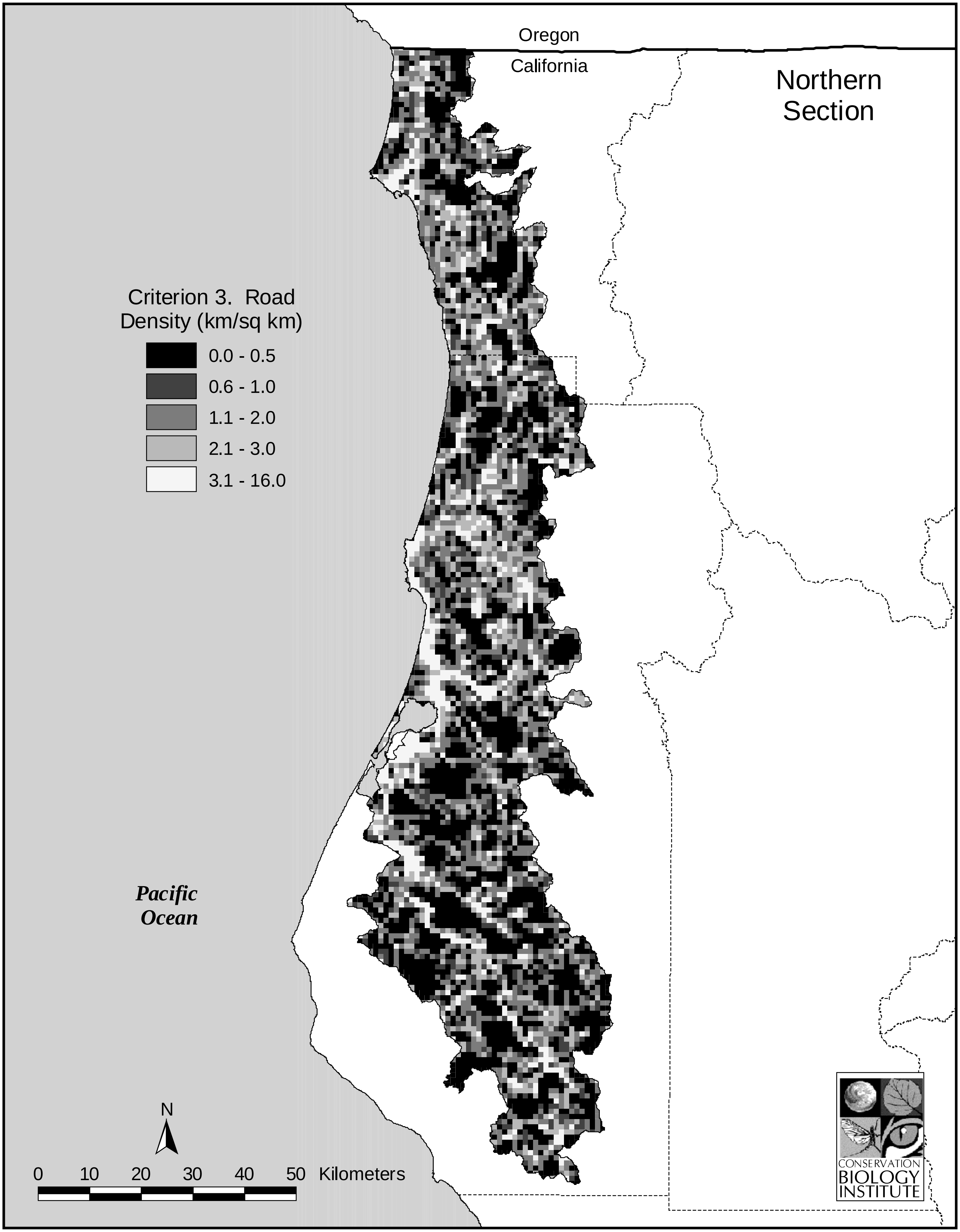

Figure 10. Road density for the northern section.

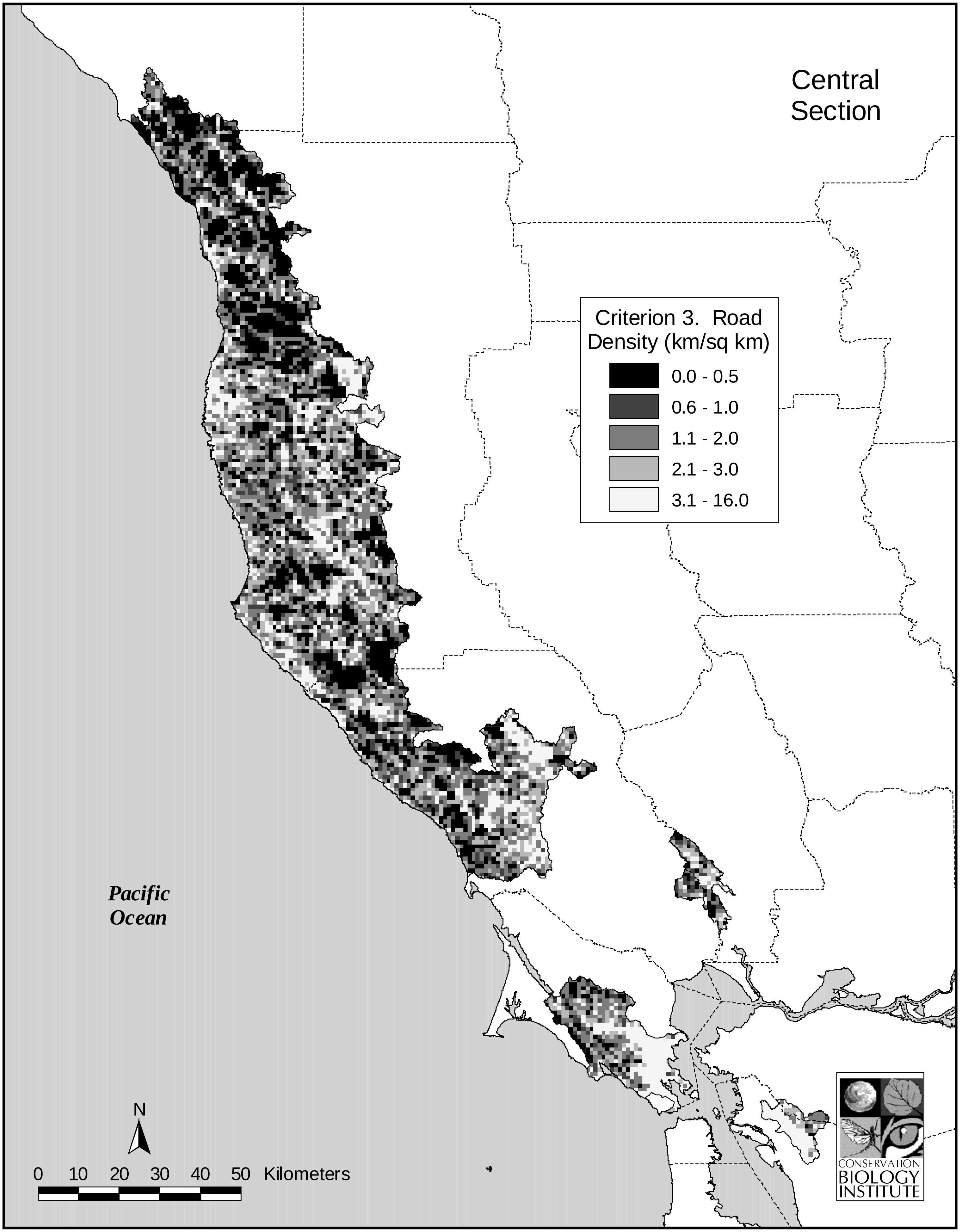

Figure 11. Road density for the central section.

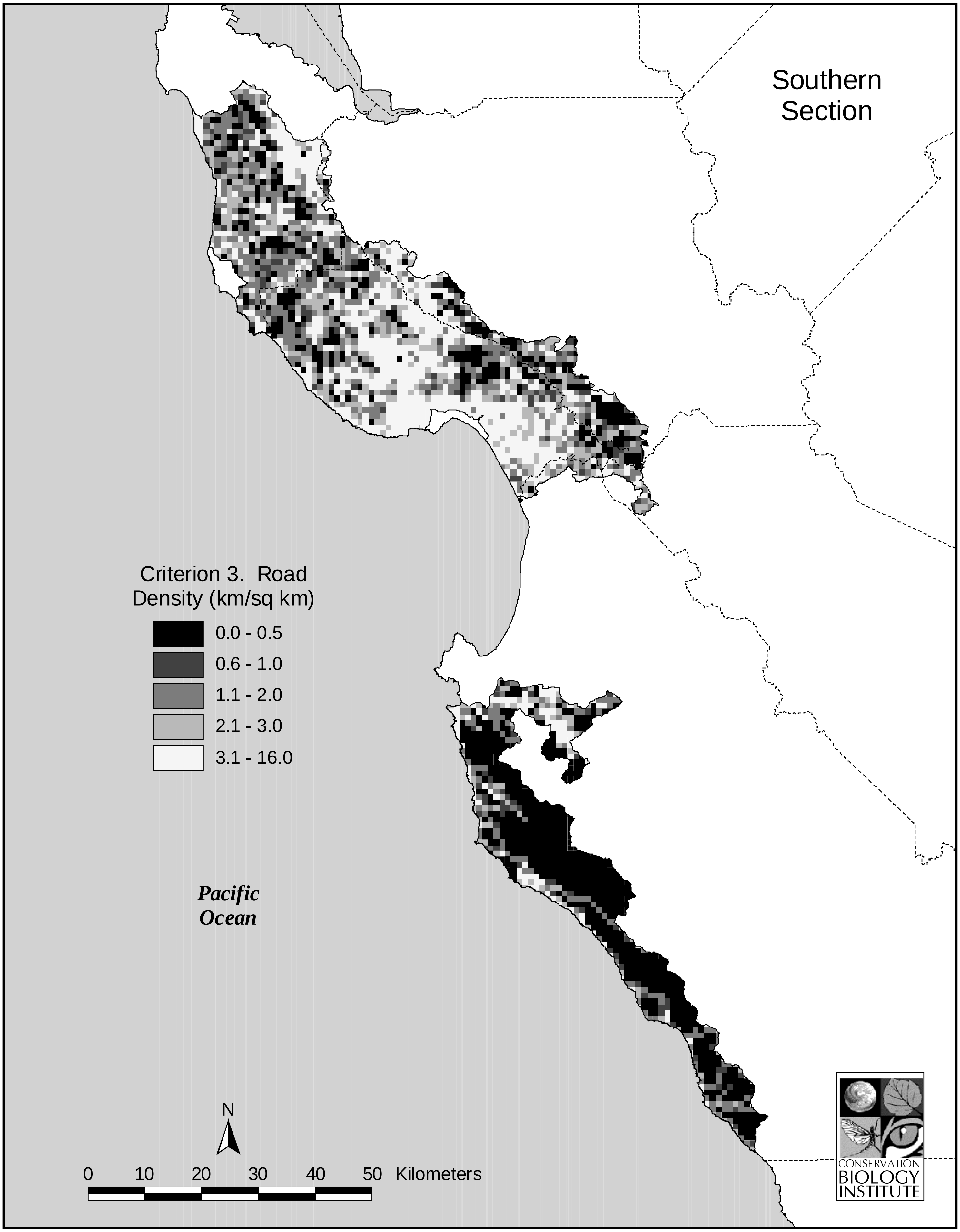

Figure 12. Road density for the southern section.

Results:

Figures 13 –15 show the heritage results for each section.

Discussion:

An important caveat for interpretation of this criterion is that the best database on imperiled species in the study region – the California Natural Diversity Database – is, like most such databases, incomplete. It contains “white holes” which could be either areas that truly lack imperiled areas or areas where no one has conducted the necessary surveys. Also, the precise locations of imperiled species populations within 1 km x 1 km grid cells become important in the more detailed analyses within focal areas and sites, but was not considered here. It is also important to note that not all, in fact most, heritage occurrence records are not old-growth redwood dependent and that no special effort was made to emphasize these particular species. Also, these databases are not particularly strong when it comes to aquatic organisms. Much more work is needed on the aquatics.

Criterion #5 – Forest Neighborhood Age [Neighborhood Function]

Rationale:

An ideal conservation strategy for redwoods would maintain an ecological mosaic with all successional stages of redwood and associated habitat types included in natural patterns of distribution and juxtaposition. Such a mosaic can only be achieved at a landscape level. Considering the historic trend of loss of old-growth redwoods, late-successional redwood forests generally have greater conservation value today than younger forests, certainly at the stand level, but also at the broader landscape level when identifying conservation focal areas. Furthermore, the age of surrounding forest patches is likely to influence, through metapopulation dynamics, the population viability of late-successional species within a given forest patch.

Data Sources:

In order to produce a forest age data layer for the entire redwood range, we had to include information from 4 different sources. Data sources included the Pacific Biodiversity Institute’s old growth coverage (PBI), 30 meter resolution Landsat TM data classified by Legacy (TM), tree habitat information from the CA Dept. of Forestry & Fire Protection (CDF), and general vegetation information from the CA GAP program. Mapping forest age, whether attempted through tree coring or remote sensing, is extremely difficult over large areas. While not perfect, tree size is often used as a surrogate for tree age, which is what we used to produce the basic data layer used in Criterion #5. Ideally, size information would be available from one source and the resolution of the data would be sufficient to address the particular question. Unfortunately, we could not get consistent coverage for the entire redwood study area.

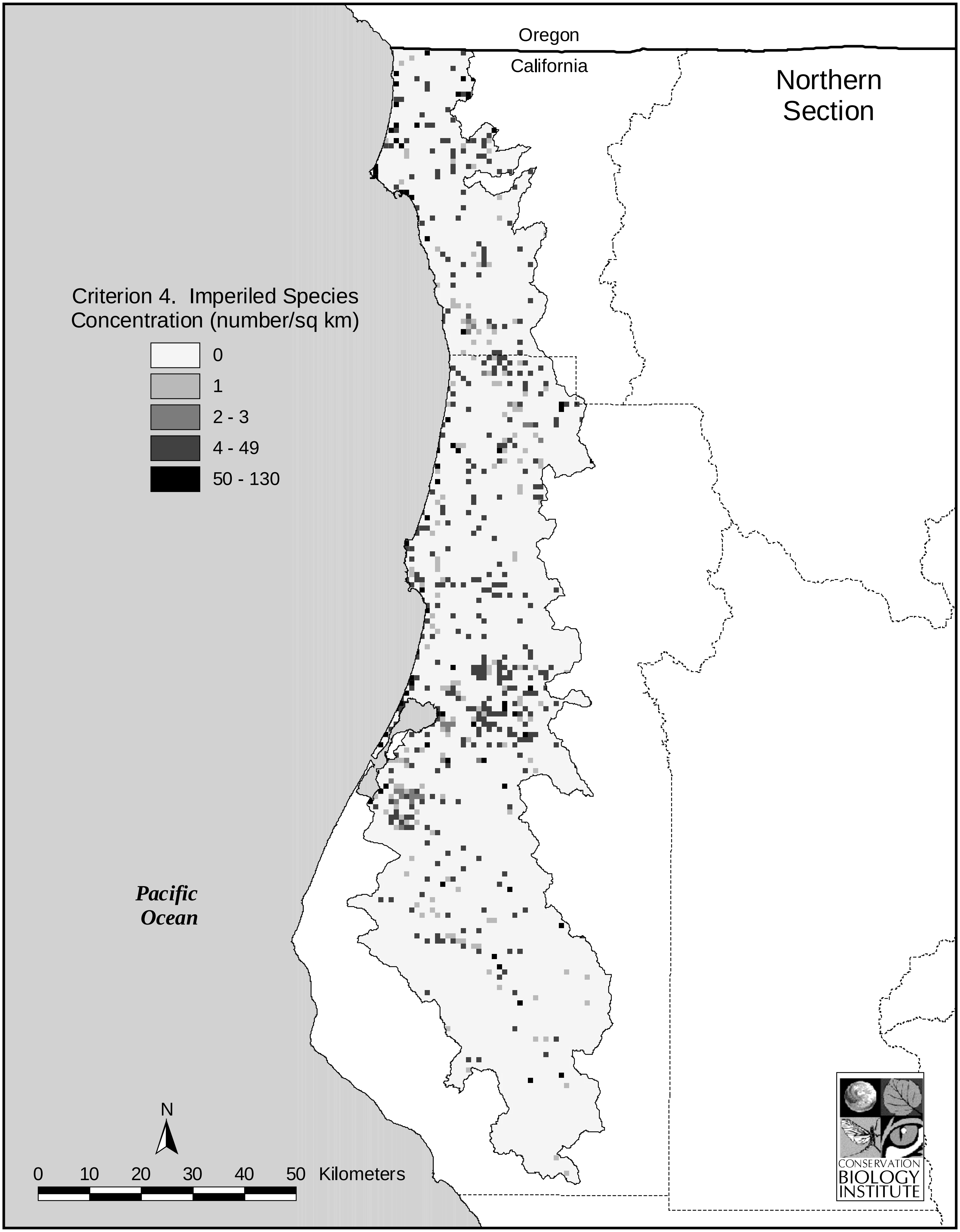

Figure 13. Imperiled species concentration for the northern section.

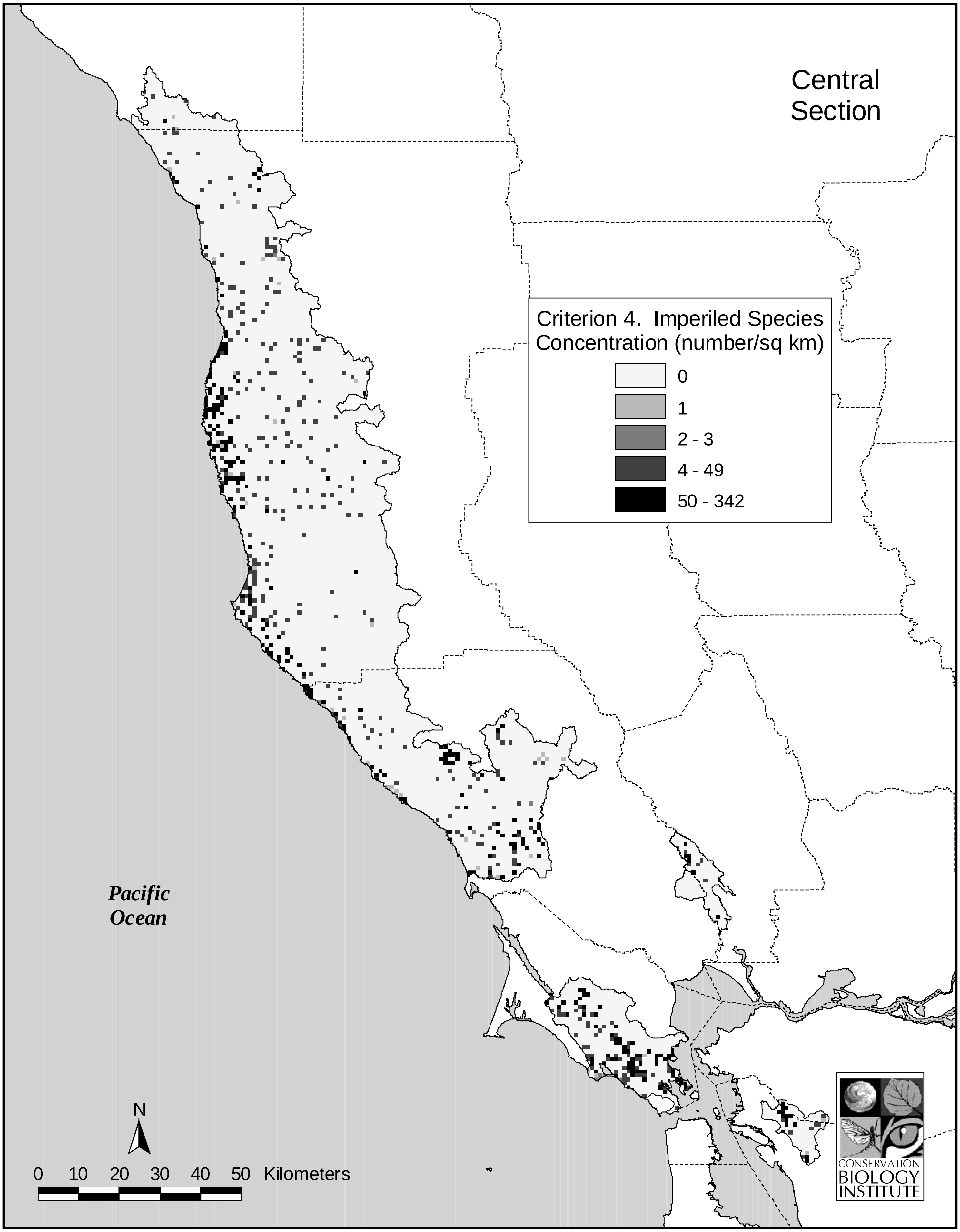

Figure 14. Imperiled species concentration for the central section.

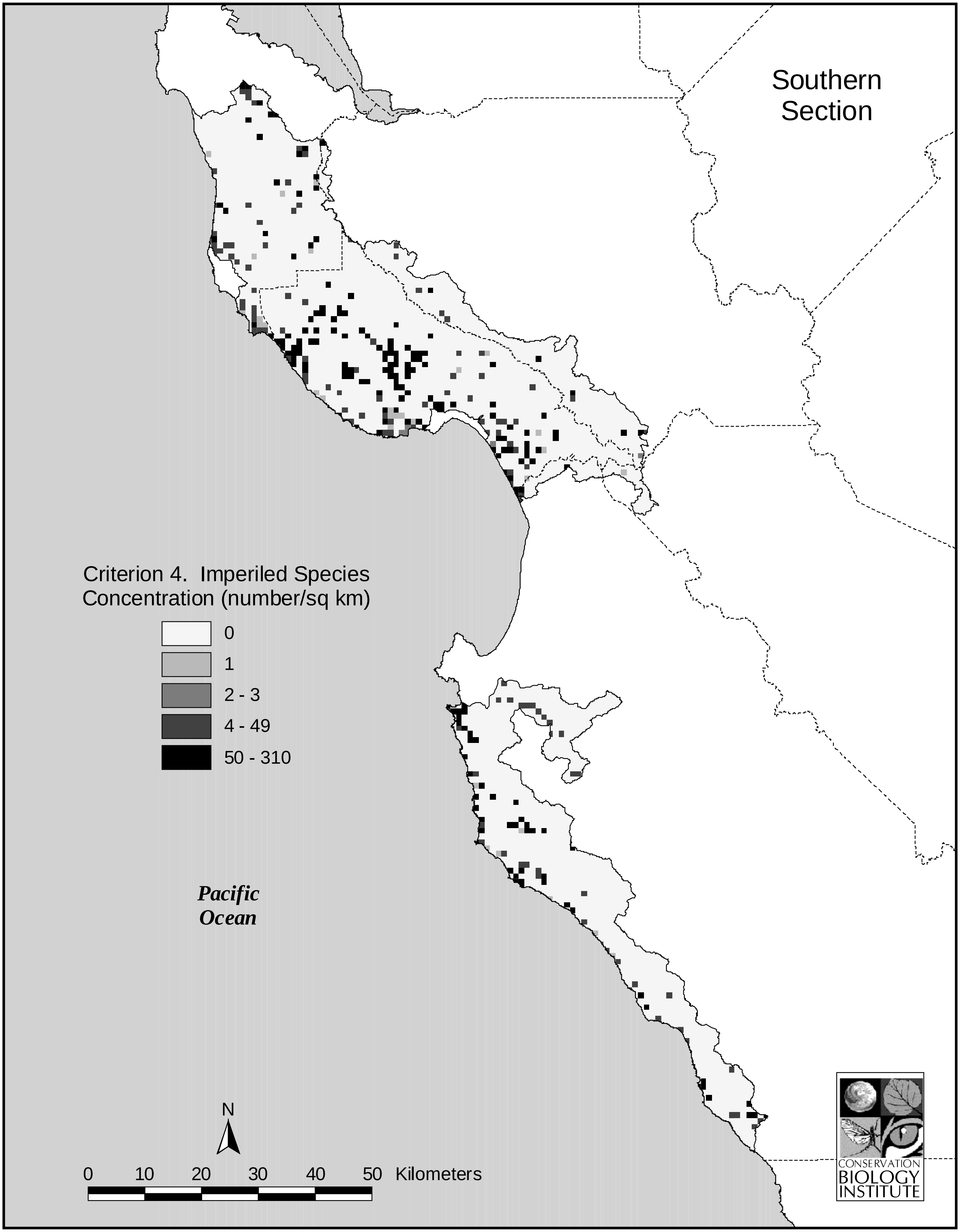

Figure 15. Imperiled species concentration for the southern section.

The northern section and approximately 90% of the central section contained reliable size class data from two sources (PBI and TM). The PBI data containing only the oldest forest patches covered the entire redwood range and was used in all the sections. Unfortunately, the TM data did not extend below the southernmost portion of the central section. For the remainder of the central section and for all the southern section, we had to rely primarily on a combination of CDF and CA GAP data, which resulted in a poorer quality data layer upon which to base this criterion.

<u>Methodology</u>:

For the area covered by TM imagery, we first assigned age class data to the tree size categories (1 = non-forest, 2 = 1”-11” diameter, 3 = 11”-36” diameter, 4 = >36” diameter). We then updated the TM-based data layer by adding the PBI old-growth forest data layer and assigned all the PBI patches with an age class of “5” representing the oldest forest. For the small area of the central section and all the southern section, we assigned age class codes 1-4 to the areas covered by the CDF data layer (using the same tree size categories as reviewed above). The PBI data layer was used to update the CDF data layer and again assigned an age class of “5” for the relatively small area not covered by either the PBI or CDF data layers (areas within the subwatershed basins, but not in mapped redwood range), we were forced to use the CA GAP vegetation layer, which did not contain tree size information. We were able to identify the non-forested portions of the data layer based on the WHR (wildlife habitat relationship) codes and assigned those regions to an age class of “1.” For the others, we simply assigned an age class of “2” to all of the remaining forested areas. Even though the class codes used for setting up this criterion ranged from 1-5, these were not used directly as the final criterion input.

These resulting age data layers for each section were vector-based. Each file was converted to a raster-based (or grid) file with 30-meter resolution. A 1km x 1km moving window was then applied to each grid to calculate the mean forest age for the section. The resulting means were then broken out into 5 equal interval classes (1-1.8 = “1”, 1.8-2.6 = “2”, 2.6 – 3.4 = “3”, 3.4-4.2 = “4”, and 4.2-5.0 = “5”).

<u>Results</u>:

Figures 16 – 18 show the results for Criterion #5 for each of the three sections. The northern section (Figure 16), which was made from the highest quality datasets and the largest amount of old growth, showed the greatest age distribution diversity. The large areas of young forest in the northern and central sections (Figure 16 and Figure 17 respectively) reflect the widespread high redwood harvest levels from the last few decades. The more generalized outcome shown in Figure 18 is reflective of the more generalized datasets that went into this criterion for this section.

<u>Discussion</u>:

This criterion is a powerful addition in the model, for it puts every location in the study area into a relative age context. Of course, this data layer is only as good as the size/age

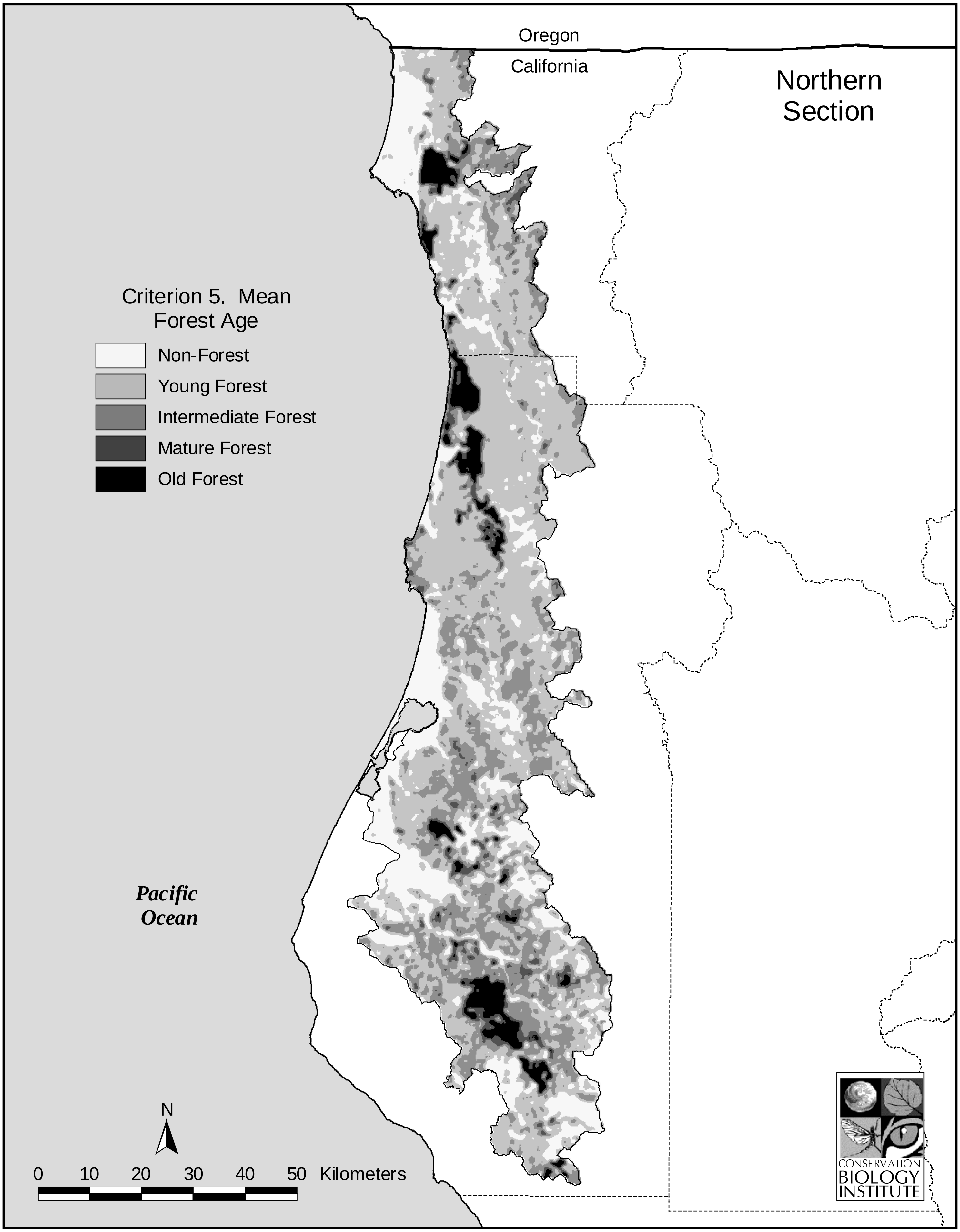

Figure 16. Mean forest age for the northern section.

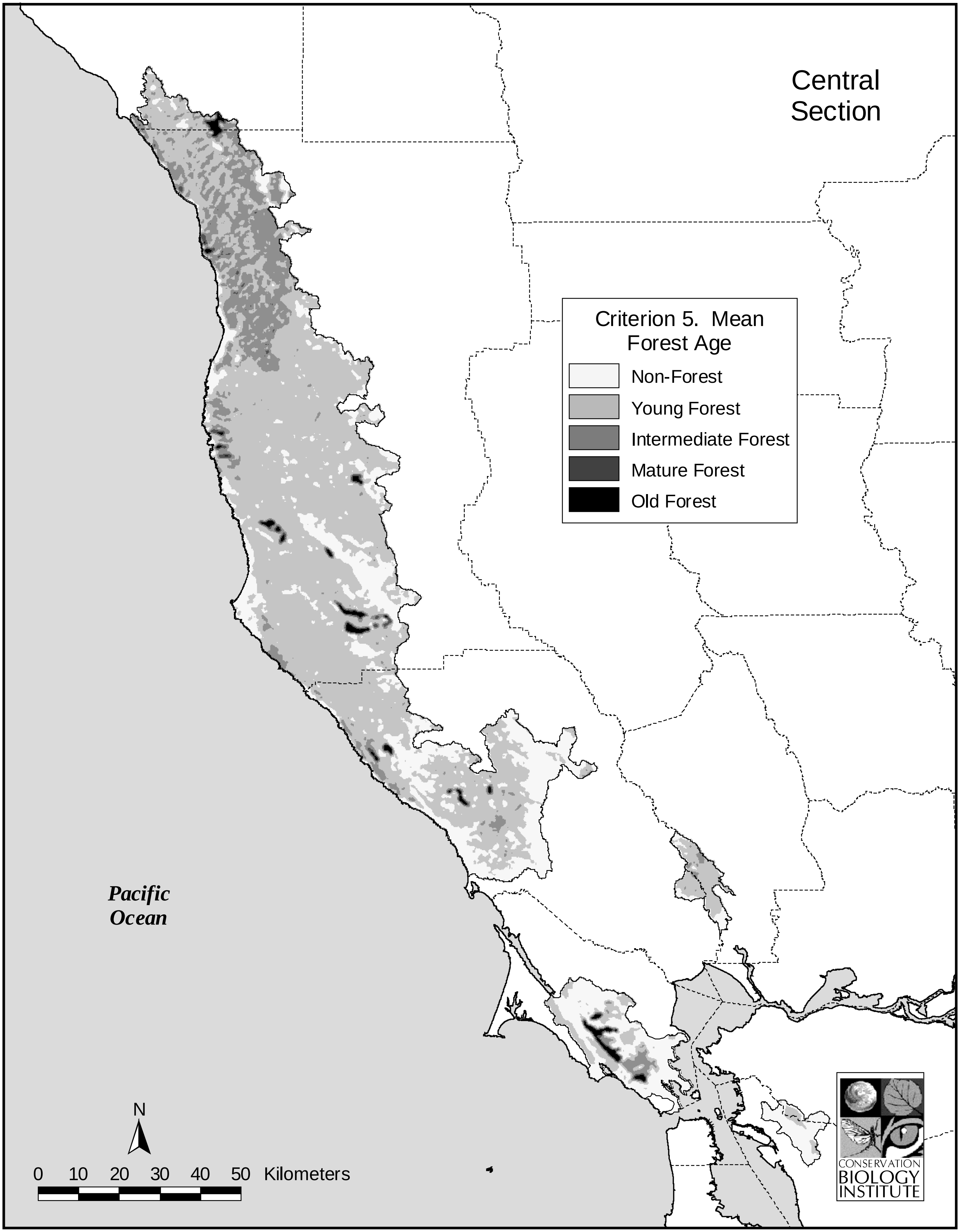

Figure 17. Mean forest age for the central section.

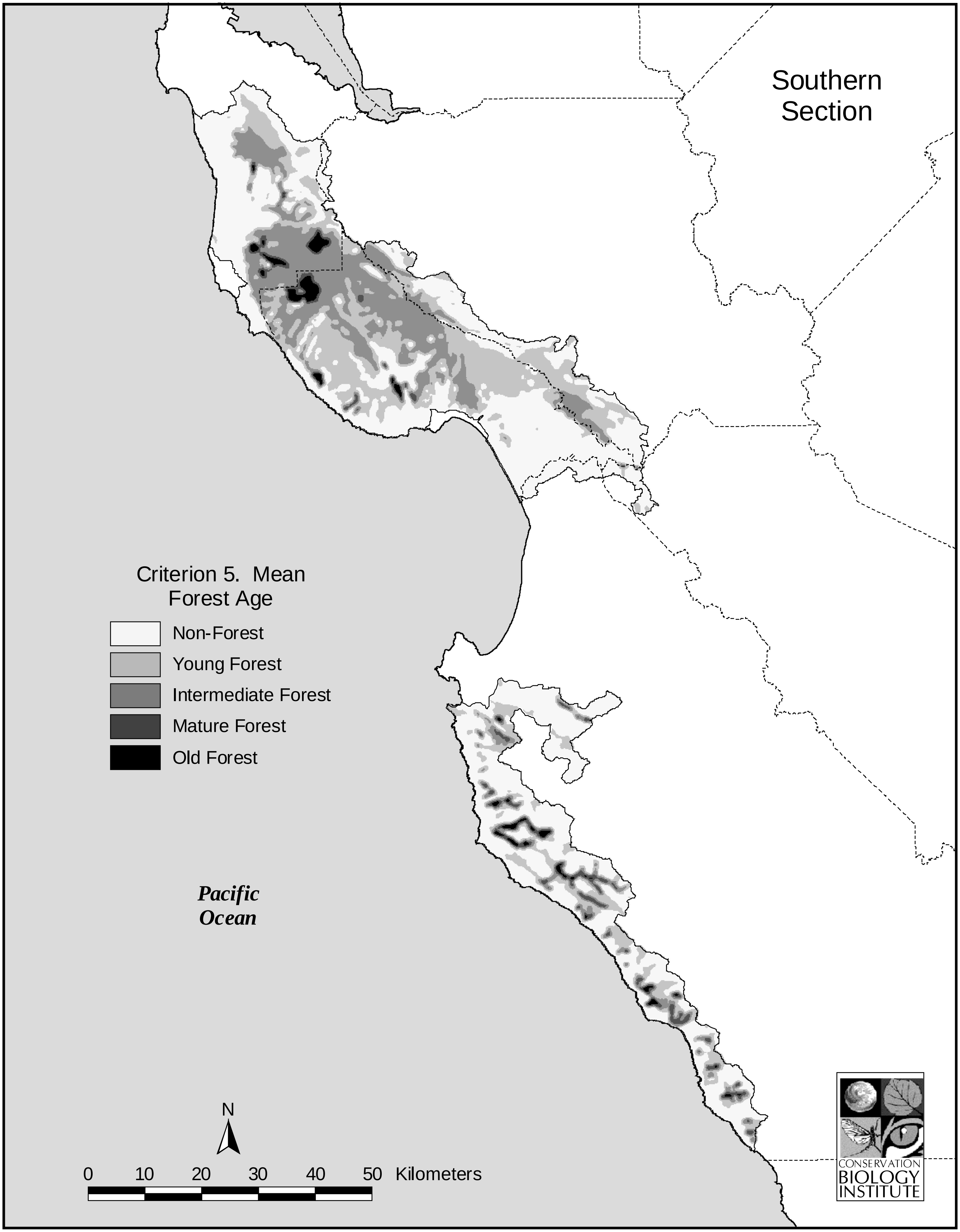

Figure 18. Mean forest age for the southern section.

data that went into it. Differences in quality are clearly illustrated when you compare the northern section (Figure 16) and southern section (Figure 18) results. Improving fundamental datasets will remain an ongoing concern for the redwoods and most other regions as well. Improving this model and our ability to accurately describe the natural landscape in a spatially explicit way will always be of paramount importance. Not only does high quality data provide the necessary scientific information needed to support particular advocacy activities, but it is also fundamental to our understanding of what will be required to protect fully functional natural ecosystems.

Criterion #6 – Forest Fragmentation [Neighborhood Function]

Rationale:

Studies in many regions have implicated anthropogenic habitat fragmentation as one of the greatest threats to biodiversity, particularly in forested ecosystems (Noss and Csuti 1997). Evaluating relative fragmentation is therefore important in any modeling exercise that attempts to identify general areas of overall conservation value.

Data Sources:

This criterion is based on two primary data sources: (1) composite forest age layer from Criterion #5 and (2) roads data from Criterion #3.

Methodology:

The first step in producing this criterion was to define the landscapes upon which to run FRAGSTATS, a fragmentation assessment software package (see McGarigal and Marks 1995). We buffered the 1:24,000 scale roads data layer by 50 meters to create initial unroaded areas in each of the redwood sections. All areas with <500 ac (or 202.35 ha) were removed from the data layer to create the final areas used for analysis. These areas were defined as "landscape units," and FRAGSTATS was run on each one individually with the forest age layer from Criterion #5 as the input data file used to define the patch types (age classes 1 – 5) within each landscape unit.

Four fragmentation metrics were chosen from the approximately 60 generated by FRAGSTATS and combined to form an overall fragmentation score. FRAGSTATS calculates metrics on three different categories: patch, class, and landscape. For this criterion, the four fragmentation metrics chosen were all from the landscape category and included: (1) mean nearest neighbor (meters), (2) mean core area per patch (hectares), (3) interspersion and juxtaposition (percent), and (4) area weighted mean shape index (no units).

Mean nearest neighbor (MNN) was calculated using the following formula and is based on the nearest edge-to-edge distance between like patches,

$$MNN = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n'} h_{ij}}{N'}$$

m = number of patch types (classes) present in the landscape, excluding the landscape border if present.

$n' = n'_i$ = number of patches in the landscape of patch type (class) i that have nearest neighbors.

h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type (class).

i = 1, … , m or m′ patch types (classes). j = 1, … , n patches.

N′ = total number of patches in the landscape that have nearest neighbors.

Range: MNN > 0, without limit.

Core area is determined by three factors, the first of which is the shape complexity of a patch, second is the size of the patch, and third is the user defined edge effects distance. For this model, edge effects distance was set at 90 meters. Mean core area per patch (MCA1) measures the average core area for all core areas within each patch, not the average size of individual core areas. MCA1 is equal to zero when there is no core area. Formula expression is as follows,

$$MCA1 = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}^{c}}{N} (1/10{,}000)$$

$n = n_i$ = number of patches in the landscape of patch type (class) i.

a_{ij}^{c} = core area (m^2) of patch ij based on specified buffer width (m).

N = total number of patches in the landscape, excluding any background patches.

Range: MCA1 $\geq$ 0, without limit.

The interspersion and juxtaposition index (IJI) measures overall landscape configuration and is represented by the formula,

$$IJI = \frac{-\sum_{i=1}^{m'} \sum_{k=i+1}^{m'} \left[\left(\frac{e_{ik}}{E}\right) \ln\left(\frac{e_{jk}}{E}\right)\right]}{\ln(½[m'(m'-1])} (100)$$

m′ = number of patch types (classes) present in the landscape, including the landscape border if present.

e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k; includes landscape boundary segments representing true edge only involving patch type i.

E = total length of edge (m) in landscape; only boundary segments representing true edge are included.

k = 1, … , m or m′ patch types (classes).

Range: $0 < IJI \leq 100$

Area weighted mean shape index measures the average complexity of patch shape compared to a standard (in this case a square cell) weighted according to overall size – larger patches are weighted more heavily than smaller ones. The formula for this metric is,

$$AWMSI = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\left(\frac{0.25 p_{ij}}{\sqrt{a_{ij}}} \right) \left(\frac{a_{ij}}{A} \right) \right)$$

p_{ij} = perimeter (m) of patch ij.
a_{ij} = area (m^2) of patch ij.
A = total landscape area (m^2).
Range: AWMSI ≥ 1, without limit.

Results for each component were ordered into five classes using an equal area technique. The ordinal scores (1-5) for each of the four metrics were then added together and ordered again into five classes (1-5) becoming the final scoring for this criterion.

Results:

Tables 3-5 provide the actual values that went into producing Criterion #6 for the focal areas model. Total number of landscapes defined for the northern section was 211, 375 for the central section, and 201 for the southern section. Twenty-four landscapes were dropped from the analysis in the northern section because they fell below the size limit. Forty-four landscapes were dropped from the central section and 140 from the southern section.

Table 3. Fragmentation results for the northern section.

Mean Nearest Neighbor	**Range (meters)**	**Ordinal Score**
	0.01 – 161.8	5
	161.8 – 182.2	4
	182.2 – 196.1	3
	196.1 – 250.3	2
	250.3 – 4,335.5	1
Mean Core Area	**Range (ha)**	**Ordinal Score**
	0.01 – 8.68	1
	8.68 – 11.64	2
	11.64 – 15.34	3
	15.34 – 21.04	4
	21.04 – 149.45	5
Interspersion & Juxtaposition	**Range (%)**	**Ordinal Score**
	0.01 – 57.13	1
	57.13 – 66.31	2
	66.31 – 75.33	3
	75.33 – 80.56	4
	80.56 – 99.74	5

Area Weighted Mean Shape Index	Range (no units)	Ordinal Score
	1.51 – 2.88	5
	2.88 – 3.54	4
	3.54 – 3.91	3
	3.91 – 4.52	2
	4.52 – 7.38	1
Cumulative Score	**Range**	**Ordinal Score**
Very High Fragmentation	4 – 9	1
High Fragmentation	10 – 12	2
Moderate Fragmentation	13	3
Low Fragmentation	14	4
Very Low Fragmentation	15 –20	5

Table 4. Fragmentation results for the central section.

Mean Nearest Neighbor	Range (meters)	Ordinal Score
	0.01 – 147.6	5
	147.6 – 174.2	4
	174.2 – 194.3	3
	194.3 – 235.9	2
	235.9 – 2,635.9	1
Mean Core Area	**Range (ha)**	**Ordinal Score**
	0.98 – 8.40	1
	8.40 – 11.48	2
	11.48 – 15.65	3
	15.65 – 18.54	4
	18.54 – 257.30	5
Interspersion & Juxtaposition	**Range (%)**	**Ordinal Score**
	0.01 – 39.29	1
	39.29 – 49.58	2
	49.58 – 55.47	3
	55.47 – 68.91	4
	68.91 – 99.90	5
Area Weighted Mean Shape Index	**Range (no units)**	**Ordinal Score**
	1.53 – 3.03	5
	3.03 – 3.79	4
	3.79 – 4.58	3
	4.58 – 6.09	2
	6.09 – 11.15	1

Cumulative Score	**Range**	**Ordinal Score**
Very High Fragmentation	5 – 10	1
High Fragmentation	11 – 12	2
Moderate Fragmentation	13 – 14	3
Low Fragmentation	15	4
Very Low Fragmentation	16 - 18	5

Table 5. Fragmentation results for the southern section.

Mean Nearest Neighbor	**Range (meters)**	**Ordinal Score**
	0.01 – 103.2	5
	103.2 – 171.2	4
	171.2 – 216.2	3
	216.2 – 287.8	2
	287.8 – 2,647.9	1
Mean Core Area	**Range (ha)**	**Ordinal Score**
	2.28 – 39.96	1
	39.96 – 59.98	2
	59.98 – 132.07	3
	132.07 – 151.17	4
	151.17 – 557.00	5
Interspersion & Juxtaposition	**Range (%)**	**Ordinal Score**
	0.01 – 1.00	1
	1.00 – 57.99	2
	57.99 – 78.17	3
	78.17 – 86.49	4
	80.56 – 99.74	5
Area Weighted Mean Shape Index	**Range (no units)**	**Ordinal Score**
	1.49 – 2.47	5
	2.47 – 2.85	4
	2.85 – 3.21	3
	3.21 – 3.49	2
	3.49 – 6.71	1
Cumulative Score	**Range**	**Ordinal Score**
Very High Fragmentation	5 – 10	1
High Fragmentation	11	2
Moderate Fragmentation	12	3
Low Fragmentation	13 - 14	4
Very Low Fragmentation	15 –18	5

Figures 19-21 show the cumulative fragmentation results for each of the three redwood sections.

Discussion:

Designing a criterion that results in one overall fragmentation score was challenging, and further experimentation will likely improve this important component in subsequent focal areas modeling. Metrics were carefully chosen as to not overcomplicate the scoring while at the same time including enough fragmentation indicators to adequately capture landscape differences in a meaningful, quantifiable way.

Note that the southern section was the only one that resulted in very different values for some of the metrics (e.g., mean core area and mean shape index). This is due to the coarser vegetation data that had to be used for this section; therefore, Criterion #6 is not as useful for this section as it is for the others due to the poorer quality of the input data.

Criterion #7 – Potential Connectivity to Existing Protected Areas [Neighborhood Function]

Rationale:

Redwood patches or collections of patches that are adjacent or close to existing protected areas have greater potential for enhancing the ecological integrity of both the existing reserves and the added sites. The same can be said, in some cases, for patches that have high potential to be physically linked to redwood parks, or other secure redwood forests, by strips of habitat through which redwood-associated species will move. Riparian networks and ridge systems (if not compromised too severely by roads) are among the natural connections in landscapes, as they offer a path of least resistance to dispersing animals (Noss and Cooperrider 1994).

Data Sources:

The base layer for this criterion included GAP protection code 1 and 2 lands that were extracted from the CA GAP administrative boundaries data layer (1:100,000). The new Headwaters area protected land was added to this layer from a file produced by Pacific Lumber Company.

Methodology:

The vector-based composite protected areas file was first clipped by each section boundary. Each resulting protected areas file was then analyzed using the "Measure Distance" command to create a raster file of continuous distances from protected areas. Increments of 5,000 meters were then defined and attributed with ordinal scores (1-5) – the closer to existing protected areas, the higher the score.

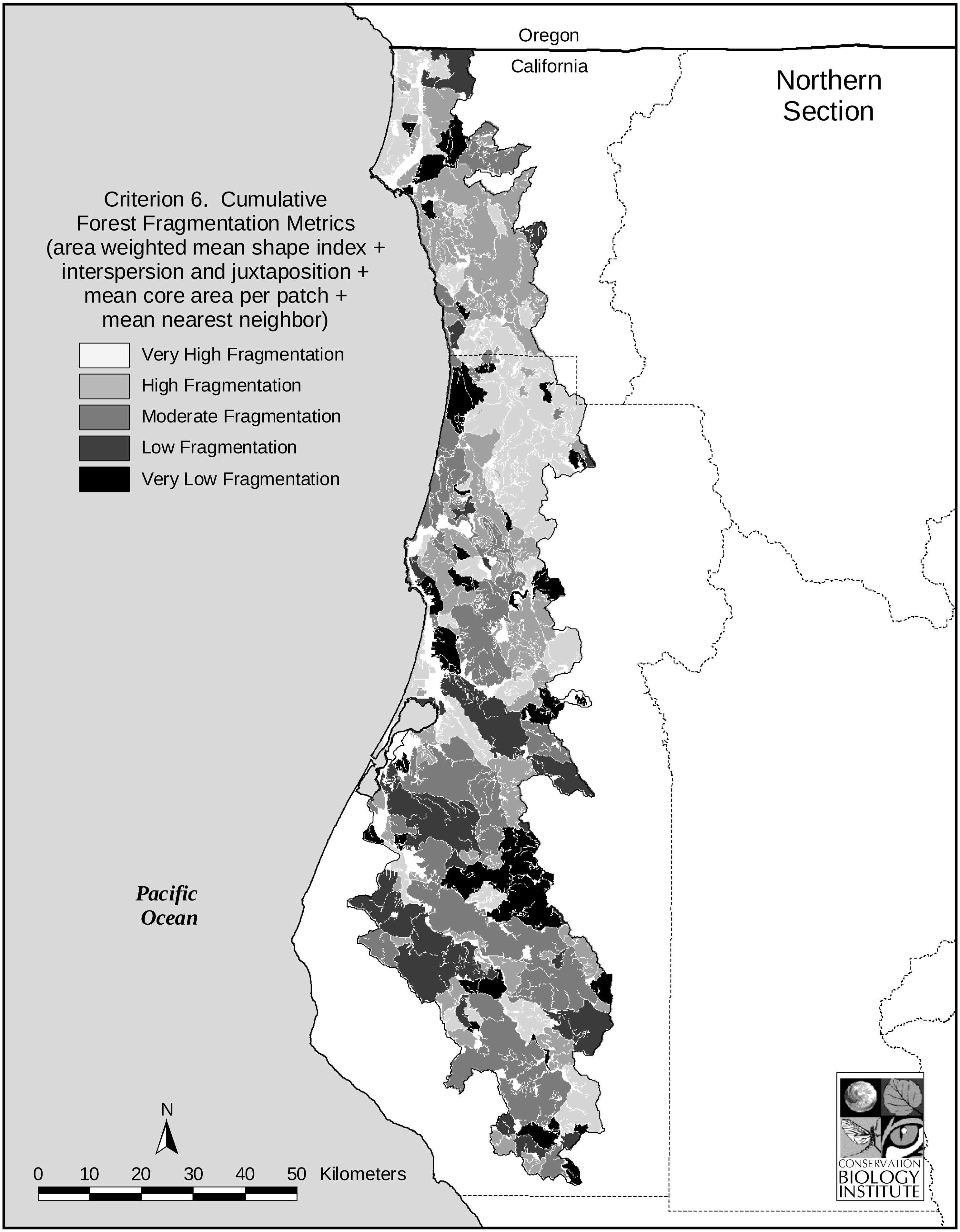

Figure 19. Cumulative forest fragmentation metrics for the northern section.

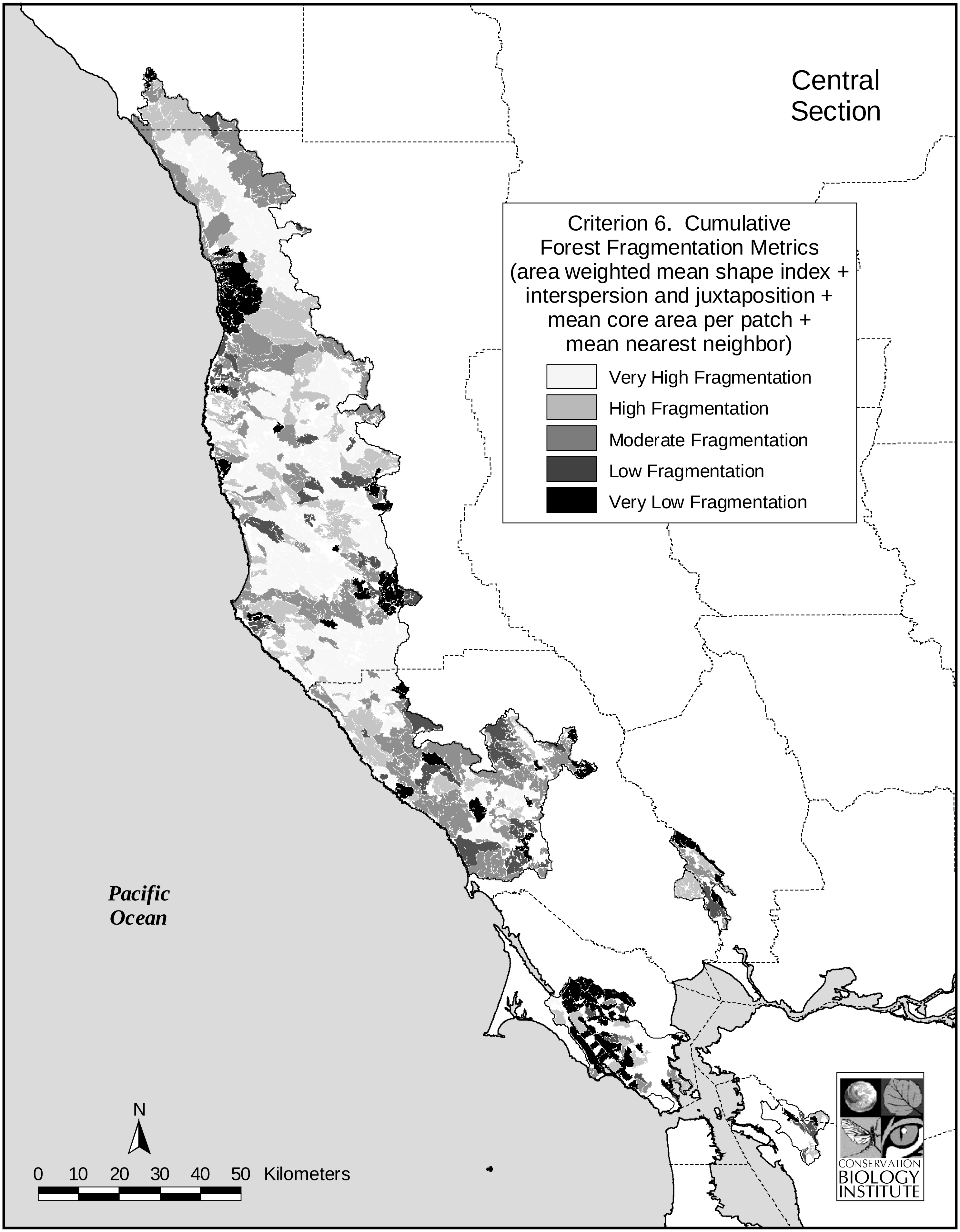

Figure 20. Cumulative forest fragmentation metrics for the central section.

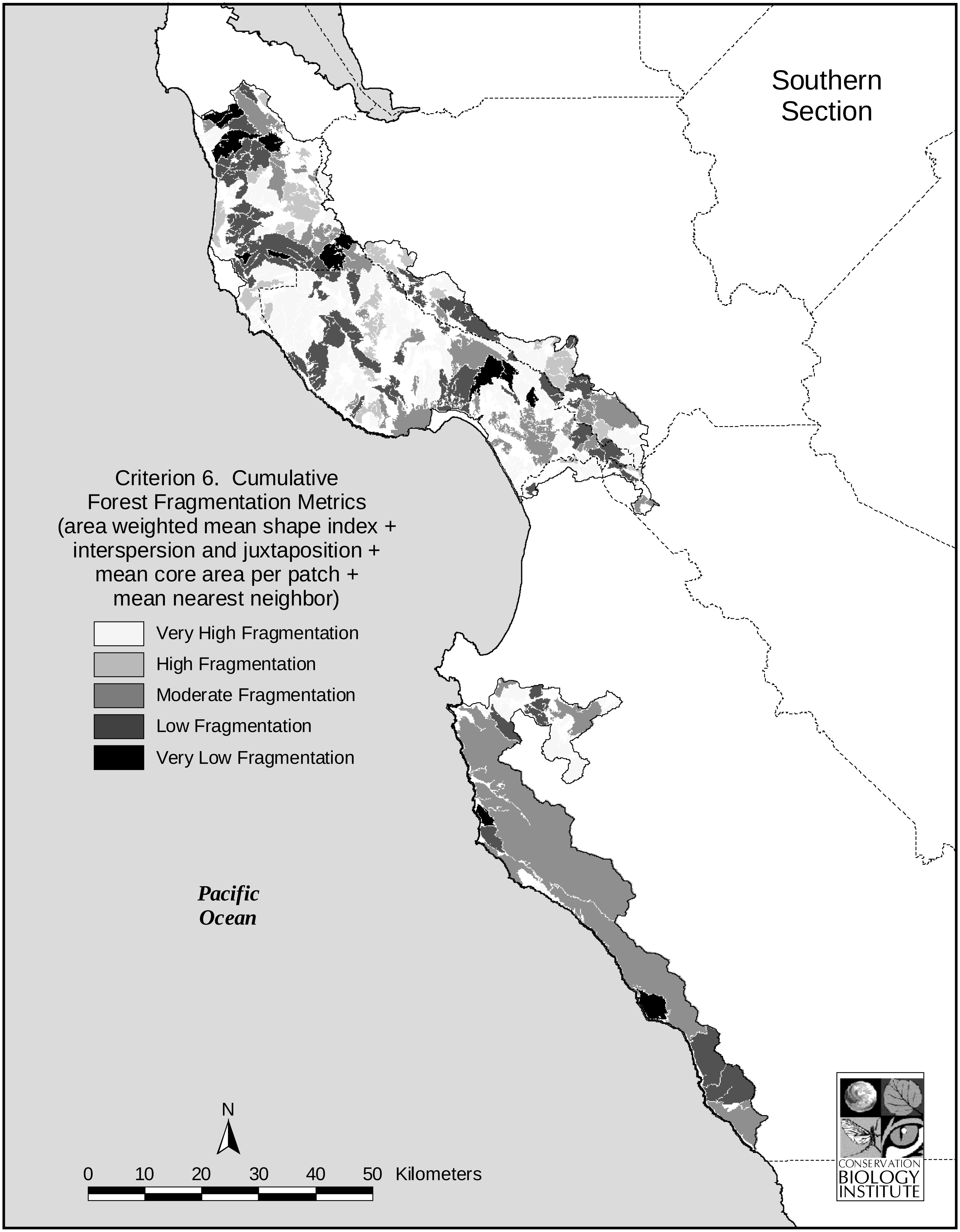

Figure 21. Cumulative forest fragmentation metrics for the southern section.

Results:

Figures 22-24 show the results for each redwoods section.

Discussion:

Examining adjacency to existing protected areas as defined in Criterion #7 was somewhat crude, but adequate at this level of evaluation. Ideally, connectivity should be examined at the next level of detail with specific species in mind and at finer map scales. Only then will the ecological benefits of connectivity be fully realized when applied to regional conservation plans.

Criterion #8 – Road/Stream Intersections [Watershed Function]

Rationale:

This was the first of two criteria that attempted to include indicators of aquatic habitat condition (particularly for salmonids) inside the study area. Road/stream intersections are used to obtain a quantifiable estimate on the potential for each watershed to degrade water quality by contributing sediment to stream channels. The more intersections, the higher the potential for that watershed to experience sedimentation during peak flows.

Data Sources:

CALWATER watersheds (CA Department of Fish and Game) were used as the organizing unit. Data analyzed included 1:24,000 scale roads and streams (U.S. Geological Survey).

Methodology:

Using the CALWATER watersheds for each redwood section in California as the summarizing unit, we calculated the number of road/stream intersections based on 1:24,000 USGS data for both roads and streams. Road surface type (i.e., dirt, gravel, paved) was not used as a factor in the analysis. Ranges of values were assigned ordinal scores using natural breaks.

Results:

Figures 25-27 show the road/stream intersection ranges upon which the ordinal 1-5 values were assigned –the higher the number, the lower the ordinal score.

Discussion:

This criterion could benefit from more timely and complete data for roads and streams. Most of the private timber companies operating in the region have much more complete data on roads and streams, but it is politically difficult to access them. We are certain

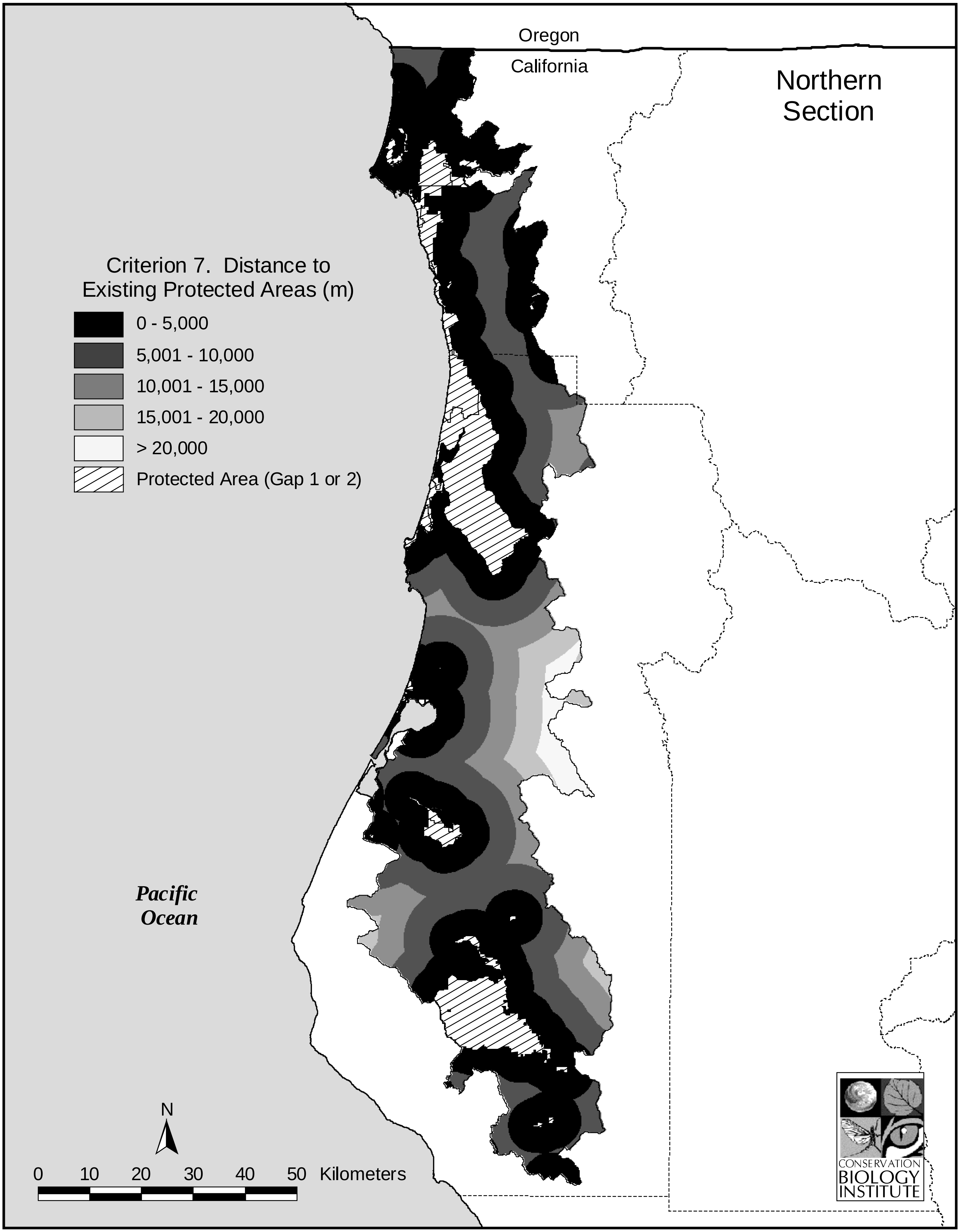

Figure 22. Distance to existing protected areas for the northern section.

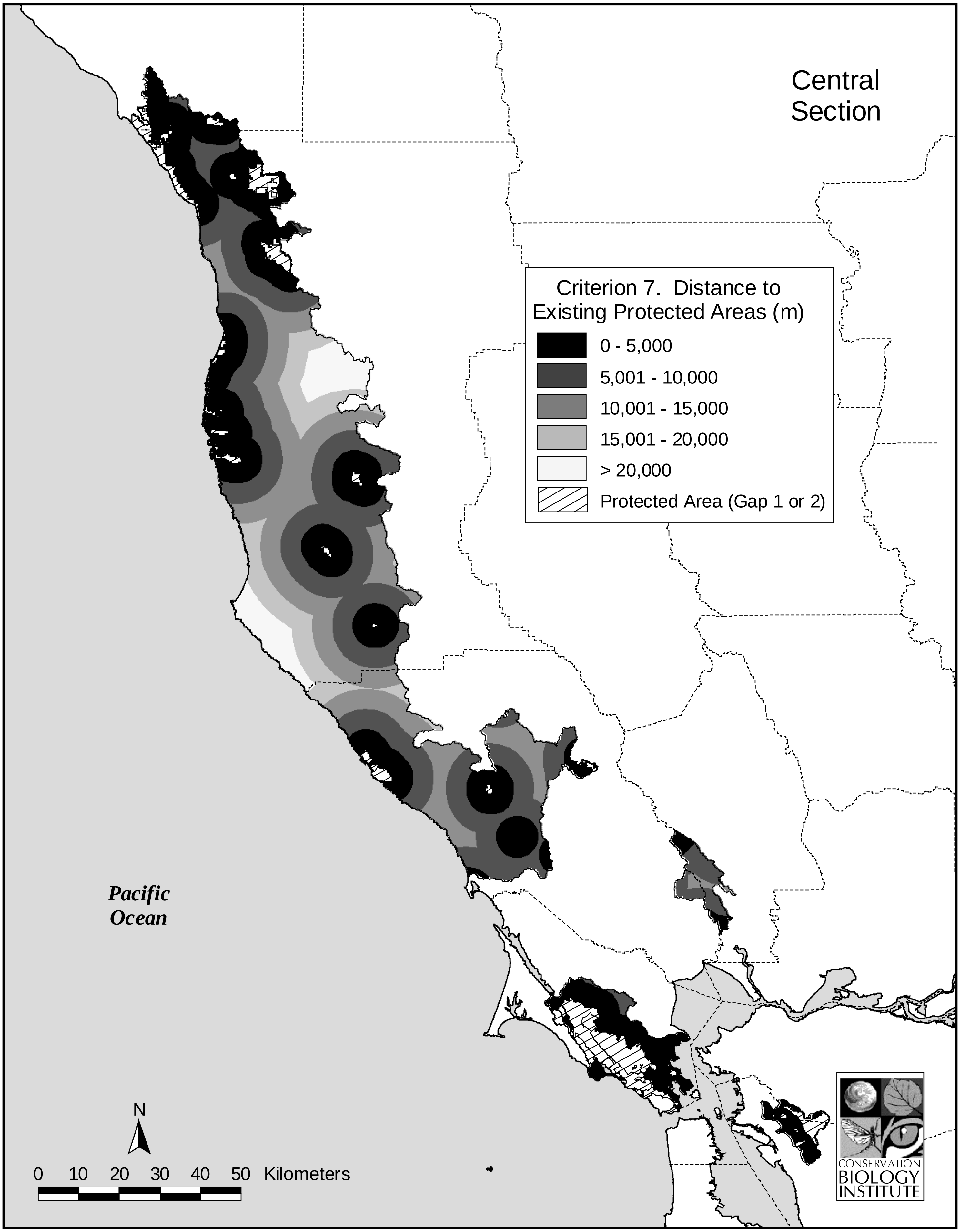

Figure 23. Distance to existing protected areas for the central section.

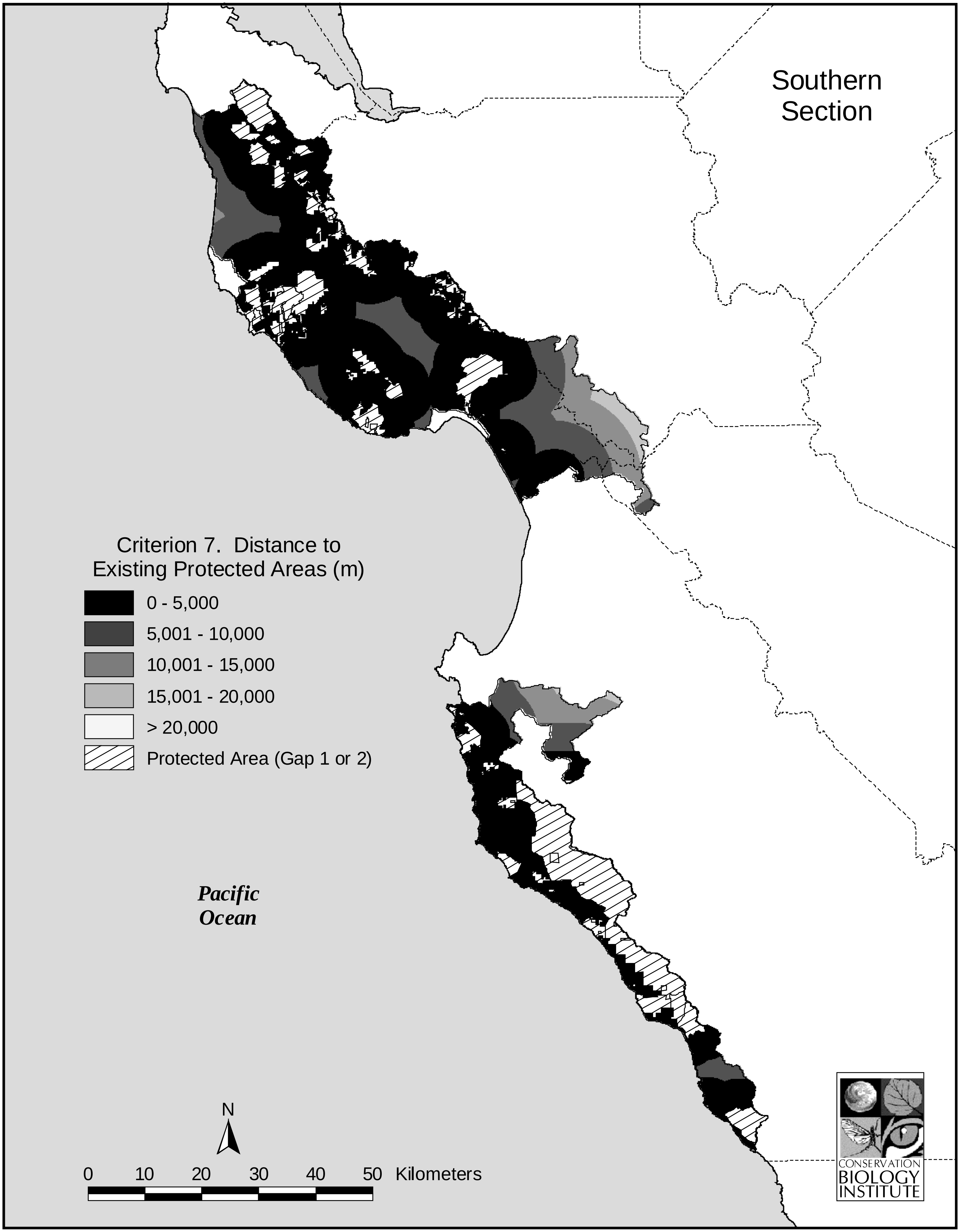

Figure 24. Distance to existing protected areas for the southern section.

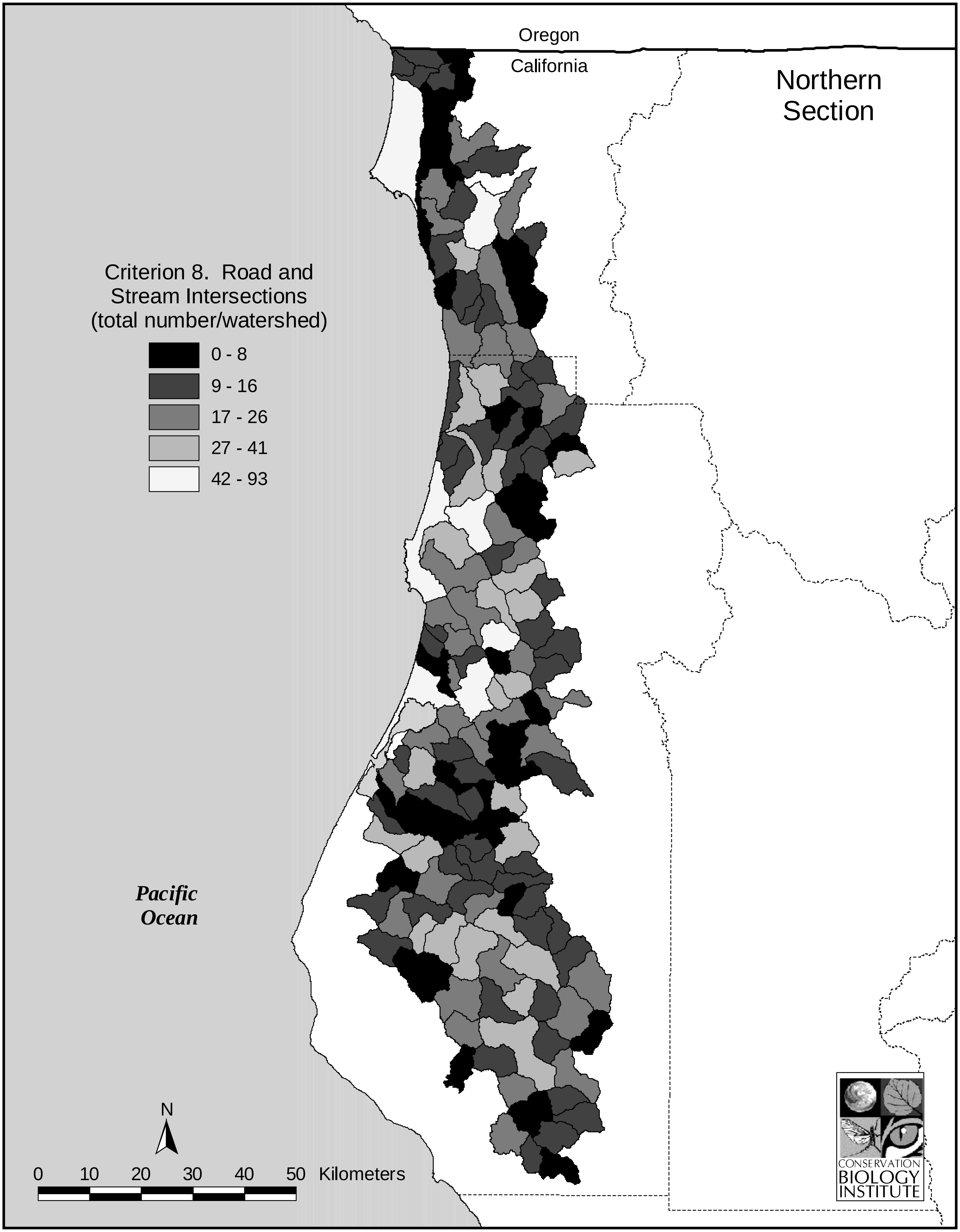

Figure 25. Road and stream intersections for the northern section.

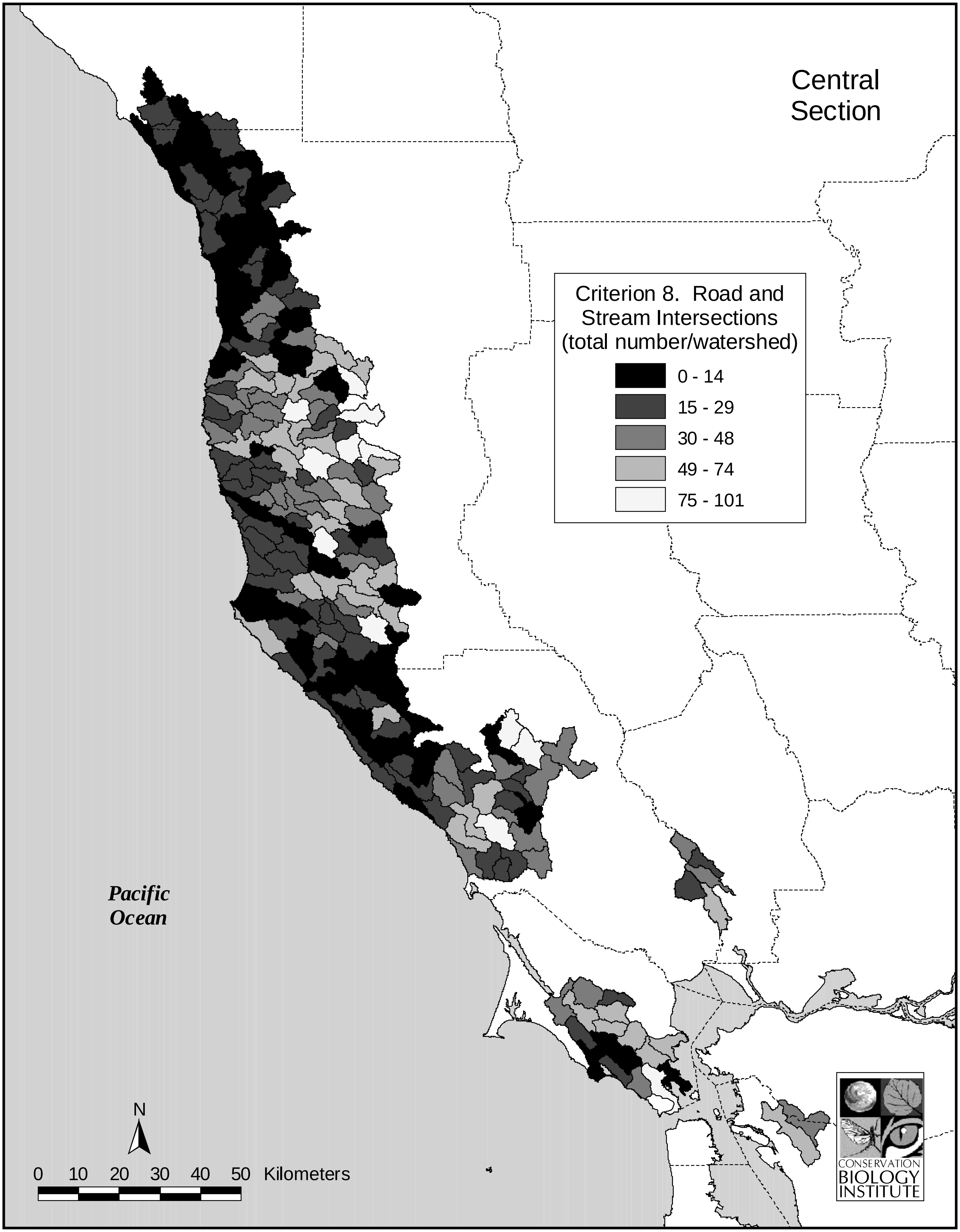

Figure 26. Road and stream intersections for the central section.

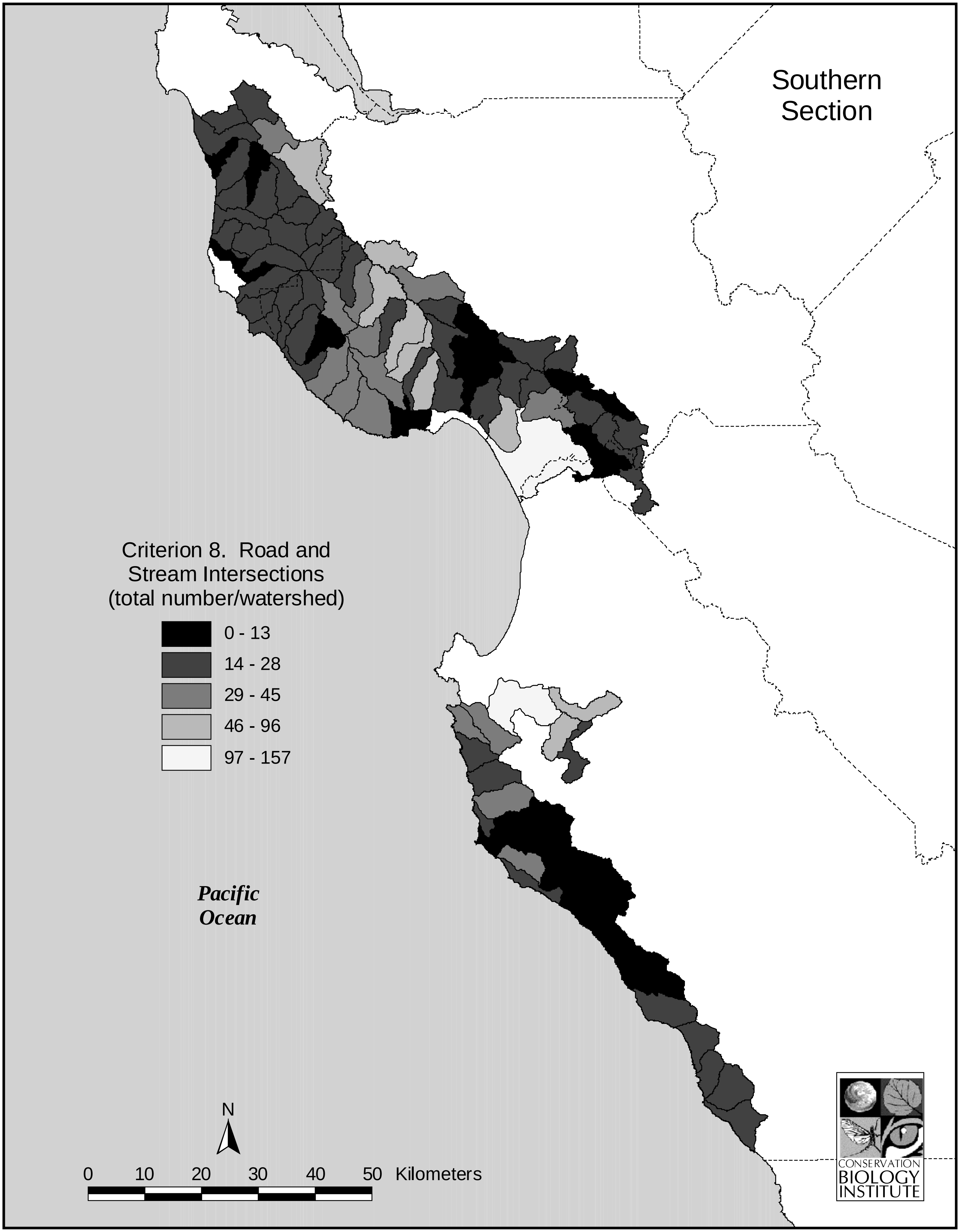

Figure 27. Road and stream intersections for the southern section.

that not all existing roads and streams were accounted for on the U.S. Geological Survey 7.5-minute quadrangle products we had access to (both electronic and paper form). Dates on these quadrangles covered approximately a 30-year time span (late 1960s to late 1990s) and some were still in their provisional state. In spite of this serious shortcoming, we still feel that we have captured enough of the data to make this initial assessment. Hopefully, the deficiencies that do exist are distributed somewhat uniformly across the region – we have no way of knowing at this point. Another issue pertains to road/stream arrangement in more highly developed areas. For some of the more developed watersheds, a low road/stream intersection score does not necessarily reflect potential level of disturbance as we intended. In these areas, some of the minor watercourses have been altered significantly, sometimes in dramatic ways (e.g., burying stream segments under development projects) adding a level of complexity not originally expected. There are a handful of watersheds that were affected in this way in the redwoods. There were so few affected that we did not demote these watersheds in the model, but that could be done in future applications for this or other locations.

Some reviewers cautioned that this criterion might be redundant to road density (criterion #3). We tested this hypothesis by comparing the scored results between road density per watershed and road/stream intersections per watershed. Spearman’s Rank Correlation Coefficient statistical test was applied to the two ranked road results for each redwood section. Table 6 summarizes the statistical correlation values for each redwood section.

Table 6. Spearman’s Rank Correlation Coefficient summaries for the focal areas model.

Redwood Region	Spearman Rho	Prob>|Rho|
Northern Section	0.4449	<.0001
Central Section	0.5221	<.0001
Southern Section	0.6248	<.0001

As a general rule-of-thumb, a strong positive correlation exists when Spearman Rho values range from between 0.8-1.0, moderate positive correlation between 0.5-0.8, and weak positive correlation between 0-0.5. Although each section varies slightly, the results show a somewhat weak correlation between road density and road/stream intersections. All results were found to be highly significant, meaning they are not random events.

Criterion #9 – Forested Riparian Zones [Watershed Function]

Rationale:

In many systems, forested riparian zones help protect the ecological integrity of streams, and this is strongly suspected to be the case for redwoods. The goal here was to quantify the amount of forests along streams summarized on a watershed by watershed basis. The older the mean age of the riparian cover, the higher it scored.

Data Sources:

Data included U.S. Geological Survey 1:24,000 scale streams, the relative forest age data assembled from the various data sources as explained under Criterion #5, and the CALWATER watersheds (CA Department of Fish and Game).

Methodology:

First, the 1:24,000 streams data layer was buffered by 100 meters on both sides of the stream to form a new map layer of the immediate riparian zones. This layer was intersected with the forest age coverage from Criterion #5 to form a new coverage of forested areas within riparian zones. Mean forest age was then calculated within the riparian zones for each subwatershed individually. These mean age values were then assigned ordinal scores using the natural breaks separation algorithm.

Results:

Figures 28 –30 show the results for the mean forest age along riparian zones per watershed. Table 7 lists the actual values for each section that made up the five ordinal classes.

Table 7. Ordinal classes for mean forest age along riparian zones per watershed for each of the three redwood sections.

Redwood Region	**Range**	**Ordinal Score**
Northern Section		
Very low amount of older forest	1.600 - 1.944	1
Low amount of older forest	1.944 - 2.271	2
Moderate amount of older forest	2.271 – 2.604	3
High amount of older forest	2.604 – 2.937	4
Very high amount of older forest	2.937 – 3.386	5
Central Section		
Very low amount of older forest	0.000 – 1.294	1
Low amount of older forest	1.294 – 1.833	2
Moderate amount of older forest	1.833 – 2.195	3
High amount of older forest	2.195 – 2.513	4
Very high amount of older forest	2.513 – 2.926	5
Southern Section		
Very low amount of older forest	0.000 – 0.621	1
Low amount of older forest	0.621 – 1.235	2
Moderate amount of older forest	1.235 – 1.629	3
High amount of older forest	1.629 – 2.024	4
Very high amount of older forest	2.024 – 2.619	5

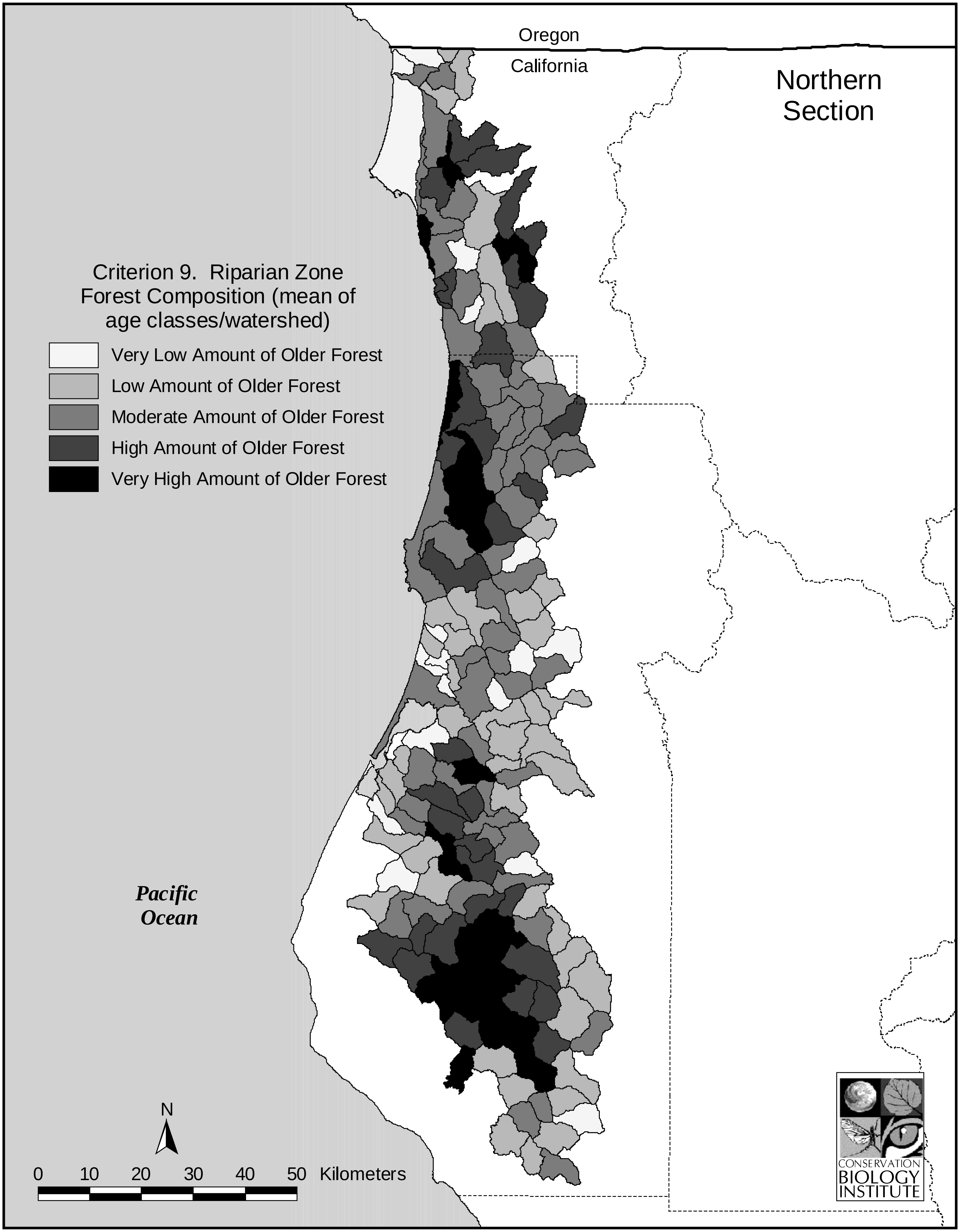

Figure 28. Riparian zone forest composition for the northern section.

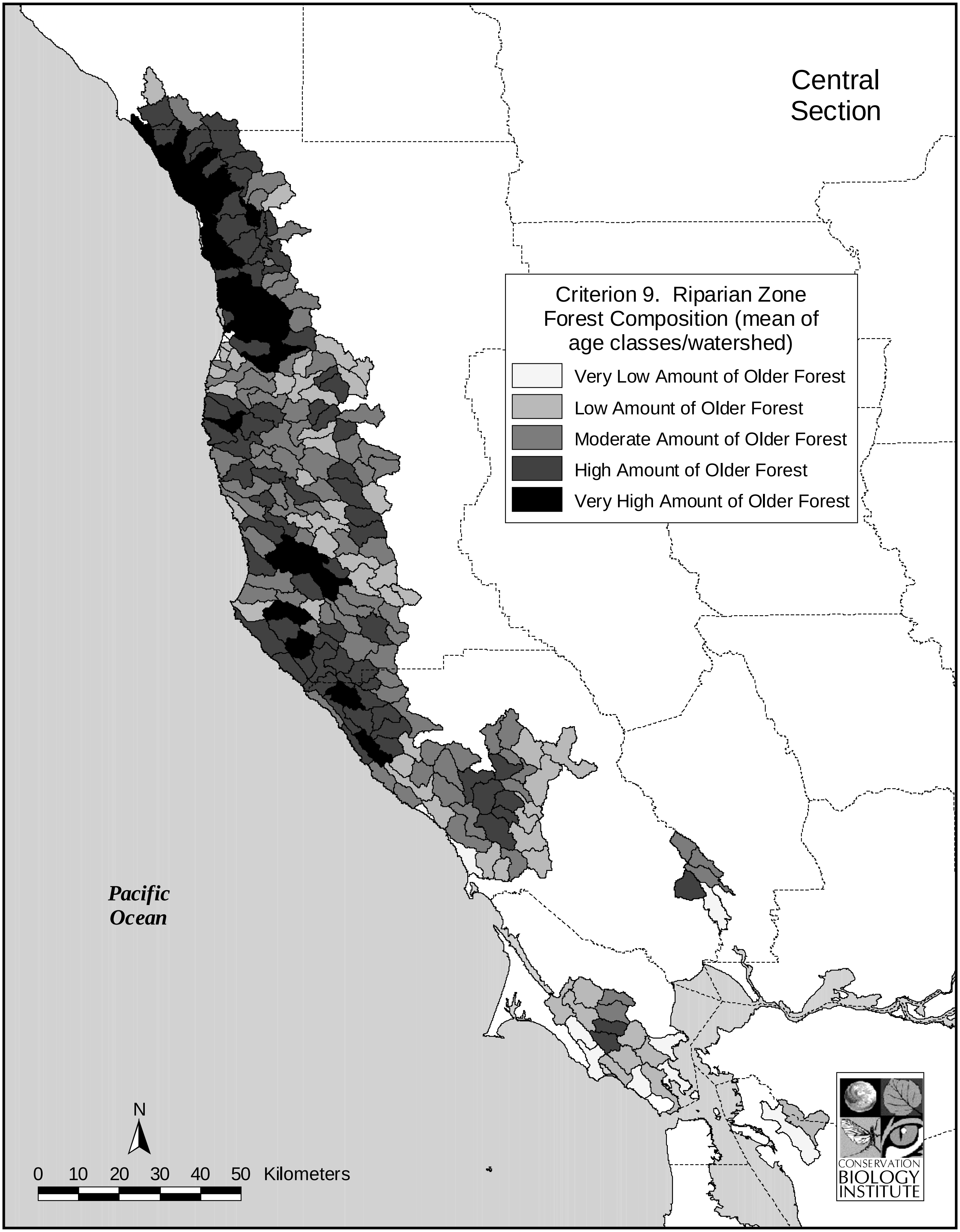

Figure 29. Riparian zone forest composition for the central section.

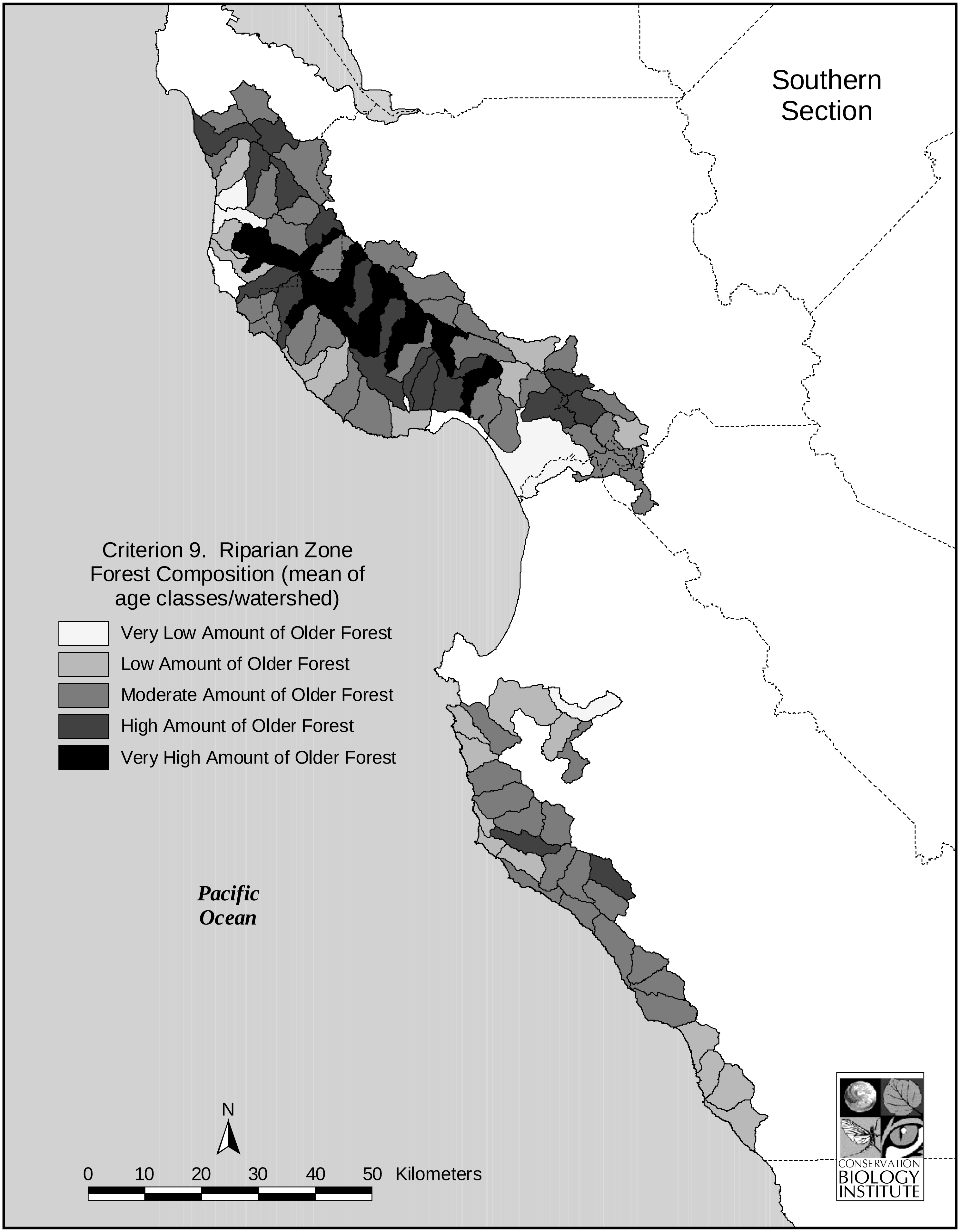

Figure 30. Riparian zone forest composition for the southern section.

Discussion:

The northern section showed the highest levels of older forest along riparian zones (see Table 7). This section also was based on the most accurate data sources available and they covered the entire area. These results are the most dependable of the three sections. The central section is predominantly covered by the same data layers as used in the northern section – only the southern most portion of the section required the inclusion of poorer quality vegetation data. This explains a class range containing a zero. The southern section was built on relatively poor data sources and should be reworked when higher resolution imagery is available.

The Composite Results

Methodology:

The final set of maps show the composite results for each of the three redwood sections displayed as a grid using a 100 x 100 meter (1 ha) cell size and also displayed by the 6th order subwatershed basins as defined by CALWATER. Both of these map products were derived from the results by adding all of the ordinal scores for each criterion, forming a single composite score. For the nine-criteria model, possible values range from 9 – 45 and for the eight-criteria model, 8 – 40. All criteria were weighted equally for this exercise. The composite file was then converted to a raster file (30m x 30m) and then resampled using a 100m x 100m resolution nearest neighbor option in ArcView to smooth the results. To calculate total score by subwatershed, the original results were averaged using the subwatershed boundaries as the organizing unit. Mean composite scores were then linked to each subwatershed in order to allow for individual ranking. In addition, the composite scores themselves were ordered forming four general equal area classes (low – very high conservation value). Finally, the top 10% of the total number of subwatersheds from each section were pulled from the final results and highlighted as the top conservation focal areas. We ran the model using all nine criteria as well as using eight (dropping Criterion #1 plus elevating all neighborhoods mapped in Criterion #2 to a score of “5”). We have elected to include map figures for both versions for the northern section only. For the other two sections, we only include the results using the eight criteria as explained earlier.

Results:

We have included several color plates in this report that may provide a more distinguishable format for viewing composite results (Appendix A). The first three (plates 1 – 3) have been added to help provide some reference to each of the three sections. Two additional color plates also were produced for each section: (1) the general final scoring results with the top scoring 10% of the subwatersheds that are largely unprotected and (2) a map showing and listing the top scoring 10% of the subwatersheds that are largely unprotected. Figures 31 and 32 show the results for the northern section using all nine criteria organized by 1-hectare cell size and by subwatershed respectively. Table 8 provides the range of scores that made up the classes depicted on the maps.

Table 8. Actual model scores for classes depicted for the cumulative model score (criteria 1 – 9) organized by 1-hectare cell size (Figure 31) and organized by subwatershed basin (Figure 32) for the northern section.

Figure 31	**Range of Cumulative Scores**
Low	10 – 18
Medium	19 – 23
High	24 – 29
Very High	30 - 42
Figure 32	**Range of Cumulative Scores**
Low	14.398 – 18.822
Medium	18.822 – 22.507
High	22.507 – 26.819
Very High	26.819 – 34.872

Figures 33 - 35 show the cumulative results for the northern section using the eight criteria method. Figures 34 and 35 also were produced as color Plate 4 and 5, both highlighting the top scoring 10% of the subwatersheds that were largely unprotected. Table 9 provides the actual ranges of cumulative scores for the northern section using the eight-criterion method.

Table 9. Actual model scores for classes depicted for the cumulative model score (criteria 2 – 9) organized by 1-hectare cell size (Figure 33) and organized by subwatershed basin (Figure 34) for the northern section.

Figure 33	**Range of Cumulative Scores**
Low	10 – 18
Medium	19 – 22
High	23 – 27
Very High	27 - 38
Figure 34	**Range of Cumulative Scores**
Low	14.410– 18.865
Medium	18.865 – 22.446
High	22.446 – 26.544
Very High	26.544 – 33.760

Note the range of values for figures 32 and 34 show very little variance. This demonstrates that dropping Criterion #1 from the model and equally scoring all neighborhoods in Criterion #2 changes the overall subwatershed scores very little.

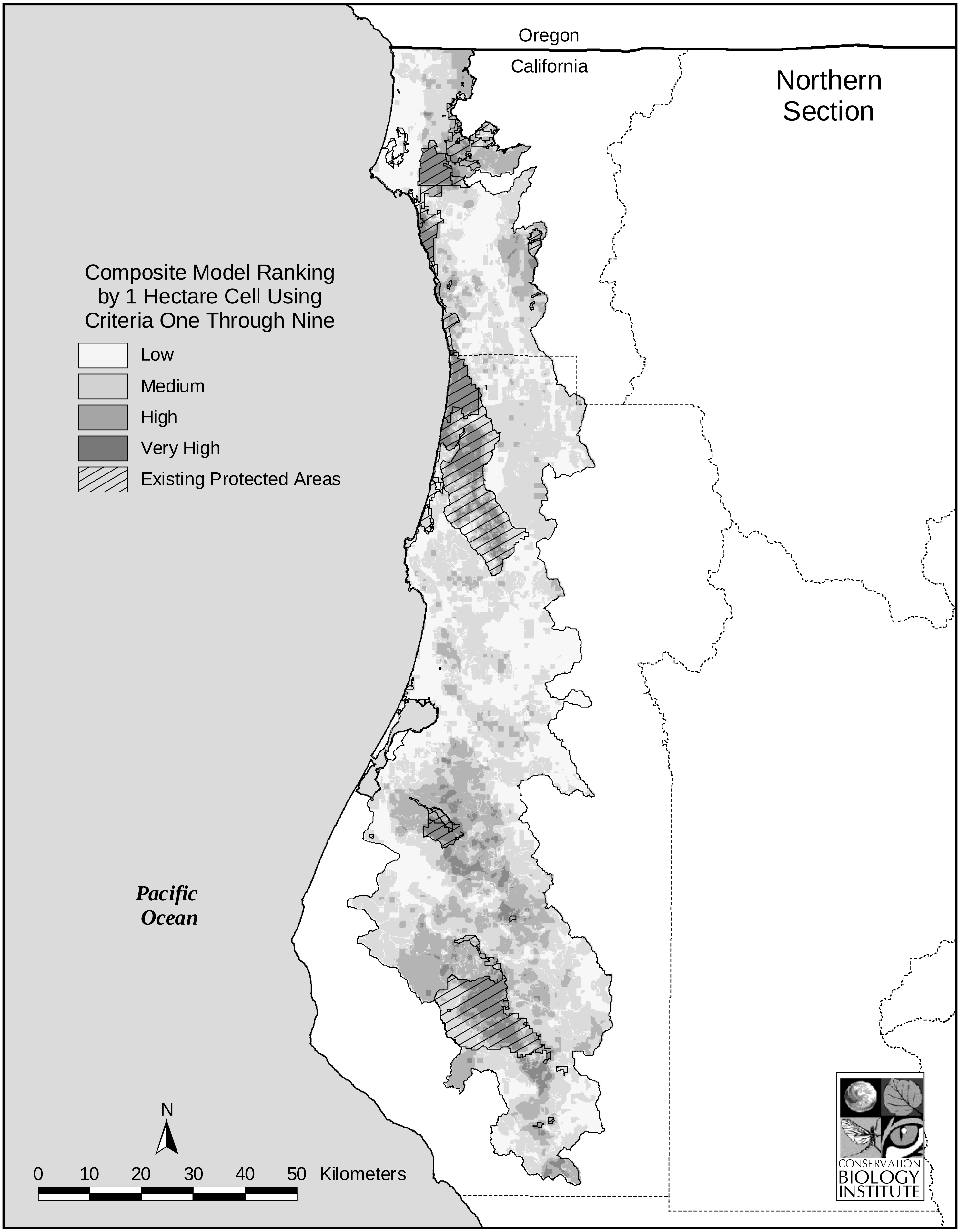

Figure 31. Composite model ranking by 1 hectare cell using criteria one through nine for the northern section.

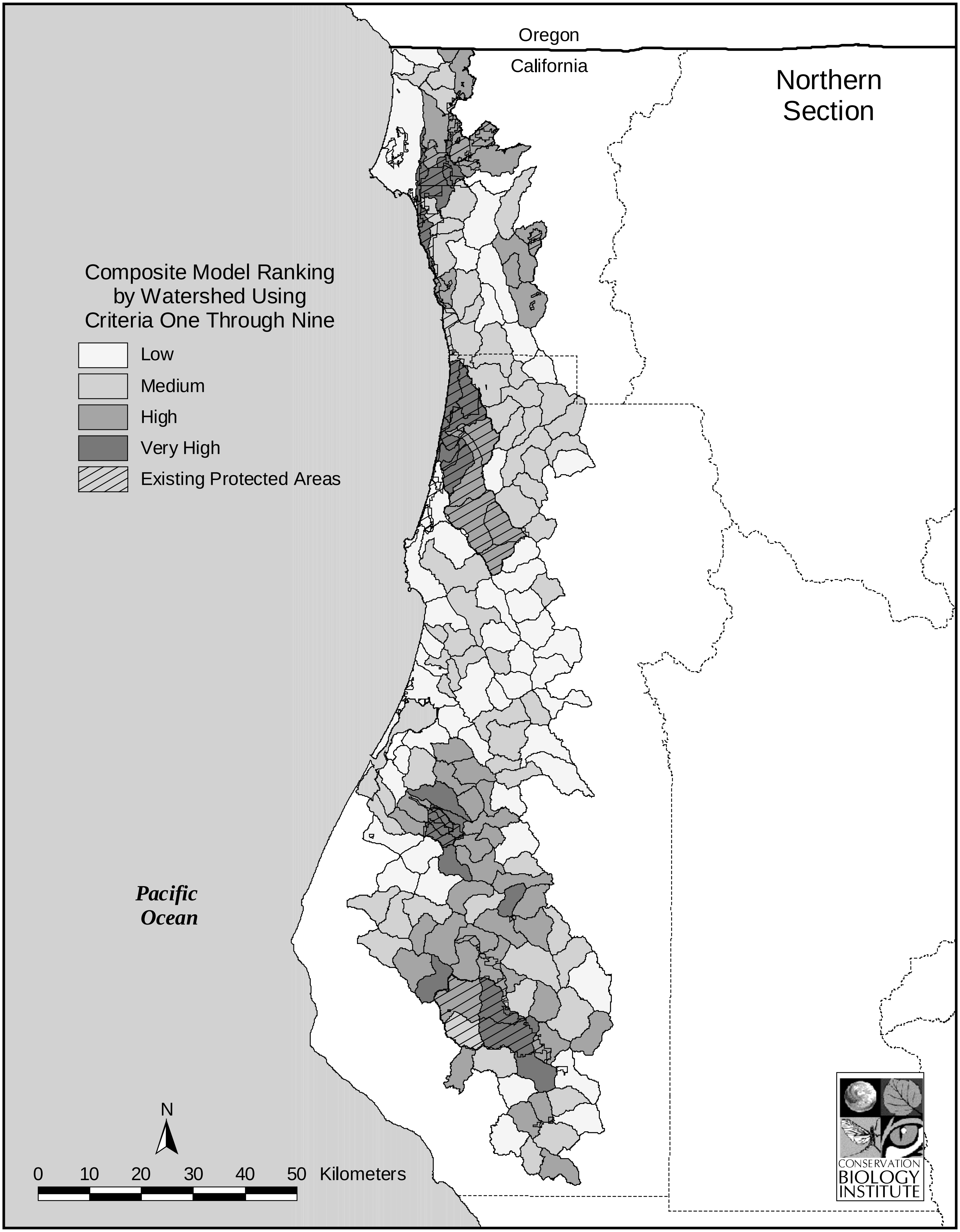

Figure 32. Composite model ranking by watershed using criteria one through nine for the northern section.

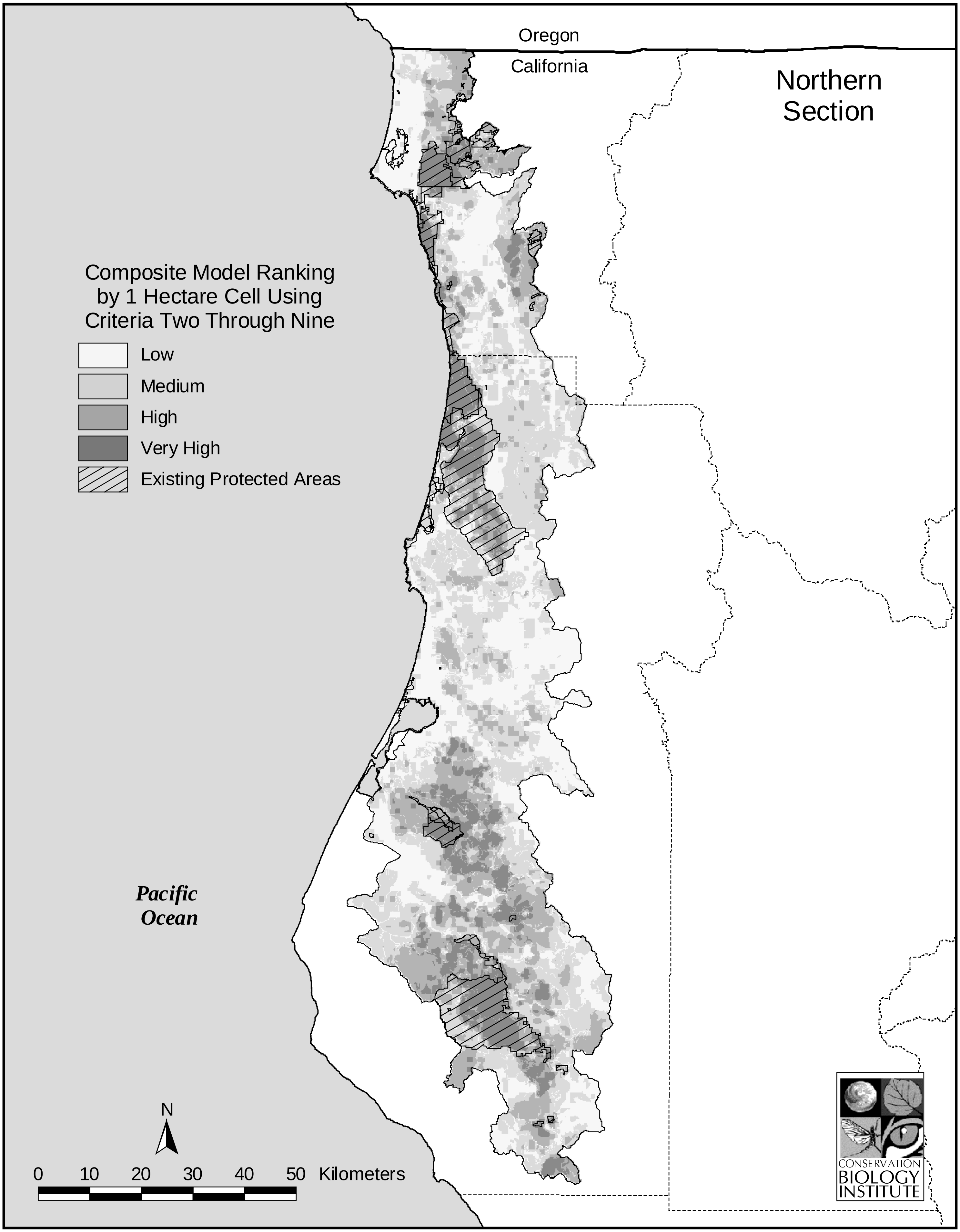

Figure 33. Composite model ranking by 1 hectare cell using criteria two through nine for the northern section.

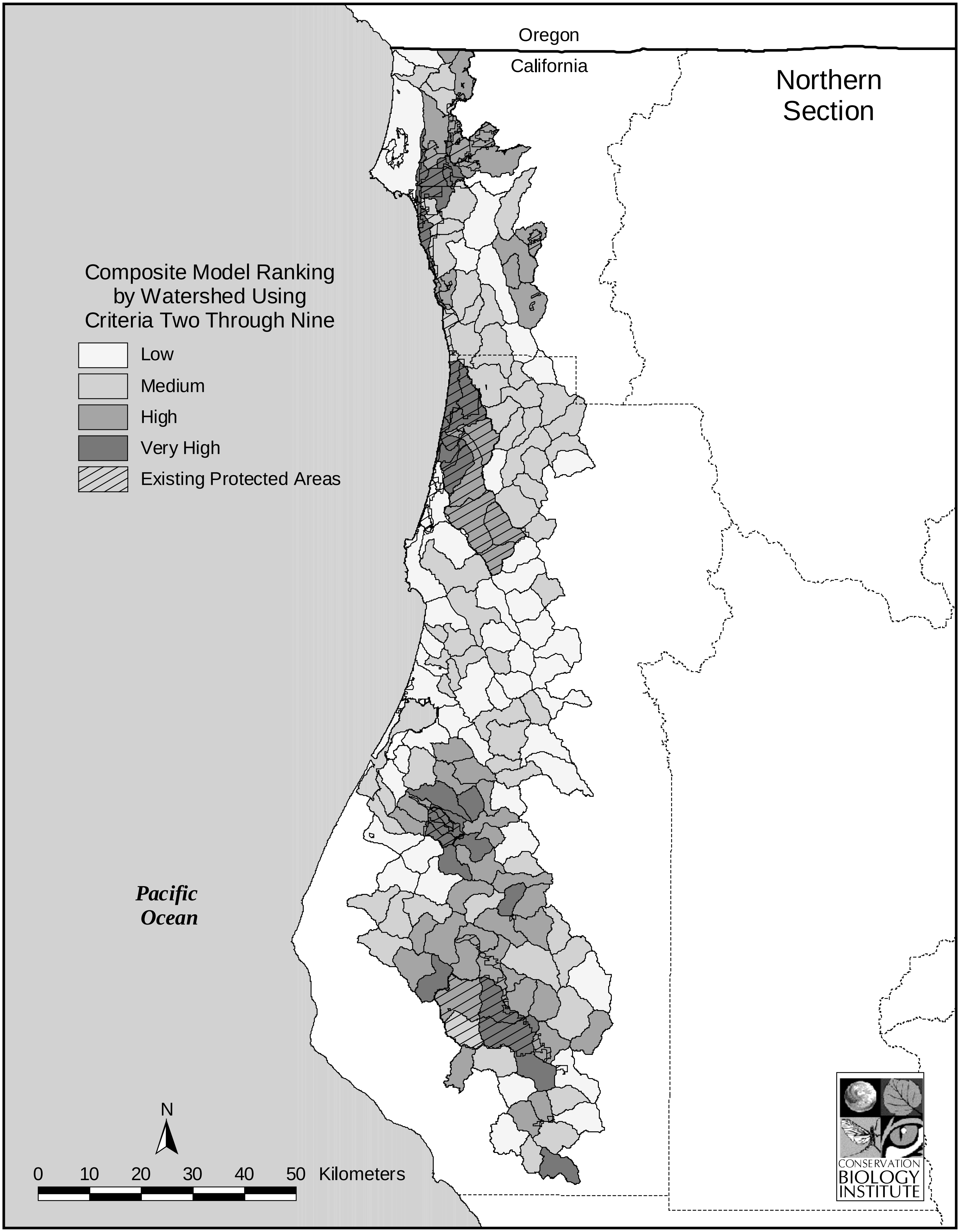

Figure 34. Composite model ranking by watershed using criteria two through nine for the northern section.

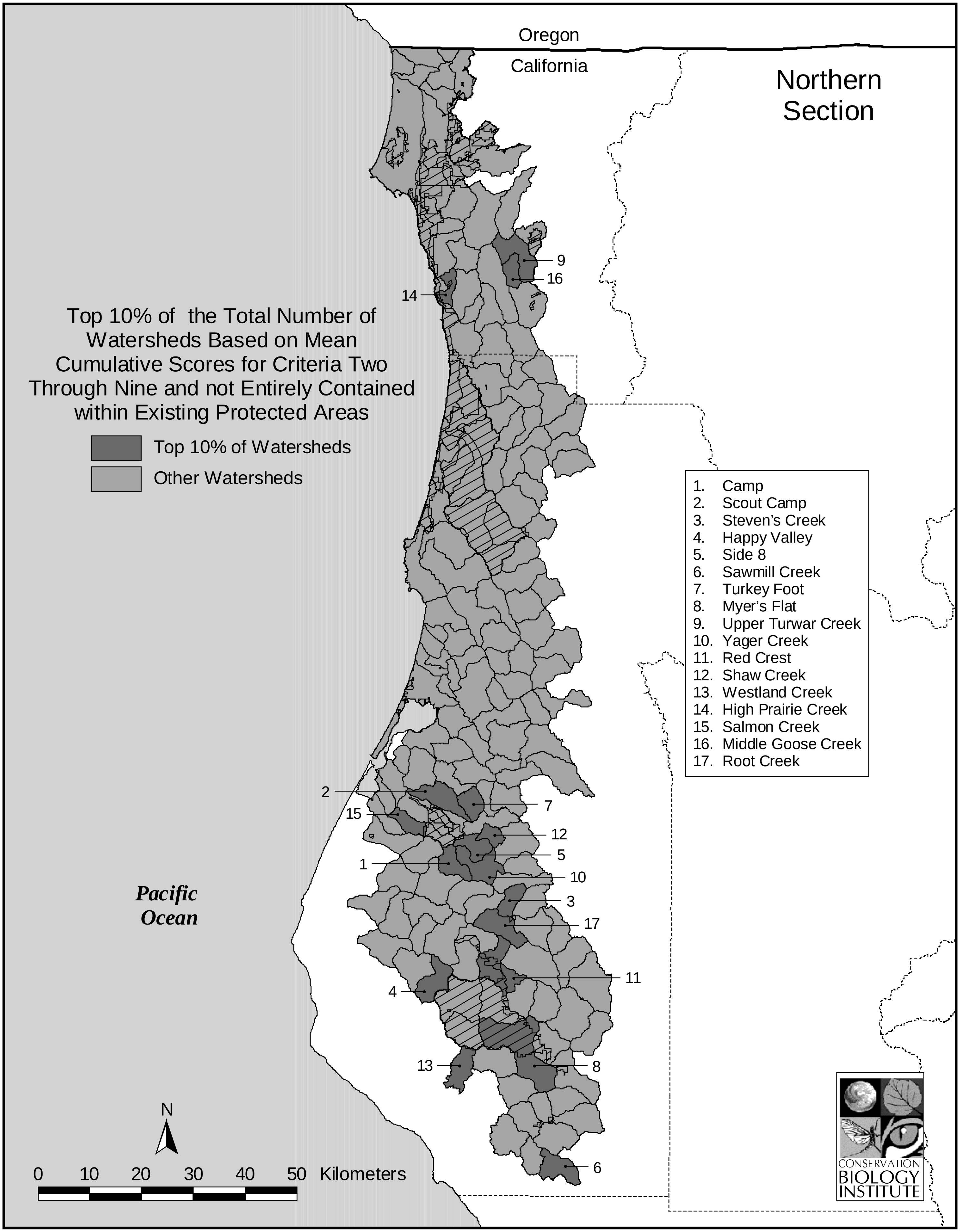

Figure 35. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the northern section.

Figures 36 – 38 show the cumulative results for the central section using the eight criteria method. Figure 37 was also produced as color Plate 6 showing the top scoring 10% of the subwatersheds in the central section that are largely unprotected. Table 10 provides the actual ranges of cumulative scores for the central section using the eight-criterion method. Figure 38 and Plate 7 show and labels the top 10% of the subwatersheds in the northern section that possessed the highest conservation value scores and were largely unprotected.

Table 10. Actual model scores for classes depicted for the cumulative model score (criteria 2 – 9) organized by 1-hectare ha cell size (Figure 36) and organized by subwatershed basin (Figure 37) for the central section.

Figure 36	**Range of Cumulative Scores**
Low	8 - 15
Medium	16 - 19
High	20 - 24
Very High	25 - 39
Figure 37	**Range of Cumulative Scores**
Low	10.053 – 15.836
Medium	15.836 – 19.398
High	19.398 – 22.682
Very High	22.682 – 29.417

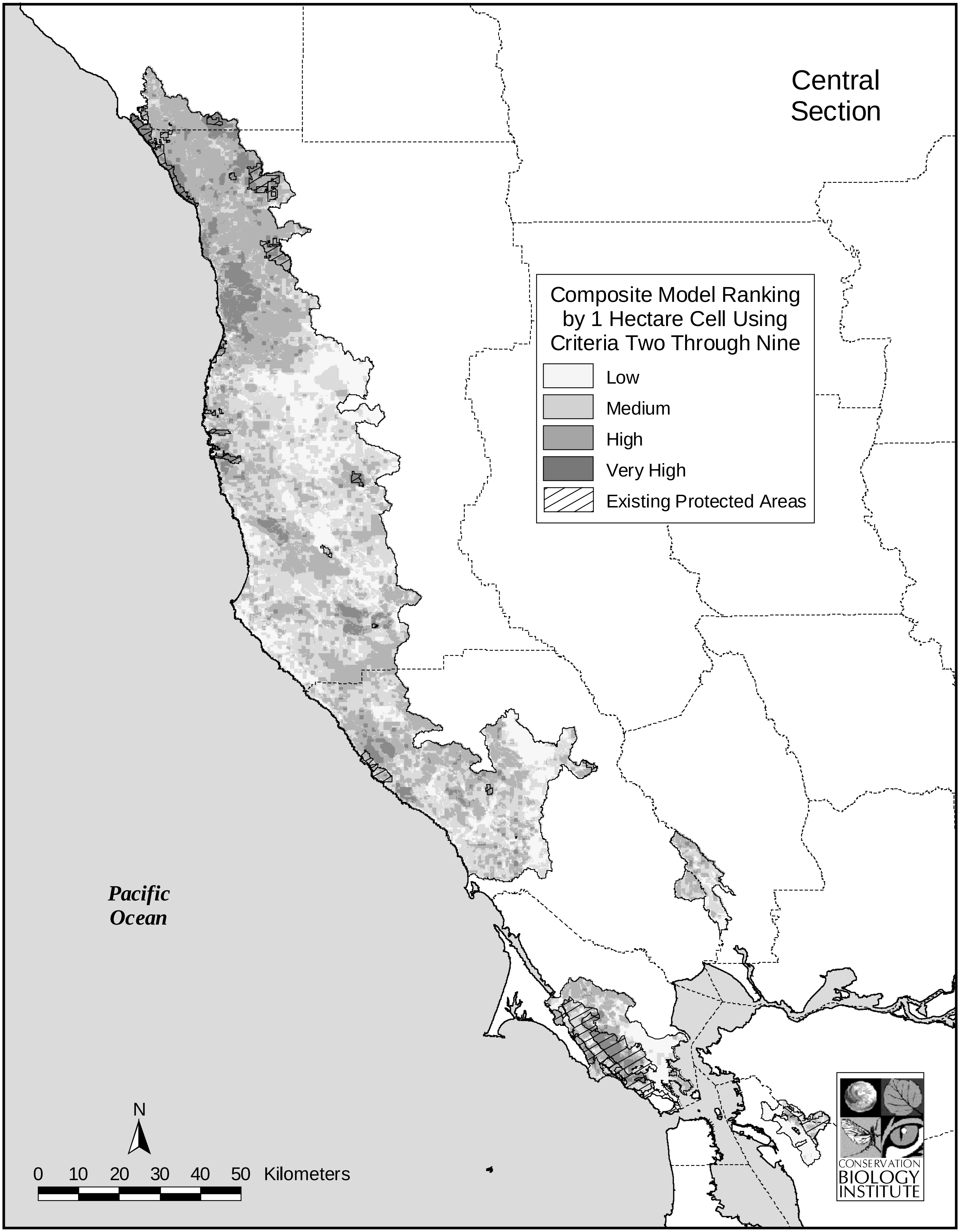

Figure 36. Composite model ranking by 1 hectare cell using criteria two through nine for the central section.

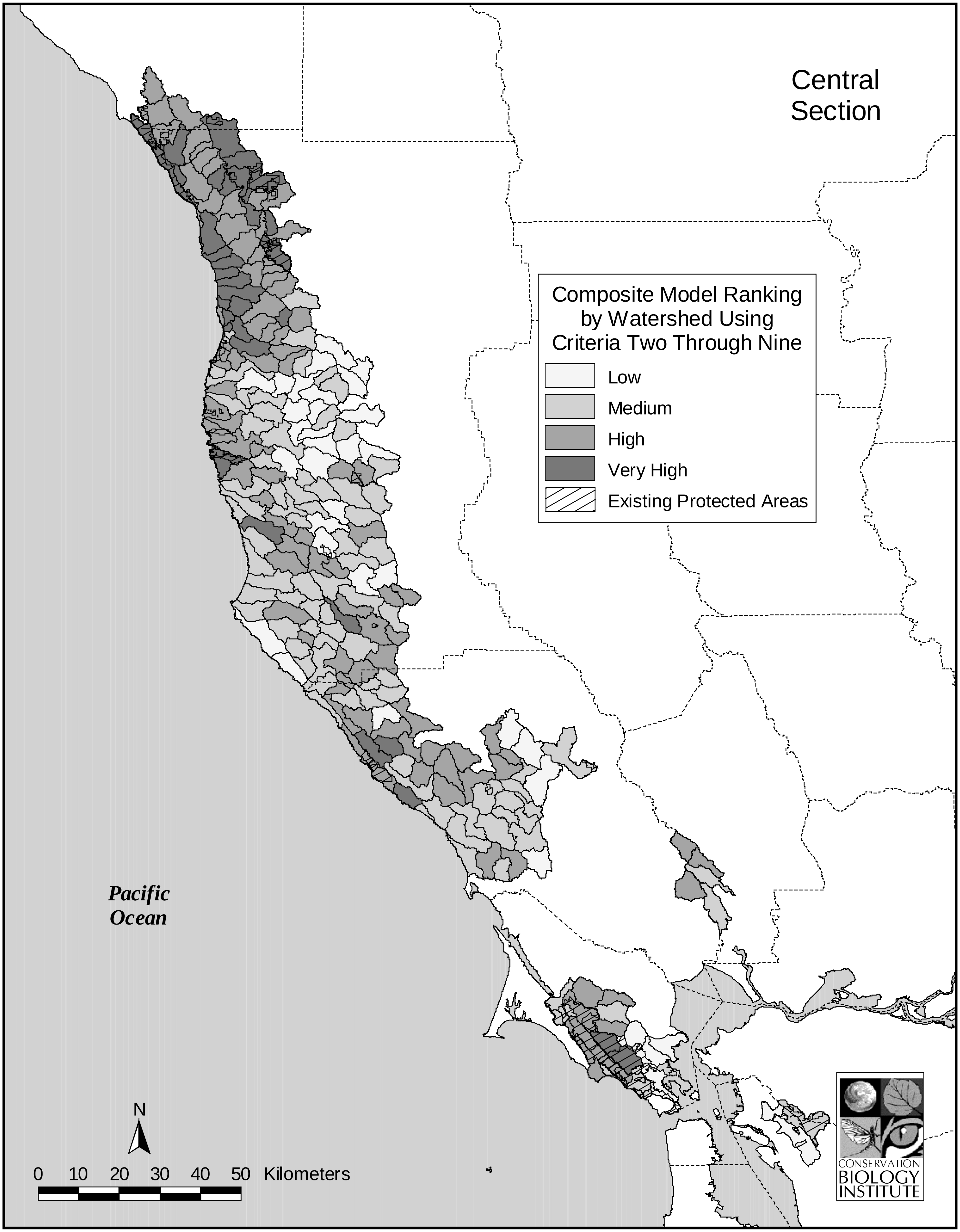

Figure 37. Composite model ranking by watershed using criteria two through nine for the central section.

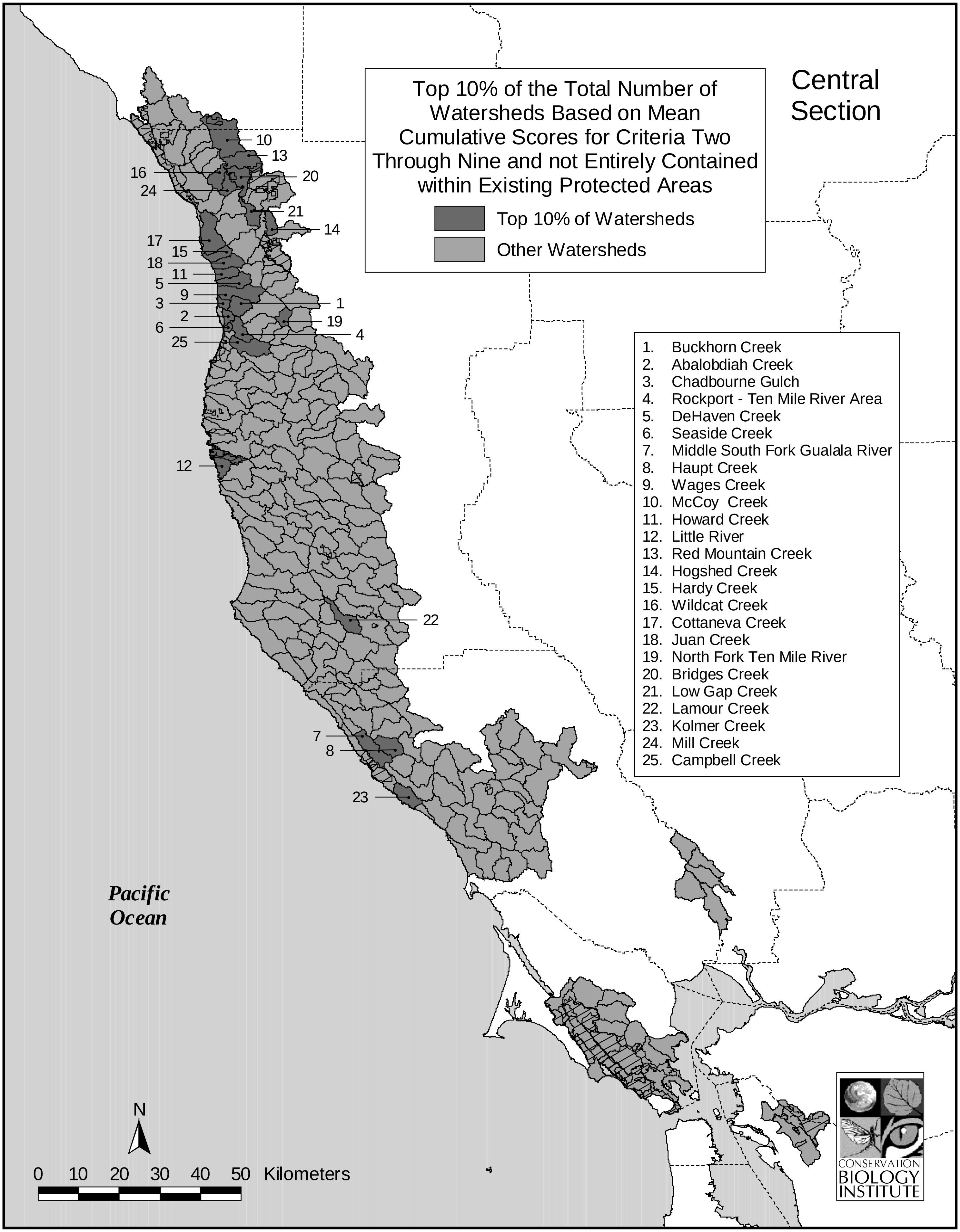

Figure 38. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the central section.

Figures 39 – 41 show the cumulative results for the southern section using the eight-criterion method. Figure 40 also was produced as color Plate 8 showing the top scoring 10% of the subwatersheds in the southern section that are largely unprotected. Table 11 provides the actual ranges of cumulative scores for the central section. Plate 9 shows and labels the top 10% of the subwatersheds in the southern section that possessed the highest conservation value scores and were largely unprotected.

Table 11. Actual model scores for classes depicted for the cumulative model score (criteria 2 – 9) organized by a 1-hectare cell size (Figure 39) and organized by subwatershed basin (Figure 40) for the southern section.

Figure 39	**Range of Cumulative Scores**
Low	8 - 16
Medium	17 – 21
High	22 - 26
Very High	27 - 38
Figure 40	**Range of Cumulative Scores**
Low	12.121 – 17.558
Medium	17.558 – 20.679
High	20.679 – 23.942
Very High	23.942 – 28.131

Discussion:

The conservation focal areas GIS-based model as explained in this report was the first attempt of its kind to assesses general conservation value of subwatersheds within a redwoods ecosystem in a scientifically replicable and useful way. Work by Davis et al. (1996) is related, but more directed at achieving representation goals. Again, the intent of this model was not to replace site level conservation planning. The purpose was to develop what amounts to a spatially explicit conservation triage technique – identifying focal areas within a large region that possess the best current ecological condition. The next step in the process will be to concentrate resources on the focal areas (including substantial fieldwork) to further evaluate and plan for their protection as part of a broader regional strategic plan. Over time, more and more focal areas should be considered at this more refined level until a truly effective conservation network is realized.

The utility of this basic model approach will depend upon review by Save-the Redwoods League, other conservation groups, and the greater scientific community. If the primary tenants of the model are believed to be in place after careful review, a new important tool will be added to the conservationists' toolbox. We expect and welcome further refinements that would improve the usefulness of this modeling approach that will hopefully be adaptable to other forested ecosystems.

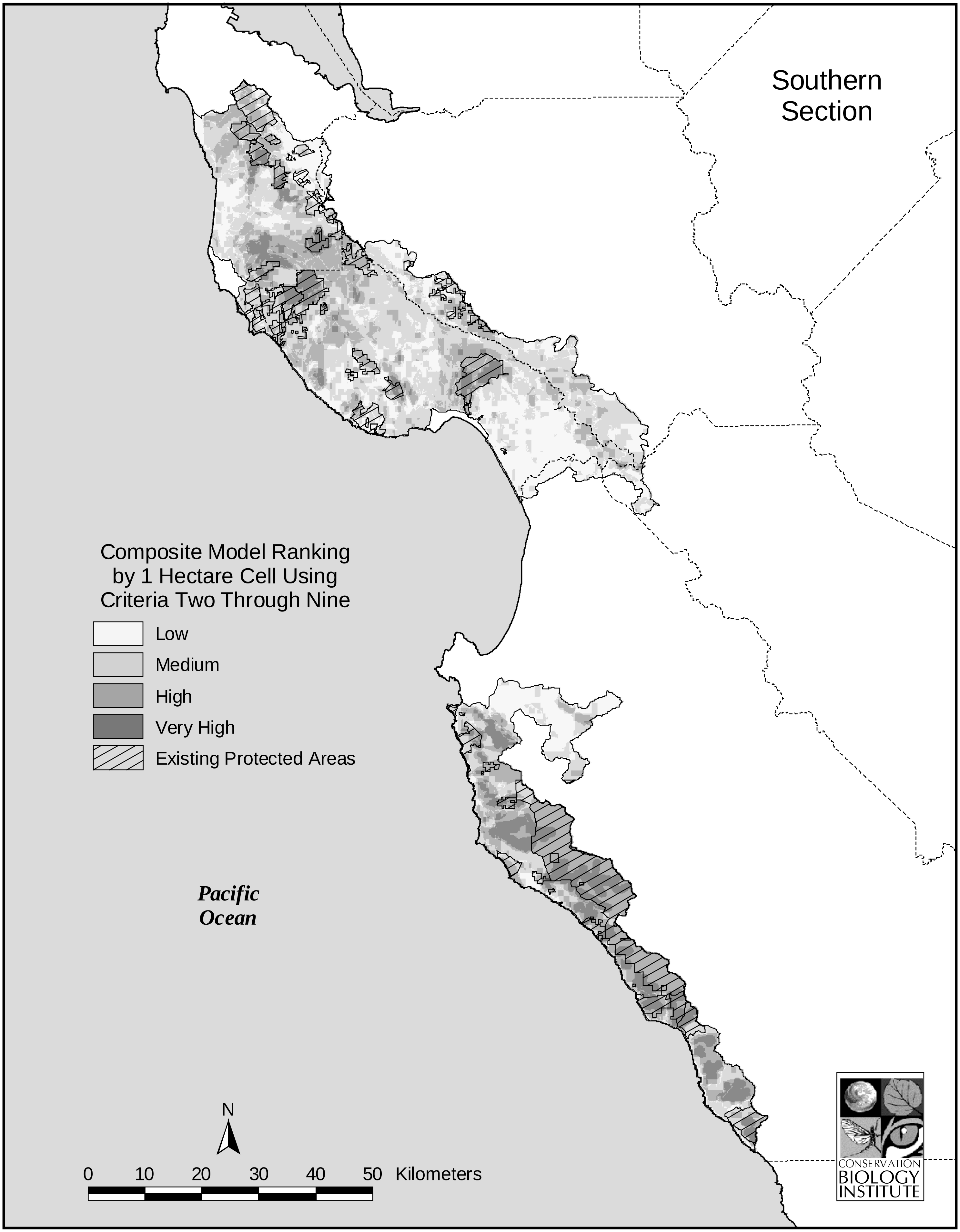

Figure 39. Composite model ranking by 1 hectare cell using criteria two through nine for the southern section.

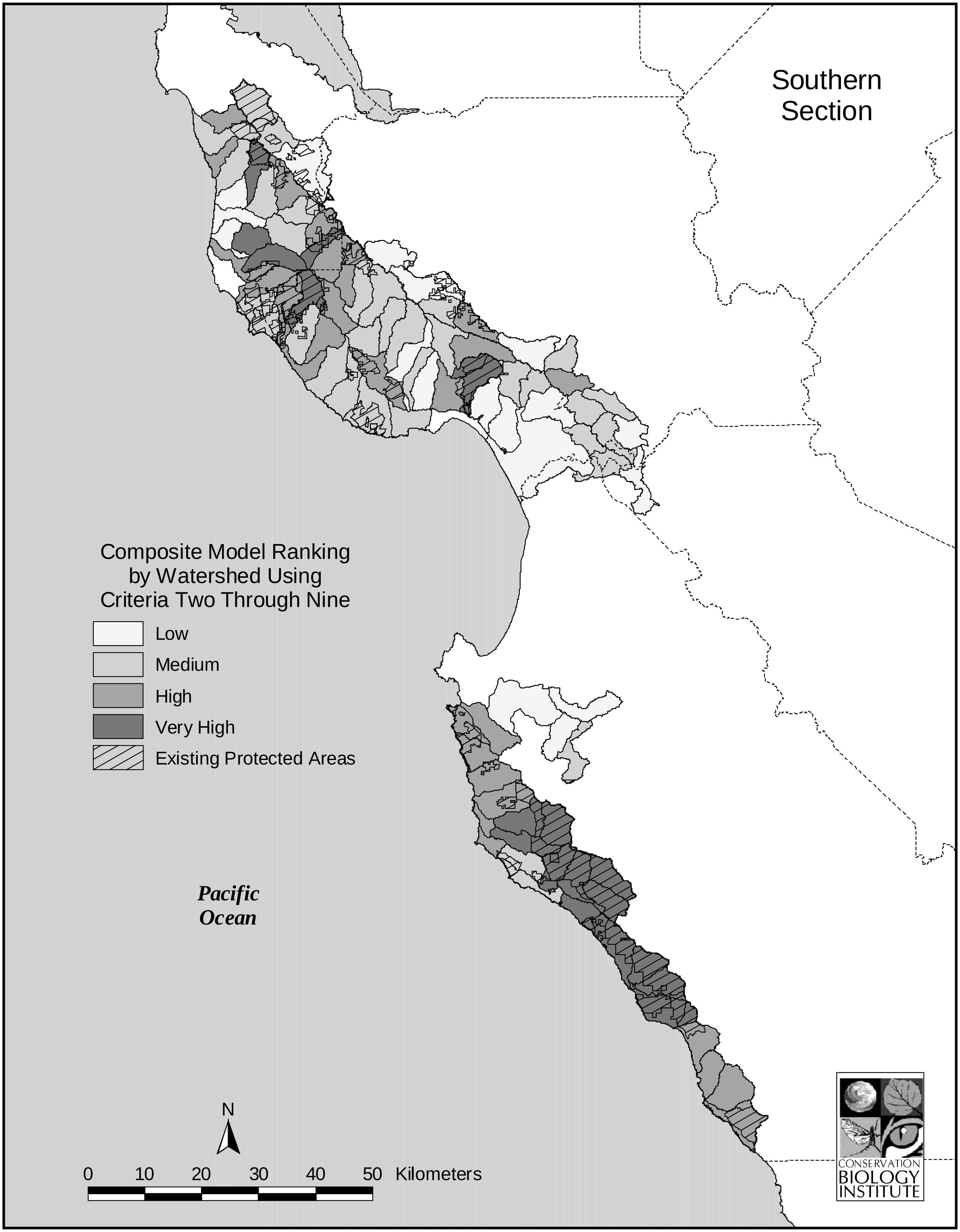

Figure 40. Composite model ranking by watershed using criteria two through nine for the southern section.

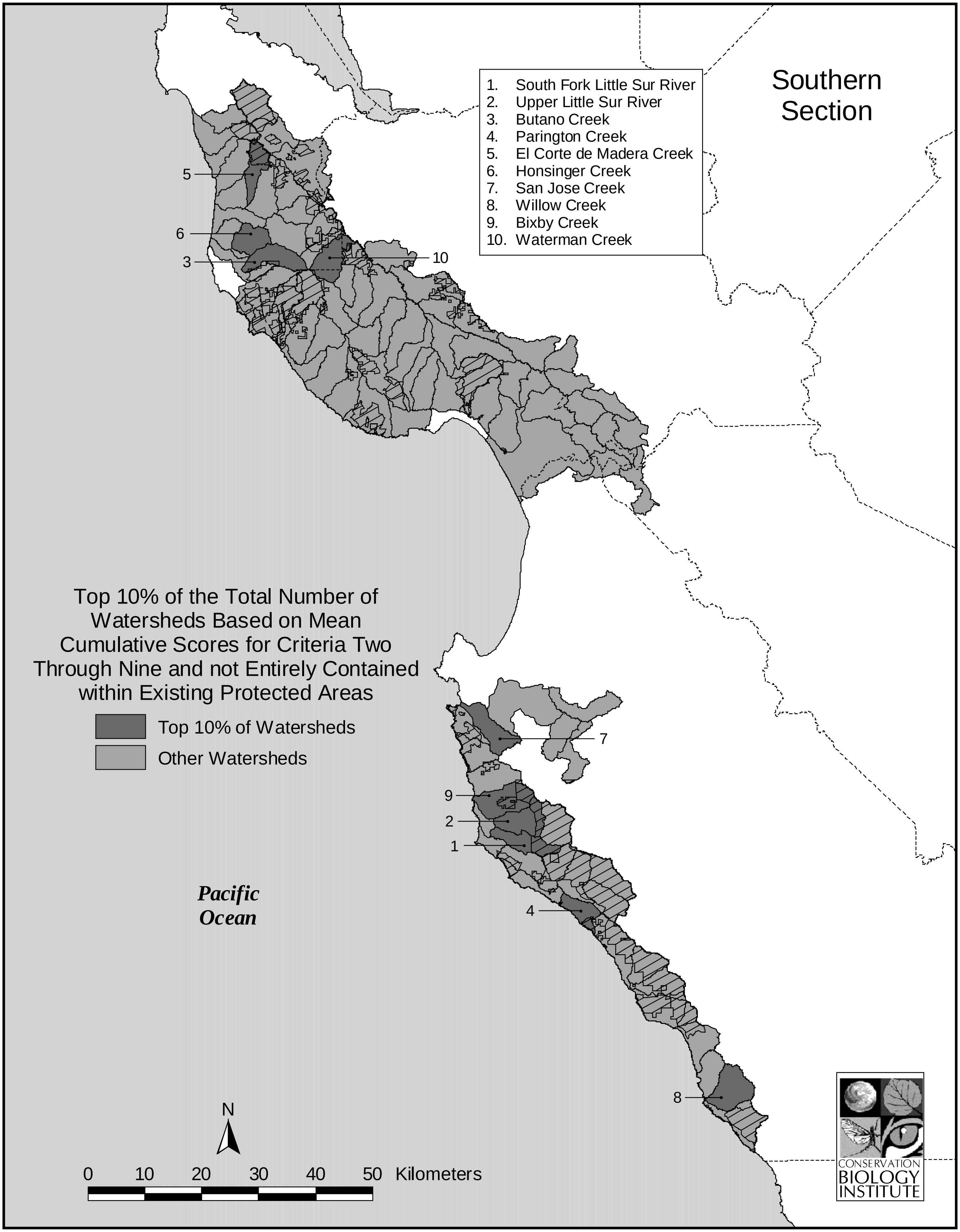

Figure 41. Top 10% of the watersheds based on mean cumulative scores for criteria two through nine for the southern section.

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List of Plates

Plate 1. Northern Section of the Redwoods Study Area.

Plate 2. Central Section of the Redwoods Study Area.

Plate 3. Southern Section of the Redwoods Study Area.

Plate 4. Northern Section: Composite Model Ranking by Watershed using Criteria Two Through Nine.

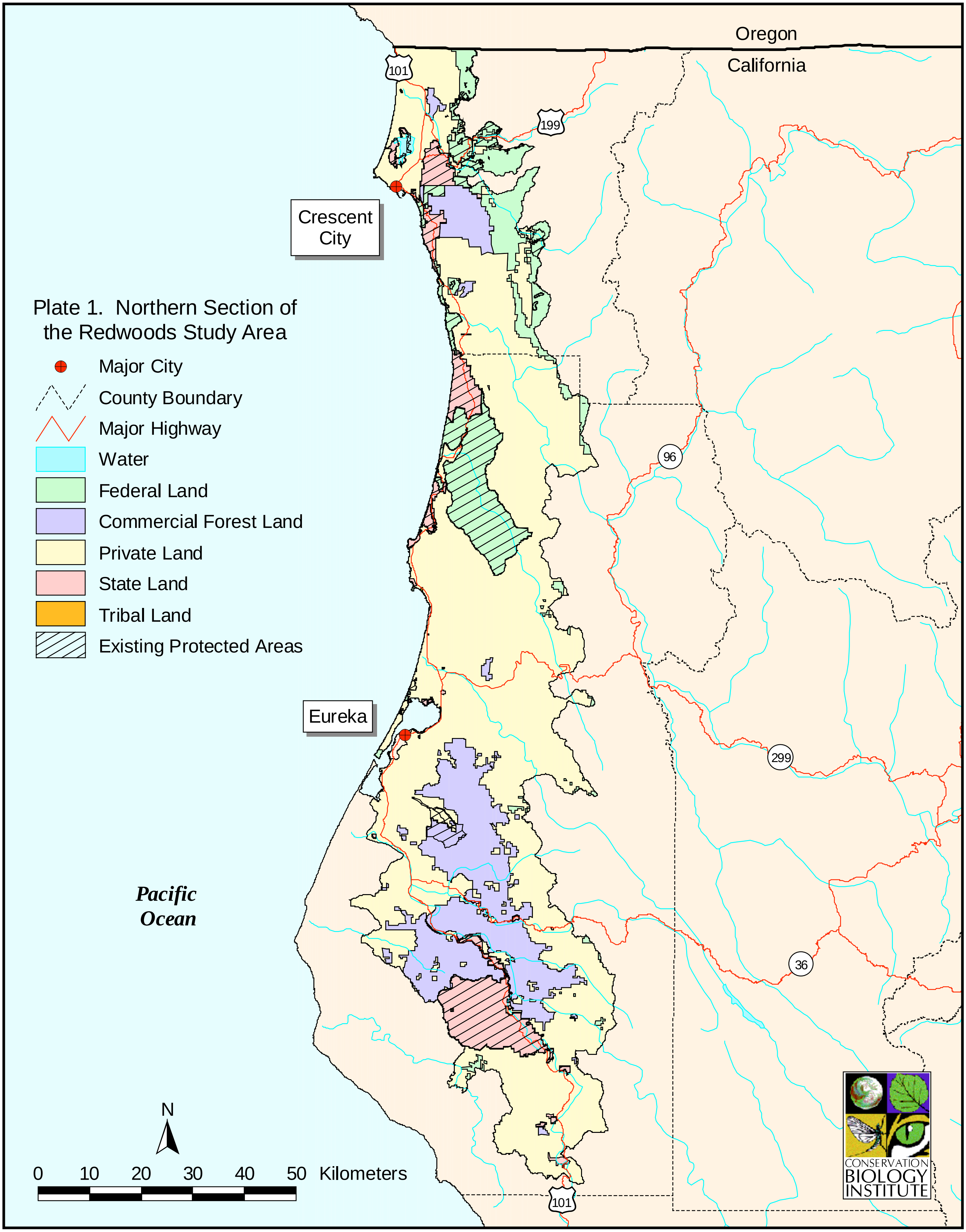
Plate 5. Northern Section: Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas.

Plate 6. Central Section: Composite Model Ranking by Watershed Using Criteria Two Through Nine.

Plate 7. Central Section: Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas.

Plate 8. Southern Section: Composite Model Ranking by Watershed Using Criteria Two Through Nine.

Plate 9. Southern Section: Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas.



Oregon
California
101
199
Crescent City
Plate 1. Northern Section of the Redwoods Study Area
Major City
County Boundary
Major Highway
Water
Federal Land
Commercial Forest Land
Private Land
State Land
Tribal Land
Existing Protected Areas
96
Eureka
299
Pacific Ocean
36
N
0 10 20 30 40 50 Kilometers
101
CONSERVATION BIOLOGY INSTITUTE

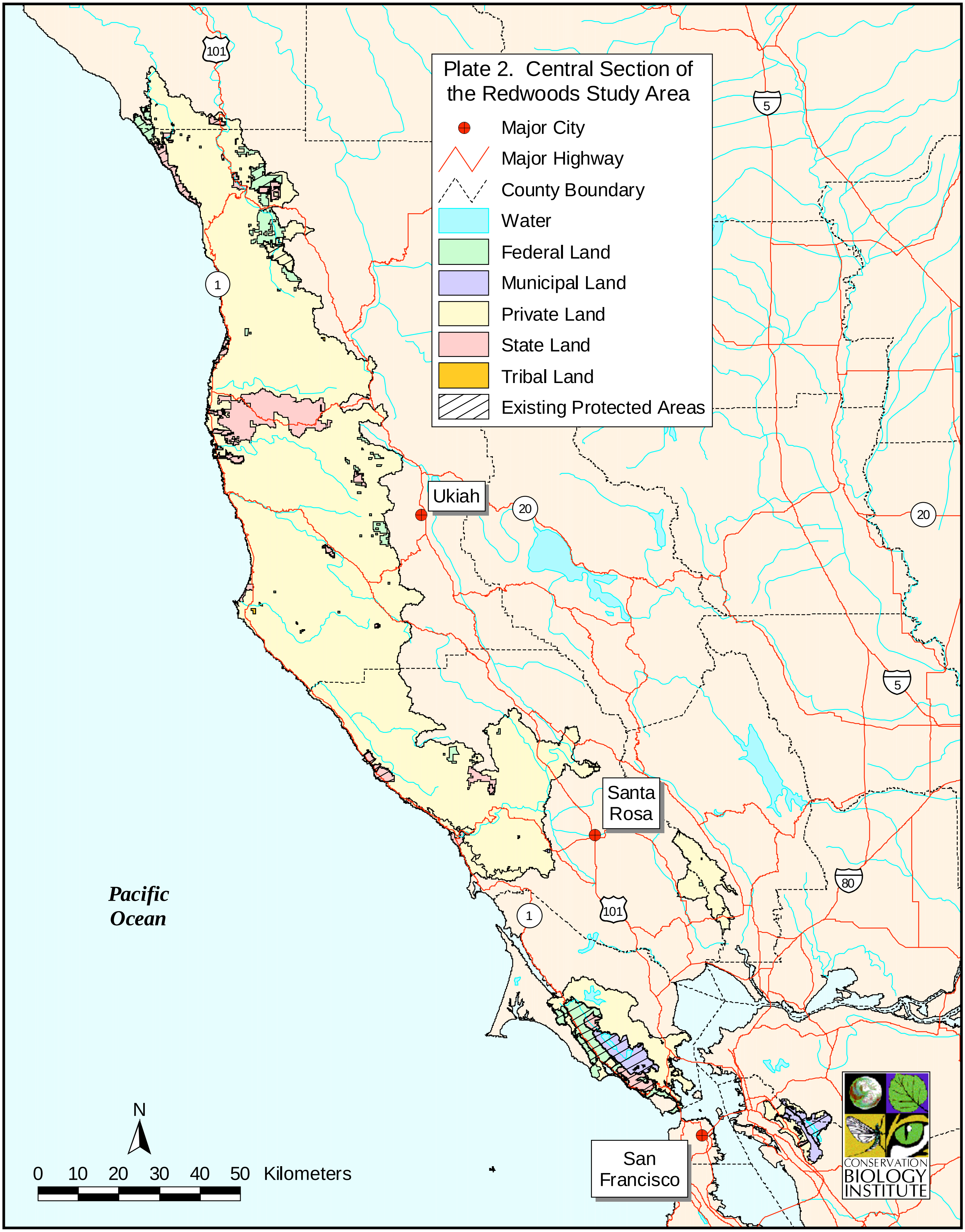


Plate 2. Central Section of the Redwoods Study Area
Major City
Major Highway
County Boundary
Water
Federal Land
Municipal Land
Private Land
State Land
Tribal Land
Existing Protected Areas
101
5
1
Ukiah
20
20
5
Santa Rosa
80
1
101
Pacific Ocean
N
0 10 20 30 40 50 Kilometers
San Francisco
CONSERVATION BIOLOGY INSTITUTE

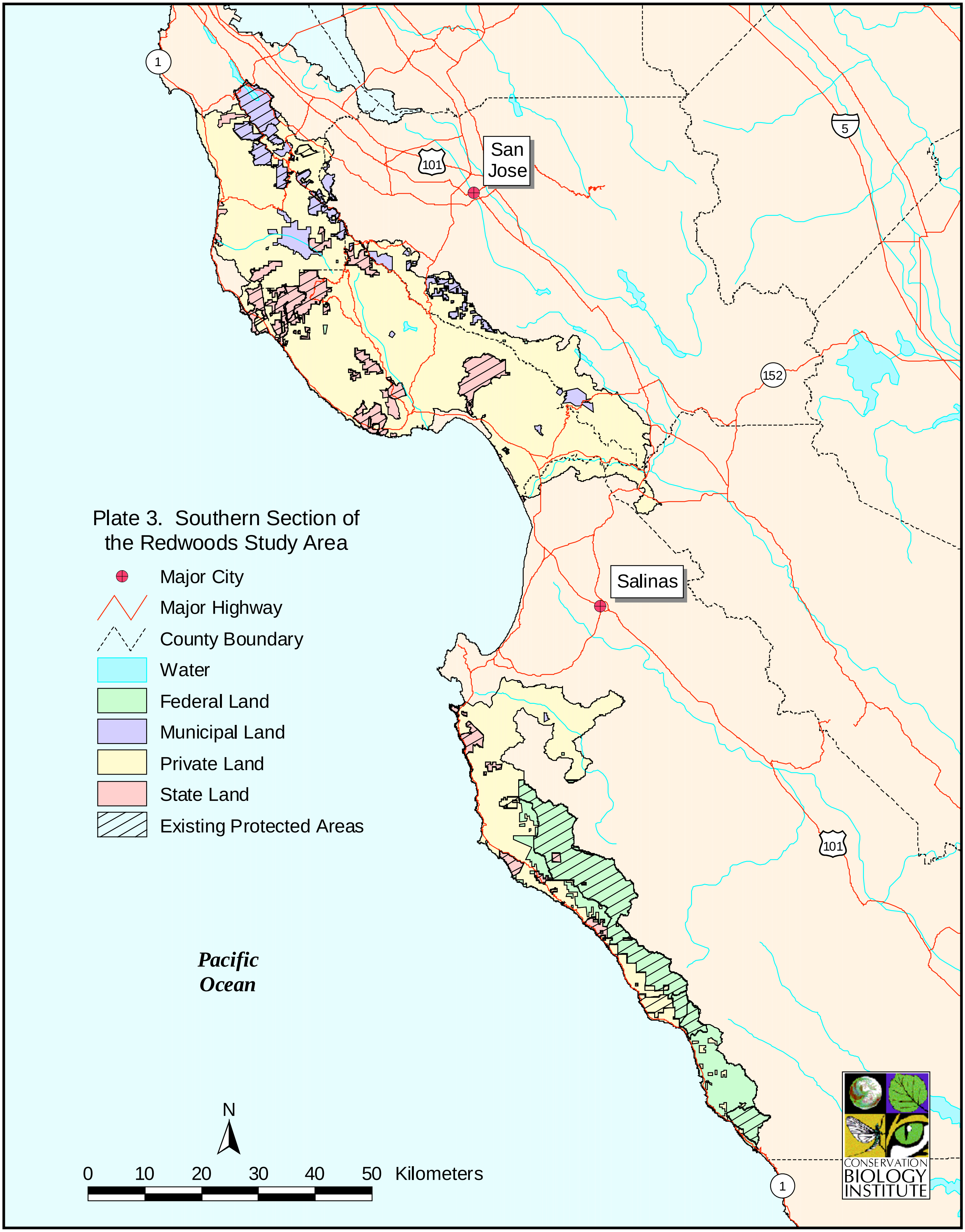
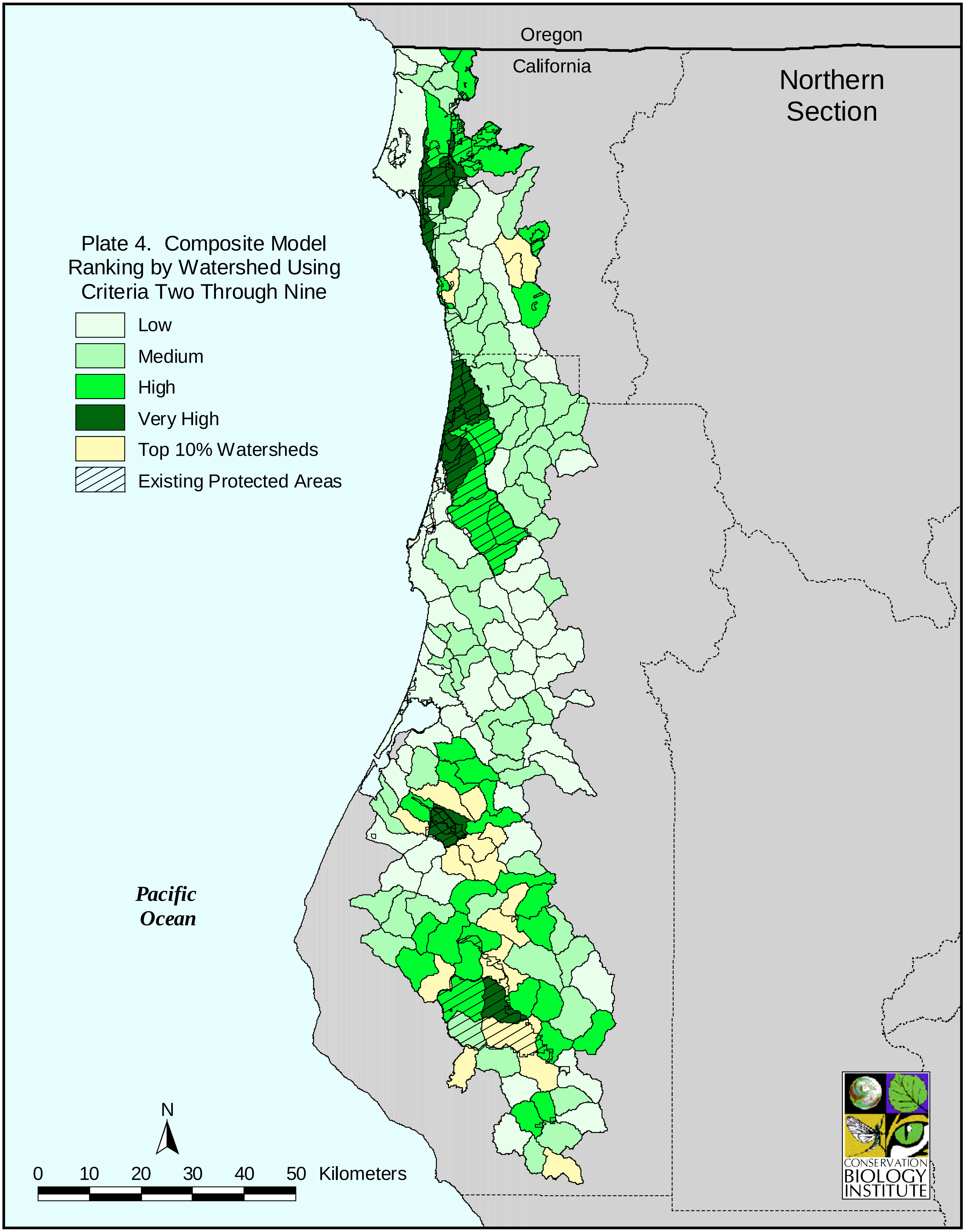


Plate 3. Southern Section of the Redwoods Study Area
Major City
Major Highway
County Boundary
Water
Federal Land
Municipal Land
Private Land
State Land
Existing Protected Areas
San Jose
Salinas
Pacific Ocean
1
101
5
152
N
0 10 20 30 40 50 Kilometers
CONSERVATION BIOLOGY INSTITUTE


Oregon
California
Northern Section
Plate 4. Composite Model Ranking by Watershed Using Criteria Two Through Nine
Low
Medium
High
Very High
Top 10% Watersheds
Existing Protected Areas
Pacific Ocean
N
0 10 20 30 40 50 Kilometers
CONSERVATION BIOLOGY INSTITUTE

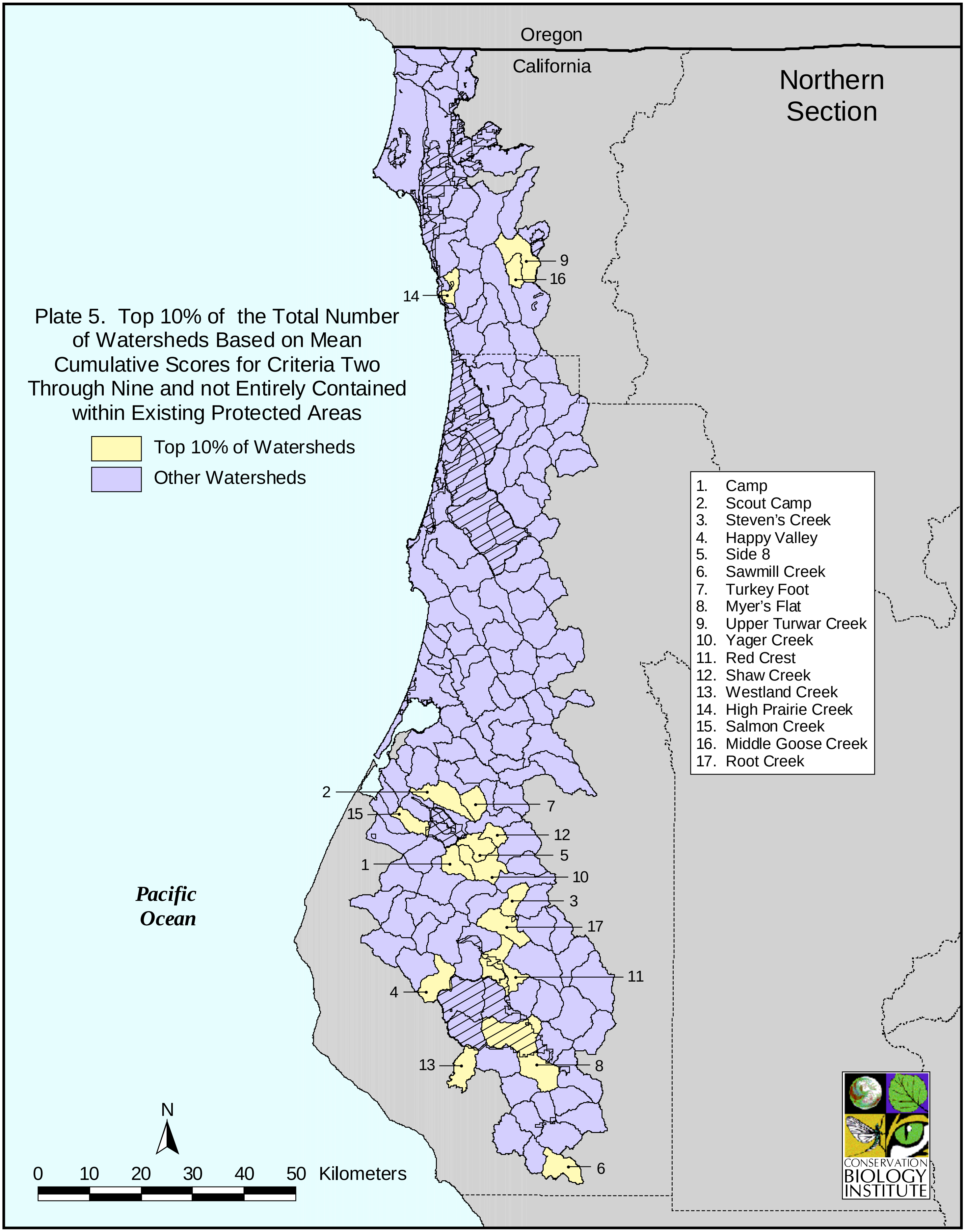
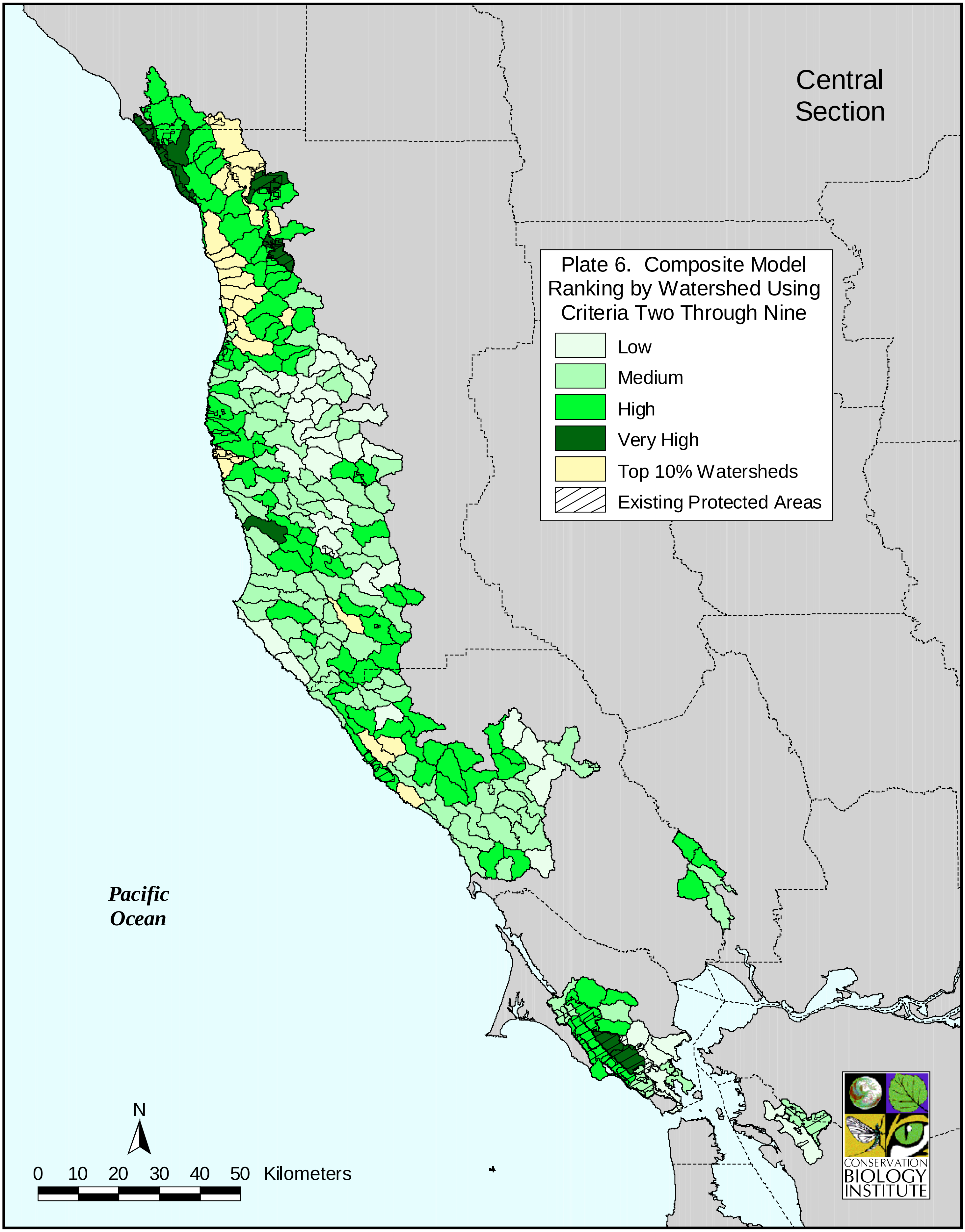


Plate 5. Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas



Central
Section
Plate 6. Composite Model Ranking by Watershed Using Criteria Two Through Nine
Low
Medium
High
Very High
Top 10% Watersheds
Existing Protected Areas
Pacific
Ocean
N
0 10 20 30 40 50 Kilometers
CONSERVATION
BIOLOGY
INSTITUTE

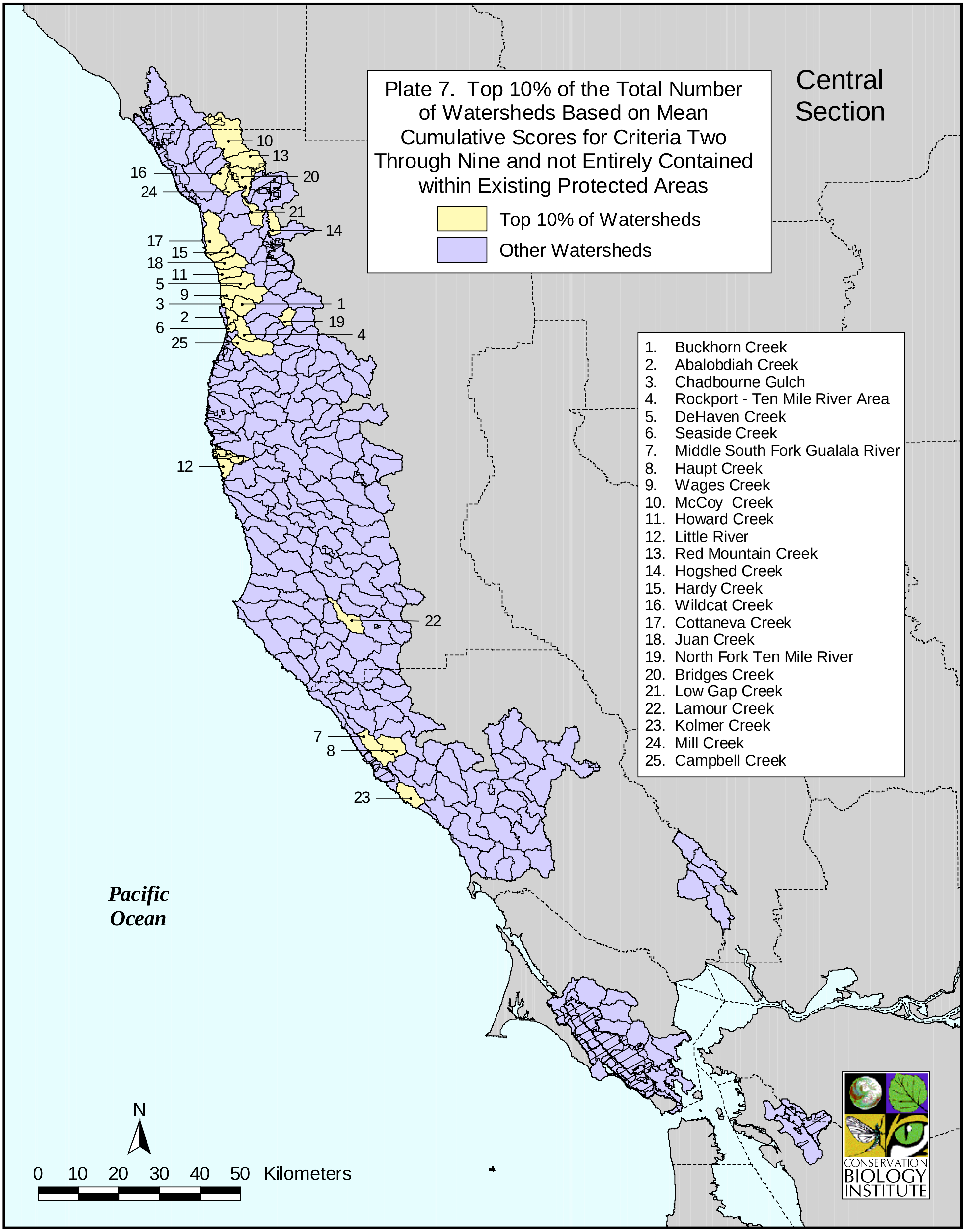
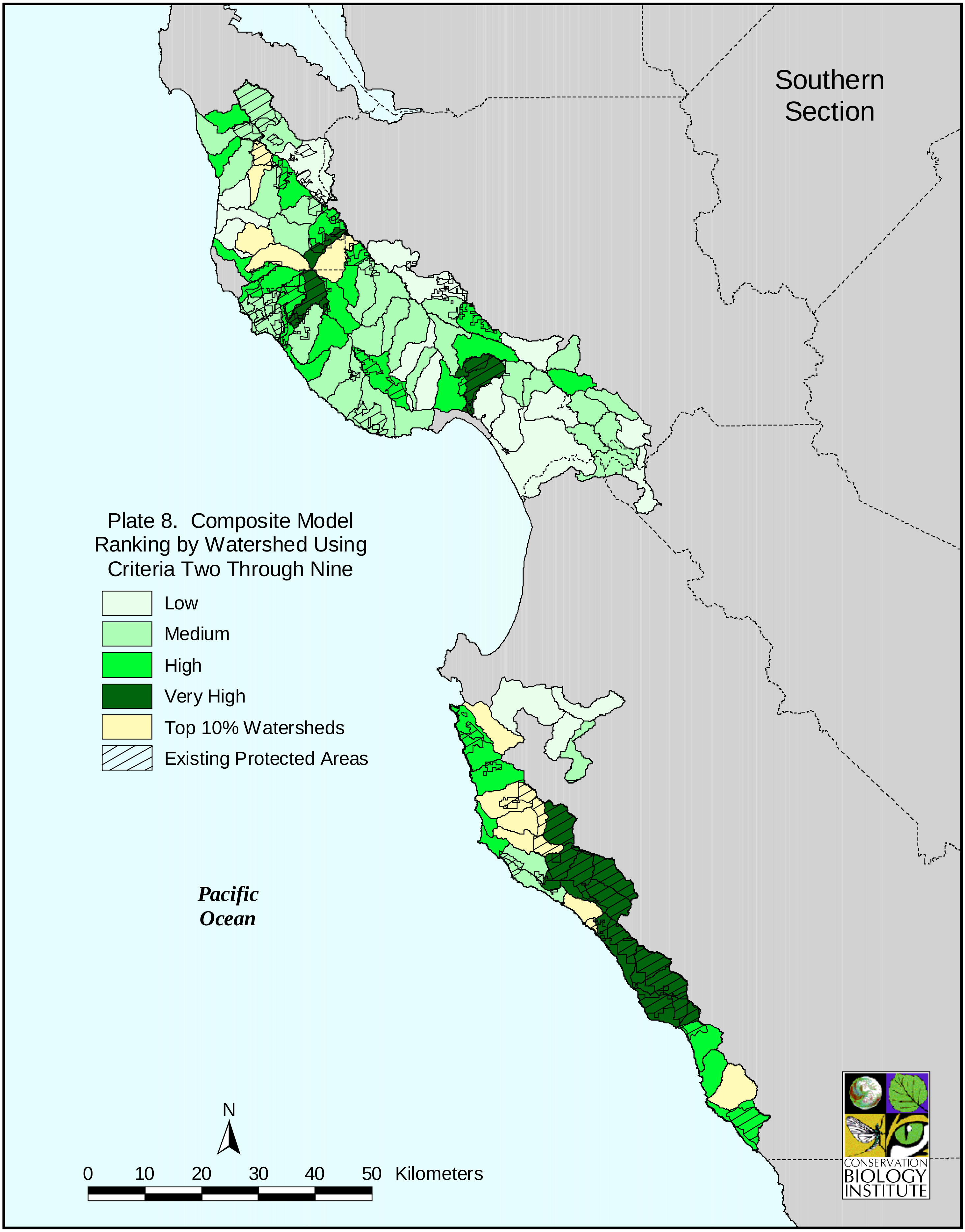


Plate 7. Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas
Top 10% of Watersheds
Other Watersheds
Central Section
1. Buckhorn Creek
2. Abalobdiah Creek
3. Chadbourne Gulch
4. Rockport - Ten Mile River Area
5. DeHaven Creek
6. Seaside Creek
7. Middle South Fork Gualala River
8. Haupt Creek
9. Wages Creek
10. McCoy Creek
11. Howard Creek
12. Little River
13. Red Mountain Creek
14. Hogshed Creek
15. Hardy Creek
16. Wildcat Creek
17. Cottaneva Creek
18. Juan Creek
19. North Fork Ten Mile River
20. Bridges Creek
21. Low Gap Creek
22. Lamour Creek
23. Kolmer Creek
24. Mill Creek
25. Campbell Creek
Pacific Ocean
N
0 10 20 30 40 50 Kilometers
CONSERVATION BIOLOGY INSTITUTE


Southern Section
Plate 8. Composite Model Ranking by Watershed Using Criteria Two Through Nine
Low
Medium
High
Very High
Top 10% Watersheds
Existing Protected Areas
Pacific Ocean
N
0
10
20
30
40
50
Kilometers
CONSERVATION BIOLOGY INSTITUTE

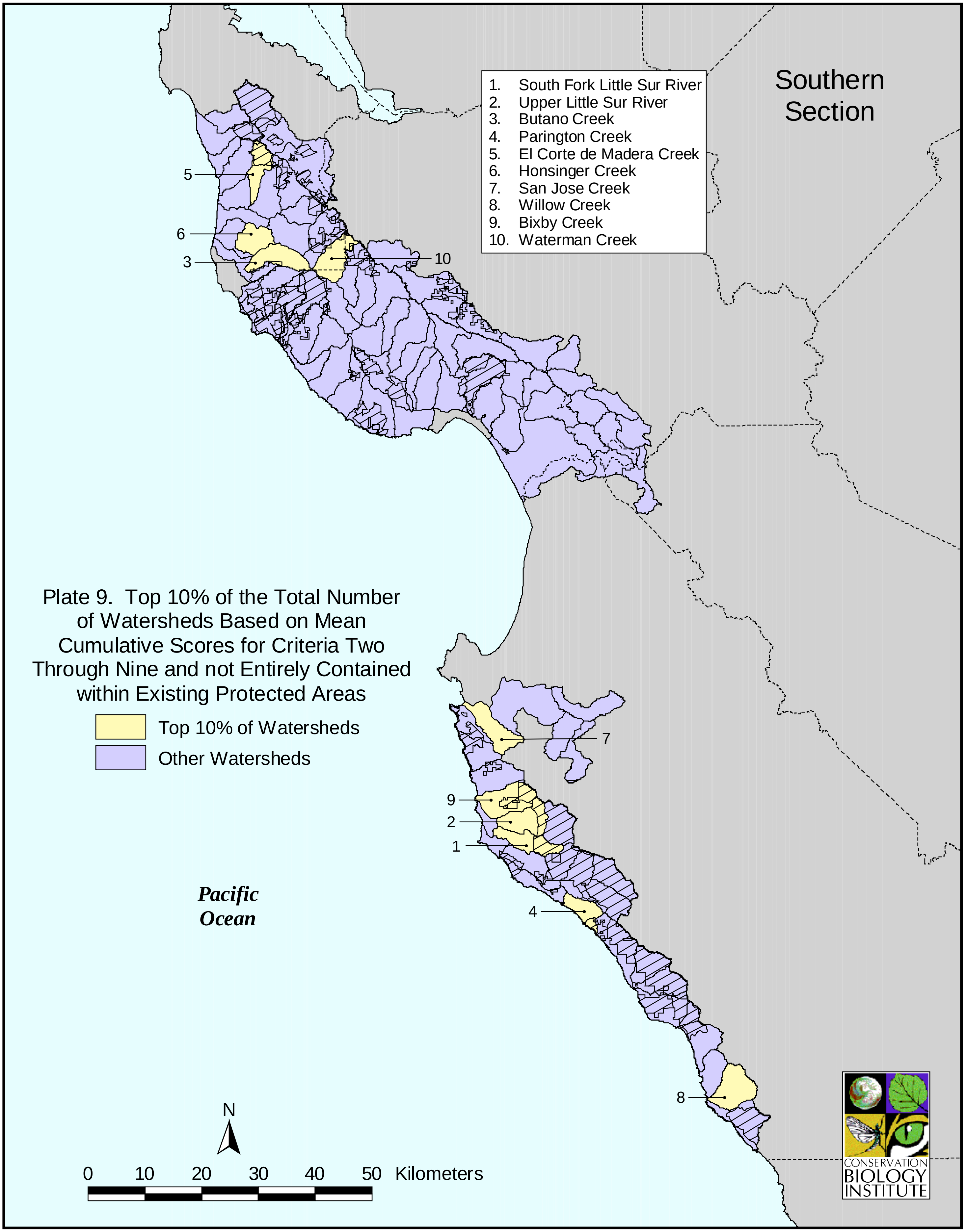


Plate 9. Top 10% of the Total Number of Watersheds Based on Mean Cumulative Scores for Criteria Two Through Nine and not Entirely Contained within Existing Protected Areas