

Market Assessment for Hydropower Turbine Design Tools Using Integrated Datasets of Dams, Turbines, Owners, and Fish



M. S. Bevelhimer
C. R. DeRolph

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Environmental Sciences Division

**MARKET ASSESSMENT FOR HYDROPOWER TURBINE DESIGN TOOLS USING
INTEGRATED DATASETS OF DAMS, TURBINES, OWNERS, AND FISH**

M. S. Bevelhimer
C. R. DeRolph

October 2019

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
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ACRONYMS

BioDE	Biologically Based Design and Evaluation of Hydropower Turbines
BioPA	Biological Performance Assessment
DOE	US Department of Energy
EHA	Existing Hydropower Assets
FERC	Federal Energy Regulatory Commission
HUC	hydrologic unit code
NHAAP	National Hydropower Asset Assessment Program
NOAA	National Oceanic and Atmospheric Administration
ORNL	Oak Ridge National Laboratory
BuRec	US Bureau of Reclamation
USFWS	US Fish and Wildlife Service

ABSTRACT

A US Department of Energy-funded project titled Biologically Based Design and Evaluation of Hydropower Turbines (BioDE) has developed modeling tools and data to inform the design and installation of more environmentally friendly hydropower turbines. A market assessment was conducted to identify prospective users of these products within the hydropower industry and regulatory community. The dataset of hydropower turbines and their defining characteristics (both physical and biological) was developed to refine program outreach and marketing associated with the BioDE tools and data. A specific objective of the analysis was to identify hydropower owners whose turbines could be likely candidates for refurbishing or replacement because of senescence or re-licensing. This report describes a dataset that combines turbine properties, licensing status, fish resources, and ownership information on nearly 5,500 turbines at nearly 2,200 hydropower projects throughout the United States. The data analysis categorizes turbines by design type, geographic region, owner, age, license expiration, fish species presence, and regulatory authority. The analysis identified federal and nonfederal (i.e., Federal Energy Regulatory Commission-licensed) owners with the most turbines of various types and the most turbines that have the potential to interact with fish species of concern.

1. BACKGROUND

A project titled Biologically Based Design and Evaluation of Hydropower Turbines (BioDE), funded by the US Department of Energy's (DOE's) Water Power Technologies Office, has developed modeling tools (specifically BioPA¹ and HBET²) and an experimental dose:response dataset to inform more environmentally friendly hydropower turbine designs. At project outset, we evaluated the number and distribution of turbine types (e.g., Kaplan, Francis, Pelton) in the United States to inform the analytical and experimental direction of BioDE research. The market assessment presented here takes that analysis a step further by including more detailed information on existing federal and nonfederal (i.e., private sector) hydropower projects and individual turbines. In this analysis, we wanted to use this information to inform communication and outreach promoting BioDE modeling tools and data products. In particular, we were interested in identifying project owners who might be considering turbine upgrade or replacement in the near future; our assumption was that they would be most interested in BioDE tools and data. We also wanted to identify other stakeholders (e.g., environmental regulators) who, based on their jurisdictional overlap with projects and aquatic resources, might also be interested in BioDE products.

The primary objectives of the BioDE market assessment were to:

1. identify potential users of BioDE tools and data (e.g., primarily turbine designers, project owners, environmental regulators), and
2. inform BioDE technical direction and priorities with regard to turbine types, project characteristics, and potential biological responses.

2. ASSESSMENT APPROACH

Figure 1 presents a framework for developing market assessment queries aimed at the two primary BioDE user groups: project owner and environmental regulators. Potential users have different areas of interest as

¹ Biological Performance Assessment (BioPA) Toolset.
<https://availabletechnologies.pnnl.gov/technology.asp?id=373>

² Hou H., Z. Deng, J.J. Martinez, T. Fu, J.P. Duncan, G.E. Johnson, and J. Lu, et al. 2018. "A Hydropower Biological Evaluation Toolset (HBET) for Characterizing Hydraulic Conditions and Impacts of Hydro-Structures on Fish." *Energies* 11, no. 4:990. PNNL-SA-124812. doi:10.3390/en11040990

defined by geographic scale; basis for interest (e.g., aging turbines, Federal Energy Regulatory Commission [FERC] relicensing); or presence of species of concern. Based on the scale and reason of interest, a different set of filtering variables would define an informational query. Queries of interest provided in this document were generated by the BioDE team to assist with programmatic outreach and research priorities.

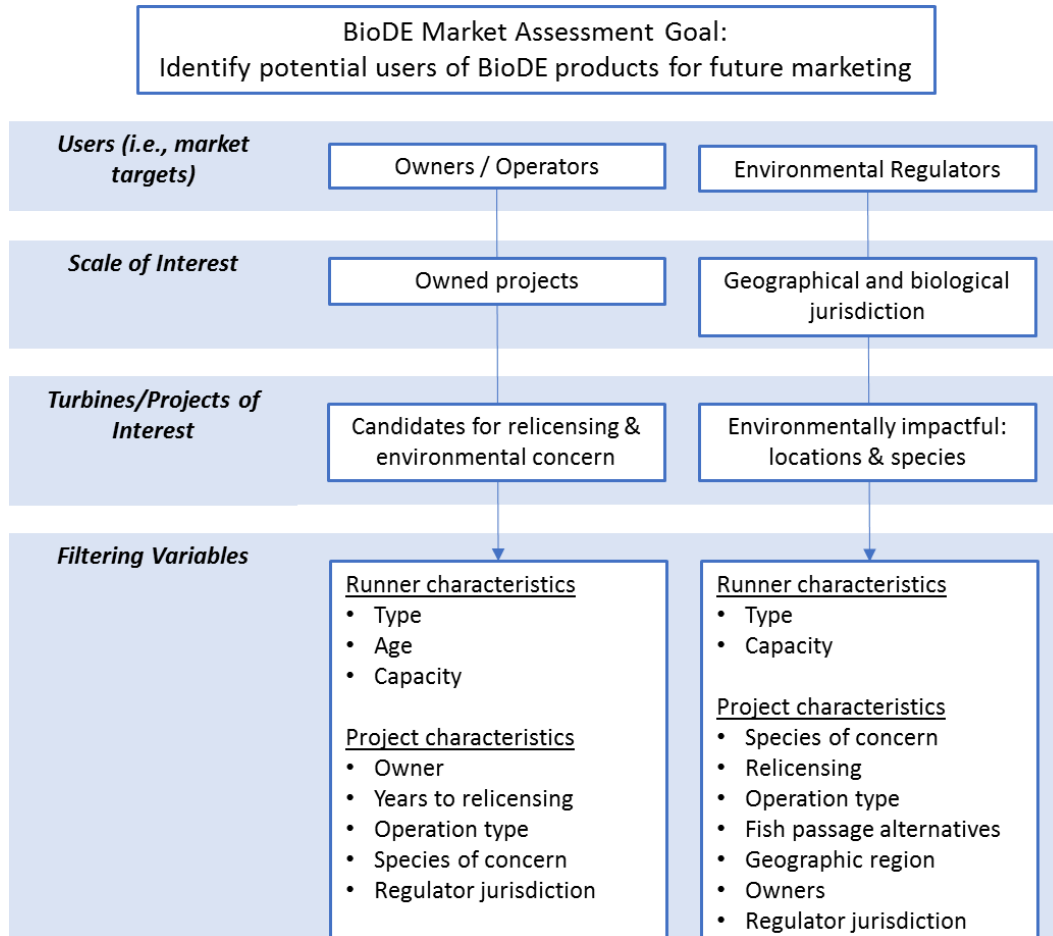


Figure 1. Conceptual framework for developing user-specific market assessment output.

2.1 DATA ANALYSIS

Three types of data were collected during this market assessment (Table 1):

1. **Project-level data:** Federal and private-sector hydropower projects names, locations, and owners (2016 version).
2. **Turbine-level data:** Individual generator/turbine characteristics at each hydropower project (2018 version).
3. **Migratory fish metrics:** Presence of fish species (mostly migratory species) that are of concern for turbine passage at the hydrologic unit code 8 (HUC 8) scale (NatureServe, 2018 version).

Table 1. Hydropower project, generator, and migratory fish metrics for BioDE market assessment database.

Metric	Description and units
Project-level metrics	
EHA_PtID	Hydropower project number
Item	Turbine number within each plant
EIA_PtID	US Energy Information Administration plant identification code
Lat	Latitude in decimal degrees
Long	Longitude in decimal degrees
Type	Conventional hydropower (HY) or pumped storage (PS)
Category	Federal or nonfederal license category (8 categories)
PtName	Plant name
OwName	Plant owner name
OwType	Specific type of private or public ownership
FcIssue	Date of FERC license issuance
FcExpire	Date of FERC license expiration
FcExpireYr	Year of FERC license expiration
HY_MWh	Average annual net hydropower generation, MWh
HY_CF	Capacity factor
Yr_Online	Year plant came online
State	US state abbreviation
City	City name
Water	River name
HUC2	2-digit HUC for project site
HUC2GRP	Watershed groupings for US states and Puerto Rico (10)
HUC10	10-digit HUC for project site
USFWS	USFWS region (8)
NOAA	NOAA fisheries region (5)
BuRec	BuRec region (5)
FERC	FERC hydropower licensing region (6)
Turbine-level metrics	
Item ID	Generator number
EIA_GnID	US Energy Information Administration generator identification code
MW	Total capacity from hydraulic turbine-generator units within each plant, MW
OpYear	Year that the first generator came online for conventional hydropower.
RhYear	The year a unit was refurbished/rehabilitated
TbTypeGen	Turbine type general - Francis, impulse, propeller, pump, other
Maker	Manufacturer of turbine
Speed	Turbine speed (RPM, revolutions per minute)
Head	Turbine rated head (feet)
Power	Turbine power (Hp, horsepower)
Capacity	Turbine hydraulic capacity (cfs, cubic feet per second)
RehabAge	Years since rehabilitation or "null" if not rehabilitated
TurbineAge	Younger of years since online or rehabilitated
TurbStatus	Active, rehabilitated, or retired
Migratory fish metrics	
PChink, PRbt, PLMBass, PBGill, PAmEel, PAmShd, PAtlSal, PStpBass, PSock, PWhtSt, PGrnSt, PAtlSt, PShtSt, PLakSt, PPalSt, PPadlfs	Presence of each species of concern within a reach's HUC 8 watershed – Chinook salmon, rainbow trout/steelhead, largemouth bass, bluegill sunfish, American eel, American shad, Atlantic salmon, striped bass, sockeye salmon, white sturgeon, green sturgeon, Atlantic sturgeon, shortnose sturgeon, lake sturgeon, palid sturgeon, paddlefish.

The turbine data were linked to the project data by a common project ID number, and the fish data were linked to each turbine by geographic location (i.e., stream reach location in the watershed, usually

HUC 8). The data were acquired from Oak Ridge National Laboratory's (ORNL's) Existing Hydropower Assets (EHA) database³ or other DOE-sponsored projects at ORNL, or they were generated specifically for this assessment. The database contains records on 2,303 hydropower projects and 5,482 turbines. Not every turbine entry has complete data for every metric.

Each project (and therefore turbine) is associated with a stream reach and several other geographic locators, including two-digit and ten-digit HUCs (i.e., HUC 2 and HUC 10); US state; and US Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration (NOAA) fisheries, US Bureau of Reclamation (BuRec), and FERC administrative regions. For presentation purposes, we combined 18 HUC 2's into 8 regions of the conterminous US (Figure 2). These eight regions are used throughout this report to provide easy geographic reference and relevance to the summary data.

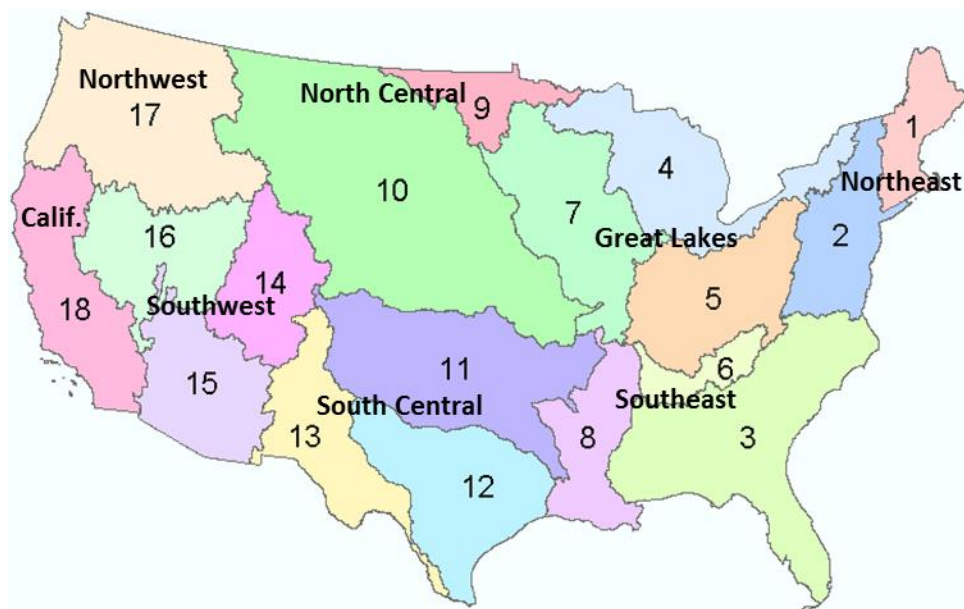


Figure 2. Eighteen HUC 2 watersheds (numbers) and eight watershed regions (text labels) for the conterminous US. Watershed regions were defined by combining 1–3 two-digit HUCs: Northeast–1 & 2; Southeast–3, 6, & 8; Great Lakes–4, 5, & 7; North Central–9 & 10; South Central–11, 12, & 13; Southwest–14, 15, & 16; Northwest–17; California 18.

This analysis used a variety of factors (e.g., turbine age, time to relicensing, geographic location, fish species presence) to filter and sort hydropower project and individual turbine information to focus the BioDE analysis and marketing prioritization and identify the project owners that could potentially benefit the most from the BioDE modeling tools and data.

3. RESULTS

The BioDE market assessment dataset is maintained as an Excel spreadsheet that is easily filtered or sorted by multiple combinations of metrics to show the distribution of turbine types and ages, geographic distribution, manufacturers, owners, and overlap with migratory fish species. Pivot tables were generated with a variety of filtering criteria to produce summaries of interest to address the market assessment task

³ M.M. Johnson, S.-C. Kao, N.M. Samu, and R. Uria-Martinez. 2019. Existing Hydropower Assets, HydroSource. Oak Ridge National Laboratory, Oak Ridge, TN.

objectives. Results from the pivot table analyses are shown in the tables and figures in this section; analyses generally progress from simple to more complex queries.

3.1 GENERAL INFORMATION

The first level of analysis quantified the number of turbines in the United States for each of the major turbine types by owner category (Table 2). The source database for turbine types includes a variety of Francis turbines (e.g., horizontal and vertical) and propeller turbines (e.g., bulb, pit, Kaplan). Because the BioPA is presently most applicable to Francis and propeller turbines, we decided to combine turbine types to just the main categories of turbines defined on the DOE Water Power Program website (<https://www.energy.gov/eere/water/types-hydropower-turbines>). A second high-level analysis was conducted to examine the regional distribution of primary turbine types (Table 3).

Table 2. Number of turbines in the United States for each of the major turbine types by owner category.

Owner category	Francis	Impulse	Propeller	Pump	Unknown	Total
Other	6	15	2	1	54	78
Private (FERC license)	1,934	372	877	176	595	3,954
Private (non-FERC license)	18	5	–	–	281	304
Private on BuRec sites	51	2	24	3	85	165
Private on USACE sites	39	2	116	9	150	316
Reclamation	177	6	5	–	6	194
Tennessee Valley Authority	56	–	52	5	3	116
US Army Corps of Engineers	169	–	186	–	–	355
Total	2,450	402	1,262	194	1,174	5,482

Table 3. Number of turbines of the major types by major watershed for federal and nonfederal projects

HUC 2 region	Francis	Impulse	Propeller	Pump	Unknown	Total
Federal						
Southeast	103	–	72	5	3	183
Great Lakes	16	–	21	–	–	37
North Central	65	–	18	–	–	83
South Central	38	–	22	–	–	60
Southwest	50	5	–	–	–	55
Northwest	100	1	108	–	–	209
California	30	–	2	–	6	38
Total	402	6	243	5	9	665
Nonfederal						
Northeast	640	35	378	76	149	1,278
Southeast	283	6	120	19	28	456
Great Lakes	513	6	275	25	369	1,188
North Central	54	29	17	5	38	143
South Central	29	7	19	6	39	100
Southwest	59	43	6	–	122	230
Northwest	239	107	156	52	113	667
California	207	132	31	6	247	623
Total	2,024	365	1,002	189	1,105	4,685

Note: Refer to figure 2 for HUC 2 watershed region coverage.

3.2 TURBINE AGE

For project owners, turbine age might be an important factor in planning for turbine replacement (Table 4). We found that nearly half of the turbines in operation today are more than 50 years old, and many are more than 100 years old. Though we conducted an analysis of retired turbines, we could not identify a common age at which turbines are replaced by owners. Instead, it appears that a variety of factors in addition to age contribute to the point at which a turbine is rehabilitated or replaced.

Table 4. Number of major turbine types by turbine age (in 2019) for turbines at federal and nonfederal projects.

Turbine age (years)	Francis	Impulse	Propeller	Pump	Unknown	Total
Federal						
1–10	65	2	14	–	–	81
11–20	87	1	37	–	–	125
21–30	55	3	27	–	2	87
31–40	24	–	30	3	1	58
41–50	32	–	40	1	–	73
51–60	52	–	38	–	6	96
61–70	63	–	48	1	–	112
71–80	14	–	7	–	–	21
81–90	3	–	2	–	–	5
91–100	7	–	–	–	–	7
Total	402	6	243	5	9	665
Nonfederal						
1–10	15	3	34	–	72	124
11–20	54	11	23	–	20	108
21–30	150	45	136	17	107	455
31–40	343	156	375	117	161	1,152
41–50	33	4	25	12	32	106
51–60	88	11	86	33	73	291
61–70	122	18	85	–	60	285
71–80	79	10	51	–	40	180
81–90	126	10	60	2	54	252
91–100	485	16	91	2	180	774
101–110	361	35	16	2	106	520
111–128	186	62	35	3	206	492
Total	2,042	381	1,017	188	1,111	4,739

Of the 1,912 turbines in the database that are 50+ years in age, 73% are Francis, and 21% are propeller. The companies having the greatest number of age 50+ turbines in their fleet are found across the United States (Table 5).

Table 5. Project owners with more than 20 turbines that are 50+ years in age.

Owner	Turbine type			
	Francis	Impulse	Propeller	Total
Erie Boulevard Hydropower LP	115	–	25	140
Duke Energy Carolinas, LLC	60	1	6	67
Pacific Gas & Electric Co.	40	23	1	64
PacifiCorp	51	9	–	60
Georgia Power Co.	44	–	10	54
Brookfield White Pine Hydro LLC	41	–	9	50
Southern California Edison Co	14	34	–	48
Great Lakes Hydro America LLC	34	–	11	45
Northern States Power Co – Minnesota	33	–	10	43
Great River Hydro, LLC	30	–	6	36
Consumers Energy Co.	32	–	3	35
Portland General Electric Co.	22	–	12	34
Wisconsin Public Service Corp.	30	–	3	33
Green Mountain Power Corp.	29	–	3	32
NorthWestern Energy	24	2	5	31
Alabama Power Co.	11	–	20	31
Consolidated Water Power Co.	29	–	2	31
Appalachian Power Co.	20	–	11	31
Idaho Power Co.	15	–	14	29
Eagle Creek RE LLC	10	–	15	25
Wisconsin Electric Power Co.	17	–	7	24
South Carolina Electric & Gas Company	22	–	–	22
Avista Corp.	18	–	3	21
Brookfield Black Bear Hydro LLC	13	–	7	20
New York Power Authority	4	–	16	20

A separate database within the EHA database at ORNL includes information on 400+ turbines that have been retired in the last 120 years. Knowing how old these turbines were when retired might help predict the age at which active turbines would be good candidates for replacement. Figure 3 shows that most turbine retirements occur when turbines are 50–100 years old, although age by itself does not appear to be a consistent indicator of retirement.

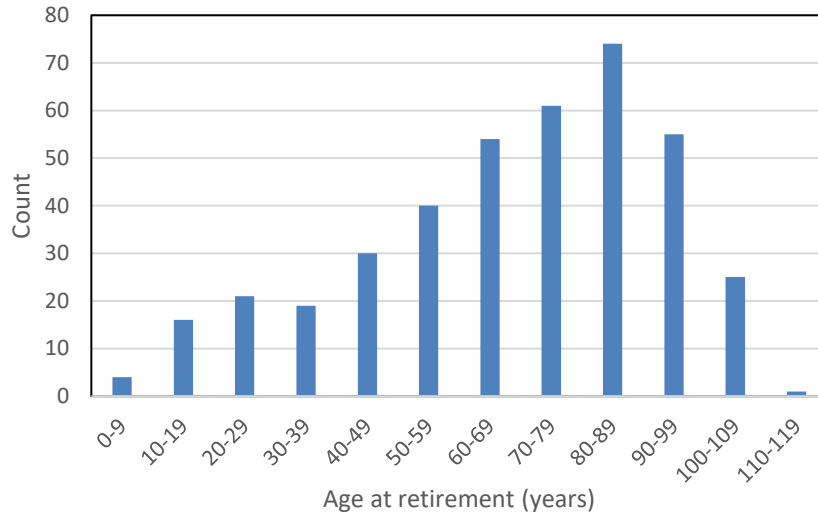


Figure 3. Number of turbines retired by 10-year age groupings.

3.3 FERC RELICENSING

Because major renovations to a project can result in the re-opening (or reassessment) of a project’s FERC license—an option most owners avoid—owner instead typically consider turbine replacement or rehabilitation at the beginning of a new licensing application cycle, even if a turbine might have several years of operational life left. Turbine replacement options are probably considered at least 5 years before license expiration and perhaps as early as 10 years prior to expiration. Two to three hundred turbines are up for relicensing in the period 2023–2026, as well as a similar amount in 2033–2037 (Figure 4).

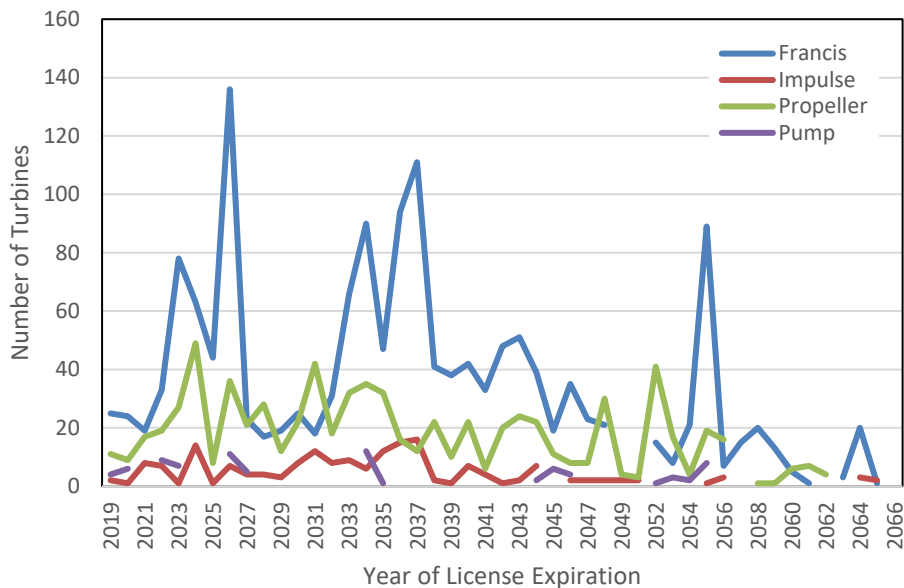


Figure 4. Number of major turbine types affected by FERC license expiration by year of expiration.

The geographic distribution of projects up for relicensing in the next 20 years is skewed toward the Northeast and Great Lakes regions, where nearly two-thirds of those projects exist (Table 6). Although decisions to replace or rehabilitate turbines at federal projects are not affected by licensing, the federal agencies that operate hydropower projects often have long-range plans for when turbines will be considered for replacement or rehabilitation. These schedules would be useful for BioDE tool marketing; however, they are not part of this assessment.

Table 6. Number of turbines affected by FERC license expiration in the next 20 years (2021–2040) by watershed region.

HUC 2	Francis	Impulse	Propeller	Pump	Total
Northeast	308	8	181	28	525
Southeast	104	4	45	11	164
Great Lakes	370	5	143	2	520
North Central	26	5	10	–	41
South Central	23	3	14	–	40
Southwest	31	18	–	–	49
Northwest	103	24	77	4	208
California	53	57	10	3	123
Total	1,018	124	480	48	1,670

Note: Refer to figure 2 for HUC 2 watershed region coverage.

3.4 OWNERS

The primary objective of this market assessment is to identify project owners that could benefit from BioDE tools and data. It stands to reason that the owners with the most turbines might be most interested in obtaining new assessment tools and information. Owners with the most turbines are a mix of federal and nonfederal entities (Table 7).

Table 7. Owners with 25+ of the two major turbine types.

Owner	Francis	Propeller	Total
Erie Boulevard Hydropower LP	124	33	157
USACE Northwestern Division	48	105	153
Tennessee Valley Authority	56	52	108
Duke Energy Carolinas LLC	69	8	77
Eagle Creek RE LLC	27	35	62
Brookfield White Pine Hydro LLC	42	17	59
Georgia Power Co.	46	12	58
US BuRec – Pac NW	52	3	55
PacifiCorp	53	–	53
Great Lakes Hydro America LLC	34	18	52
Pacific Gas & Electric Co.	50	1	51
Northern States Power Co. – Minnesota	34	17	51
US BuRec – Great Plains	42	–	42
Green Mountain Power Corp	34	8	42
New York Power Authority	17	24	41
Great River Hydro LLC	35	6	41
Consumers Energy Co.	38	3	41
Alabama Power Co.	18	23	41

Table 7. Owners with 25+ of the two major turbine types (continued).

Owner	Francis	Propeller	Total
Consumers Energy Co.	38	3	41
Wisconsin Public Service Corp	35	5	40
Idaho Power Co.	16	23	39
Consolidated Water Power Co.	32	6	38
USACE-Missouri River District	25	11	36
Portland General Electric Co.	22	12	34
PUD No. 1 of Chelan County	6	25	31
South Carolina Electric & Gas Company	31	–	31
Appalachian Power Co.	20	11	31
NorthWestern Energy	24	6	30
USACE – Nashville District	13	15	28
USACE – Mobile District	10	17	27
USACE – Little Rock District	18	9	27
Avista Corp.	22	5	27
US BuRec – Mid-Pacific	24	2	26
US BuRec – Lower Colorado	26	–	26
CHI Energy Inc.	14	12	26
US BuRec – Upper Colorado	25	–	25
Brookfield Black Bear Hydro LLC	13	12	25

Note: Federal owners are highlighted in grey.

3.5 SPECIES OF CONCERN

By merging information on fish species presence (original data source: *NatureServe*), we were able to evaluate whether there are specific turbine types or owner categories (e.g., federal vs. private) that overlap most with the habitats of various migratory and resident fish species of concern. The list of 16 species evaluated includes four salmon/trout species and 6 sturgeon species. Most of the 16 species have been represented either directly or with surrogate species in the laboratory dose–response studies conducted as part of the BioDE project or from other sources. Because the species have large geographic distributions, their overlap with hydropower turbines is extensive (Table 8).

Because our BioDE dose–response work targets specific fish taxa and because regulatory concerns seem to focus on select species, it is useful to identify project owner by the number of turbines they operate that could interact with species of greatest concern. Tables 9 and 10 contain federal and nonfederal owners for a few select species as examples; Tables A-1 and A-2 in appendix A include all species of interest. The data in Table 10 apply only to owners with licenses expiring in the next 20 years. We also conducted this analysis on projects whose licenses expire in the period 2023–2027 (see table A-3 in appendix A), as those owners might be most likely to consider turbine replacement or rehabilitation in the very near future.

Table 8. Number of turbines of the major types that overlap with the distribution of various species of turbine passage or regulatory concern.

Row labels	Francis	Impulse	Propeller	Pump	Unknown	Total
Chinook salmon	382	136	209	20	190	937
Rainbow trout/steelhead	517	195	275	45	320	1,352
Largemouth bass	997	15	524	52	379	1,967
Bluegill sunfish	830	9	468	48	352	1,707
American eel	1,104	44	677	98	267	2,190
American shad	518	21	255	64	87	945
Atlantic salmon	539	23	275	51	105	993
Striped bass	322	13	220	29	36	620
Sockeye salmon	157	38	165	9	48	417
White sturgeon	256	64	207	17	96	640
Green sturgeon	53	35	23	9	52	172
Atlantic sturgeon	263	11	172	33	23	502
Shortnose sturgeon	240	10	124	29	30	433
Lake sturgeon	527	9	324	31	291	1,182
Pallid sturgeon	30	0	26	0	2	58
Paddlefish	267	0	235	15	72	589
Total no. of turbines	2,450	402	1,262	194	1,174	5,482

Table 9. Federal owners with 5+ turbines located at projects that overlap with Chinook salmon, American eel, and American shad.

Owner	Francis	Propeller	Total
Chinook salmon			
California	8	2	10
US BuRec – Mid-Pac	8	2	10
Northwest	76	102	178
USACE Northwestern Div.	40	102	142
US BuRec – Pac NW	36	–	36
American eel			
Great Lakes	12	12	24
USACE – Nashville District	12	7	19
USACE – Detroit District	–	5	5
North Central	8	11	19
USACE – Missouri River District	8	11	19
South Central	29	18	47
USACE – Little Rock District	18	9	27
USACE – Tulsa District	11	9	20
Southeast	35	56	91
Tennessee Valley Authority	18	42	60
USACE – Mobile District	–	14	14
USACE – Wilmington District	12	–	12
USACE – Vicksburg District	5	–	5
American shad			
Southeast	29	3	32
USACE – Savannah District	20	3	23
USACE – Wilmington District	9	–	9

Note: Refer to table A-1 in appendix A for a full list of species.

Table 10. Nonfederal owners with 12+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with Chinook salmon, American eel, and American shad.

Owner	Francis	Propeller	Total
Chinook salmon			
California	18	3	21
Pacific Gas & Electric Co.	15	–	15
Northwest	46	27	73
PUD No. 1 of Chelan County	4	14	18
Portland General Electric Co	3	12	15
City of Tacoma – WA	14	1	15
PacifiCorp	13	–	13
City of Seattle – WA	12	–	12
American eel			
Great Lakes	129	30	159
Erie Boulevard Hydropower LP	65	11	76
Northern States Power Co – Minnesota	18	11	29
Northeast	220	95	315
Great Lakes Hydro America LLC	34	14	48
Brookfield White Pine Hydro LLC	27	11	38
Green Mountain Power Corp	22	5	27
Boott Hydropower, Inc. & E. L. Field Hydroelectric Facility Trust	19	–	19
Great River Hydro LLC	15	–	15
City of Holyoke Gas and Electric Dept.	10	5	15
Safe Harbor	2	12	14
Brookfield Black Bear Hydro LLC	5	8	13
BIF III Holtwood LLC	10	2	12
Southeast	48	18	66
Georgia Power Co.	25	6	31
American shad			
Northeast	131	59	190
Brookfield White Pine Hydro LLC	23	10	33
Great Lakes Hydro America LLC	22	5	27
Boott Hydropower, Inc. & Eldred L. Field Hydroelectric Facility Trust	19	–	19
City of Holyoke Gas and Electric Dept.	10	5	15
Safe Harbor	2	12	14
Brookfield Black Bear Hydro LLC	5	8	13
BIF III Holtwood LLC	10	2	12
Southeast	47	4	51
Georgia Power Co.	25	2	27

Note: Refer to table A-2 in appendix A for a full list of species.

These queries can be refined to identify owners for specific types of hydropower projects (e.g., nonfederal owners with propeller-type turbines) located at projects with FERC licenses expiring in the period 2023–2027 and that overlap with American eel presence (Table 11). The 5-year span from 2023–2027 was selected based on the assumption that any decisions regarding replacement or rehabilitation in the next 3–4 years would have probably already been made.

Table 11. Nonfederal owners with propeller-type turbines located at projects with FERC licenses expiring in the period 2023–2027 and that overlap with American eels.

Owner	Propeller
Great Lakes	
Erie Boulevard Hydropower LP	7
Ampersand Mount Ida Hydro LLC	8
Northeast	
Great Lakes Hydro America LLC	14

3.6 REGULATORS

Although project owners are the primary target of BioDE outreach efforts, we have also interacted with regulators in the past and expect to continue to market BioDE information to regulators who influence hydropower infrastructure and operations decisions. For the BioDE tools to be most useful to project owners, the tools should not only help them make decisions related to turbine replacement and rehabilitation, but ideally should also be accepted by the regulatory community as scientifically sound and reliable.

NOAA fisheries, which are responsible for addressing hydropower licensing issues related to ocean-run migratory fish, are organized into five regions (Figure 5). Note that some of the regions extend beyond the range of anadromous fish, but NOAA has some jurisdiction in these areas, including activities in upstream watersheds where those activities might affect downstream migratory fish or their habitats. Federal hydropower projects reside mostly in NOAA’s West Coast and Southeast regions, while nonfederal projects with upcoming FERC license expirations are most prevalent in the New England–Mid-Atlantic region (Table 12).

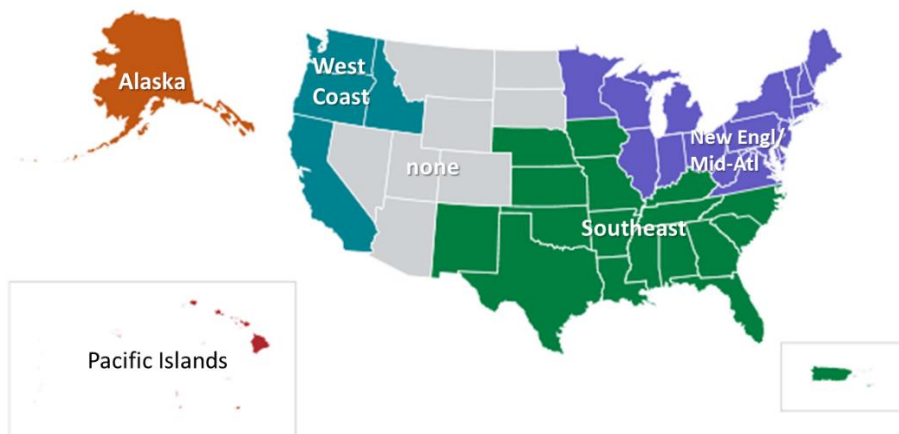


Figure 5. Five NOAA fisheries regions.

Table 12. Count and distribution of major turbine types by NOAA fisheries region at federal projects, nonfederal projects, and nonfederal projects with upcoming expiring FERC licenses (2021–2040).

NOAA fisheries region	Francis	Impulse	Propeller	Pump	Total
Federal					
None (inland)	120	5	8	–	133
West	127	1	110	–	238
South	143	–	120	5	268
Northeast	12	–	5	–	17
Total	402	6	243	5	656
Nonfederal					
None (inland)	97	86	5	14	202
West	438	232	58	187	915
South	319	5	22	157	503
Northeast	1,170	44	104	660	1,978
Alaska	24	28	–	1	53
Pacific Islands	–	1	–	–	1
Total	2,048	396	189	1,019	3,652
Nonfederal (FERC license expiring 2021–2040)					
None (inland)	51	29	8	–	88
West	155	78	86	7	326
South	119	3	61	8	191
Northeast	693	16	325	33	1,067
Alaska	17	19	–	–	36
Total	1,035	145	480	48	1,708

The USFWS, which is organized into eight regions across the United States (Figure 6), is most concerned with fish listed under the Endangered Species Act. Federal hydropower projects reside mostly in regions 1, 4, and 6, while about half of nonfederal projects with upcoming FERC license expirations are found in regions 3 and 5 (Table 13).



Figure 6. Eight USFWS regions.

Table 13. Count and distribution of major turbine types by USFWS region at federal projects, nonfederal projects, and nonfederal projects with upcoming expiring FERC licenses (2021–2040).

USFWS region	Francis	Impulse	Propeller	Pump	Total
Federal					
1	76	1	102	–	179
2	40	1	13	–	54
3	5	–	13	–	18
4	120	–	96	5	221
5	12	–	–	–	12
6	105	3	17	–	125
8	44	1	2	–	47
Total	402	6	243	5	656
Nonfederal					
1	164	54	90	17	325
2	23	–	7	6	36
3	339	3	155	1	498
4	275	5	135	16	431
5	847	41	514	103	1,505
6	162	132	86	40	420
7	24	28	1	–	53
8	214	133	31	6	384
Total	2,048	396	1,019	189	3,652
Nonfederal (FERC license expiring 2021–2040)					
1	66	9	44	3	122
2	19	–	2	–	21
3	266	3	93	–	362
4	96	3	52	8	159
5	431	13	239	33	716
6	87	41	40	1	169
7	17	19	–	–	36
8	53	57	10	3	123
Total	1,035	145	480	48	1,708

For the purposes of hydropower project licensing, FERC partitions the country into six regions (Figure 7). Although they are the two smallest regions in terms of area, the New England and Mid-Atlantic regions had more turbines at licensed projects than the other regions (Table 14). The distribution of turbines at projects with licenses expiring in the period 2021–2040 is virtually the same as the overall distribution.

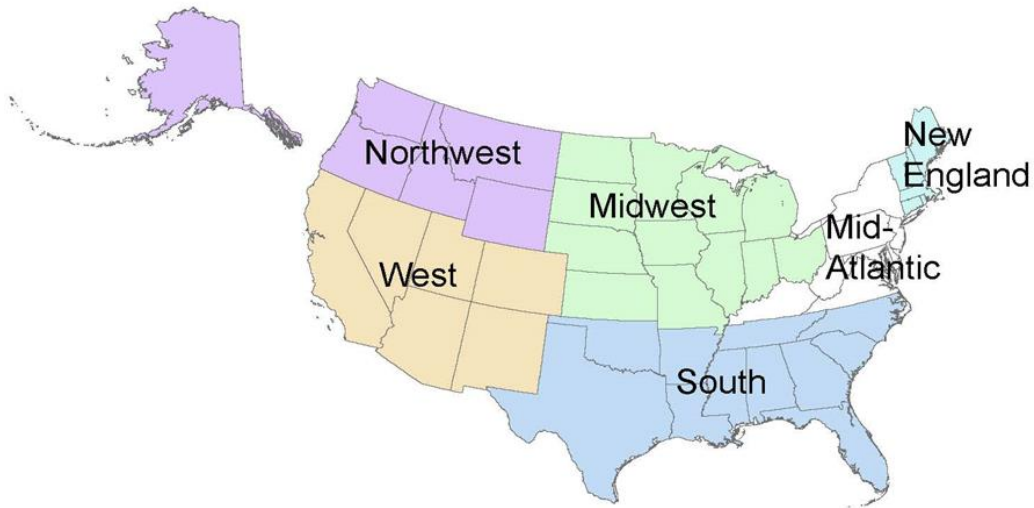


Figure 7. Six FERC regions.

Table 14. Count and distribution of major turbine types by FERC region at all FERC-licensed projects and at FERC-licensed projects with licenses expiring in the period 2021–2040.

FERC region	Francis	Impulse	Propeller	Pump	Total
FERC-licensed projects					
Midwest	344	6	161	1	512
New England	466	24	268	47	805
Mid-Atlantic	381	17	256	56	710
Northwest	299	148	165	51	663
South	293	3	131	22	449
West	259	181	36	11	487
Total	2,042	379	1,017	188	3,626
FERC-licensed projects 2021–2040					
Midwest	266	3	93	–	362
New England	239	6	113	18	376
Mid-Atlantic	192	7	126	15	340
Northwest	147	47	84	4	282
South	110	1	53	8	172
West	81	79	11	3	174
Total	1,035	143	480	48	1,706

4. CONCLUSIONS

The primary objective of the BioDE market assessment task reported here was to develop a dataset of hydropower turbines and their defining characteristics (both physical and biological) for the purpose of refining program outreach and marketing of BioDE tools and data. The results presented here identified

the federal and nonfederal owners with the most turbines of various types and the most turbines that have the potential to interact with various species of interest.

The data did not reveal a reliable relationship between turbine age and point of replacement or rehabilitation, so we focused our analysis on number of years until FERC license expiration as an indicator of when project owners might consider replacement. The resulting dataset is maintained as an Excel spreadsheet, and although most of the results shown in the report were derived from pivot table analysis, the spreadsheet is also populated with filters (i.e., pull-down menus) that can be used to easily generate specific queries. Furthermore, once specific owners are identified, the pull-down menus can be used to filter the main dataset by an owner and other attributes (e.g., turbine type and year of FERC license expiration) to find project details. For example, for the seven propeller turbines owned/operated by Erie Boulevard Hydropower that have licenses expiring soon and have American eels present (see Table 11), we find that those seven turbines are located at two FERC-licensed projects (P-2538 and P-2569) on the Black River in upstate New York and that they have a capacity range of 900–1800 cfs, a head range of 15.5–32 ft, and a nameplate capacity range of 0.7–2.8 MW.

This type of information could be useful in marketing the BioDE modeling tools and dataset if we can cite other successful applications at projects with similar characteristics. Similarly, we can specifically target projects with characteristics that match those where BioDE tools have been applied successfully. In the analysis presented, other than turbine type, we did not summarize by turbine characteristics such as runner speed, head, or generating capacity, but such analyses could easily be conducted if some marketing objective included a more specific project target (e.g., a specific turbine size).

We have tried to present in this report a variety of analyses so that users of the dataset can quickly identify which queries best match their needs. With that in mind, however, the data summary in table A-3 in appendix A is probably most useful for identifying owners to whom BioDE should be marketed based on when their licenses expire, the types of turbines they have, where they are located, and the species with which they potentially interact.

5. ACKNOWLEDGMENTS

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APPENDIX A. EXPANDED OUTPUT

Table A-1. Federal owners with 5+ turbines located at projects that overlap with seven species of interest.

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Chinook salmon			
California	8	2	10
US BuRec – Mid-Pac	8	2	10
Northwest	76	102	178
USACE Northwestern Division	40	102	142
US BuRec – Pac NW	36		36
Total	84	104	188
Rainbow trout/steelhead			
California	30	2	32
US BuRec – Mid-Pac	22	2	24
California Dept. of Water Resources	8		8
Northwest	91	102	193
USACE Northwestern Division	48	102	150
US BuRec – Pac NW	43		43
Total	121	104	225
Largemouth bass			
Great Lakes	16	16	32
USACE – Nashville District	13	15	28
North Central	8	10	18
USACE – Missouri River District	8	3	11
USACE – Kansas City District		7	7
South Central	33	22	55
USACE – Little Rock District	18	9	27
USACE – Tulsa District	13	9	22
USACE – Fort Worth District	2	4	6
Southeast	103	72	175
Tennessee Valley Authority	54	52	106
USACE – Mobile District	10	17	27
USACE – Savannah District	20	3	23
USACE – Wilmington District	12		12
USACE – Vicksburg District	7		7
Total	160	120	280
Bluegill sunfish			
Great Lakes	16	21	37
USACE – Nashville District	13	15	28
USACE – Detroit District		5	5

Table A-1. Federal owners with 5+ turbines located at projects that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
North Central	8	10	18
USACE – Missouri River District	8	3	11
USACE – Kansas City District		7	7
South Central	36	22	58
USACE – Little Rock District	18	9	27
USACE – Tulsa District	13	9	22
USACE – Fort Worth District	2	4	6
Southeast	91	72	163
Tennessee Valley Authority	54	52	106
USACE – Mobile District	10	17	27
USACE – Savannah District	20	3	23
USACE – Vicksburg District	7		7
Total	151	125	276
American eel			
Great Lakes	12	12	24
USACE – Nashville District	12	7	19
USACE – Detroit District		5	5
North Central	8	11	19
USACE – Missouri River District	8	11	19
South Central	29	18	47
USACE – Little Rock District	18	9	27
USACE – Tulsa District	11	9	20
Southeast	35	56	91
Tennessee Valley Authority	18	42	60
USACE – Mobile District		14	14
USACE – Wilmington District	12		12
USACE – Vicksburg District	5		5
Total	84	97	181
American shad			
Southeast	29	3	32
USACE – Savannah District	20	3	23
USACE – Wilmington District	9		9
Total	29	3	32
Atlantic salmon			
Total	0	0	0

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest.

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Chinook salmon			
California	18	3	21
Pacific Gas & Electric Co.	15		15
East Bay Municipal Util. Dist.	3	3	6
Northwest	46	27	73
PUD No. 1 of Chelan County	4	14	18
Portland General Electric Co	3	12	15
City of Tacoma – WA	14	1	15
PacifiCorp	13		13
City of Seattle – WA	12		12
Total	64	30	94
Rainbow trout/steelhead			
California	19	3	22
Pacific Gas & Electric Co.	16		16
East Bay Municipal Util. Dist.	3	3	6
Northwest	52	58	110
Idaho Power Co.	2	20	22
PUD No. 1 of Chelan County	4	14	18
Portland General Electric Co.	3	12	15
City of Tacoma – WA	14	1	15
PacifiCorp	13		13
City of Seattle – WA	12		12
Boise-Kuna Irrigation District	2	3	5
City of Spokane		5	5
Columbia Basin Hydropower	2	3	5
Total	71	61	132
Largemouth bass			
Great Lakes	303	71	374
Erie Boulevard Hydropower LP	60	11	71
Northern States Power Co – Minnesota	29	14	43
Consolidated Water Power Co.	32	6	38
Consumers Energy Co.	30	3	33
Wisconsin Public Service Corp.	29	1	30
Wisconsin Electric Power Co.	15	5	20
Domtar Industries, Inc.	14		14
ALLETE, Inc.	12	1	13
Wisconsin River Power Company		9	9
Wisconsin Power & Light Co.	8	1	9

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
N E W Hydro LLC	3	6	9
Northbrook Lyons Falls LLC	8		8
Renewable World Energies LLC	7		7
Domtar Paper Company Rothschild	7		7
Boyce Hydro Power LLC	3	4	7
Northern Indiana Pub Serv Co.	7		7
Ampersand Hydro LLC		7	7
Appalachian Power Co.	7		7
Indiana Michigan Power Co.	7		7
C-S Canal Hydro, LLC	6		6
Northbrook Wisconsin LLC	6		6
Thunder Bay Power Co LLC	6		6
Brainerd Public Utilities	5		5
City of Hamilton – OH	2	3	5
Northeast	22	8	30
Green Mountain Power Corp.	19	5	24
Sheldon Vermont Hydro Co., Inc.	3	3	6
South Central	10	6	16
Grand River Dam Authority	10		10
Arkansas Electric Coop Corp.		6	6
Southeast	80	20	100
Georgia Power Co.	40	10	50
South Carolina Electric & Gas Company	12		12
Duke Energy Carolinas, LLC	10		10
Alabama Power Co.	9	1	10
First National Bank-Commerce		8	8
Lockhart Power Co.	5		5
PowerSouth Energy Cooperative	4	1	5
Total	415	105	520
Bluegill sunfish			
Great Lakes	236	60	296
Erie Boulevard Hydropower LP	39	7	46
Northern States Power Co – Minnesota	29	14	43
Consolidated Water Power Co.	32	6	38
Wisconsin Public Service Corp.	29	1	30
Wisconsin Electric Power Co.	15	5	20
Domtar Industries, Inc.	14		14
ALLETE, Inc.	12	1	13

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Wisconsin River Power Company		9	9
Wisconsin Power & Light Co.	8	1	9
N E W Hydro LLC	3	6	9
Northbrook Lyons Falls LLC	8		8
Indiana Michigan Power Co.	7		7
Domtar Paper Company Rothschild	7		7
Northern Indiana Pub Serv Co.	7		7
Ampersand Hydro LLC		7	7
Renewable World Energies LLC	7		7
C-S Canal Hydro LLC	6		6
Northbrook Wisconsin LLC	6		6
City of Hamilton – OH	2	3	5
Brainerd Public Utilities	5		5
Northeast	10	1	11
Green Mountain Power Corp.	10	1	11
South Central	10	6	16
Grand River Dam Authority	10		10
Arkansas Electric Coop Corp.		6	6
Southeast	80	20	100
Georgia Power Co.	40	10	50
South Carolina Electric & Gas Company	12		12
Duke Energy Carolinas, LLC	10		10
Alabama Power Co.	9	1	10
First National Bank-Commerce		8	8
Lockhart Power Co.	5		5
PowerSouth Energy Cooperative	4	1	5
Total	336	87	423
American eel			
Great Lakes	129	30	159
Erie Boulevard Hydropower LP	65	11	76
Northern States Power Co - Minnesota	18	11	29
Wisconsin Power & Light Co.	8		8
Ampersand Hydro LLC		8	8
Northbrook Lyons Falls LLC	8		8
Appalachian Power Co.	7		7
Northern Indiana Pub Serv Co.	7		7
C-S Canal Hydro, LLC	6		6
ALLETE, Inc.	5		5

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
CHI Energy, Inc	5		5
Northeast	220	95	315
Great Lakes Hydro America LLC	34	14	48
Brookfield White Pine Hydro LLC	27	11	38
Green Mountain Power Corp.	22	5	27
Boott Hydropower, Inc. & E. L. Field Hydroelectric Fac. Trust	19		19
Great River Hydro, LLC	15		15
City of Holyoke Gas and Electric Dept.	10	5	15
Safe Harbor	2	12	14
Brookfield Black Bear Hydro, LLC	5	8	13
BIF III Holtwood LLC	10	2	12
Eagle Creek RE LLC	3	8	11
PE Hydro Generation, LLC	10	1	11
New York Power Authority	4	6	10
KEI (Maine) Power Management LLC	6	3	9
Central Vermont Pub Serv Corp.	4	4	8
Potomac Edison Co.	5	2	7
Merimil Ltd Partnership	6	1	7
Palmer Hydroelectric	2	5	7
Sheldon Vermont Hydro Co., Inc.	3	3	6
Brookfield Power New England	6		6
Erie Boulevard Hydropower LP	6		6
Public Service Co. of NH	4	2	6
Consolidated Hydro NH Inc.	5		5
Virginia Electric & Power Co.	5		5
Central Maine Power Co.	2	3	5
Appalachian Power Co.	5		5
South Central	10	6	16
Grand River Dam Authority	10		10
Arkansas Electric Coop Corp.		6	6
Southeast	48	18	66
Georgia Power Co.	25	6	31
South Carolina Electric & Gas Company	8		8
Alabama Power Co.	7	1	8
First National Bank-Commerce		8	8
Appalachian Power Co.	4	2	6
PowerSouth Energy Cooperative	4	1	5

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Total	407	149	556
American shad			
Northeast	131	59	190
Brookfield White Pine Hydro LLC	23	10	33
Great Lakes Hydro America LLC	22	5	27
Boott Hydropower, Inc. & E. L. Field Hydroelectric Fac. Trust	19		19
City of Holyoke Gas and Electric Dept.	10	5	15
Safe Harbor	2	12	14
Brookfield Black Bear Hydro LLC	5	8	13
BIF III Holtwood LLC	10	2	12
Eagle Creek RE LLC	3	6	9
KEI (Maine) Power Management LLC	6	2	8
Palmer Hydroelectric	2	5	7
Merimil Ltd Partnership	6	1	7
Brookfield Power New England	6		6
Central Maine Power Co.	2	3	5
Virginia Electric & Power Co.	5		5
Consolidated Hydro NH Inc.	5		5
Appalachian Power Co.	5		5
Southeast	47	4	51
Georgia Power Co.	25	2	27
Duke Energy Carolinas LLC	10		10
South Carolina Electric & Gas Company	8		8
Appalachian Power Co.	4	2	6
Total	178	63	241
Atlantic salmon			
Great Lakes	79	11	90
Erie Boulevard Hydropower LP	65	11	76
Northbrook Lyons Falls LLC	8		8
C-S Canal Hydro LLC	6		6
Northeast	171	57	228
Great Lakes Hydro America LLC	34	14	48
Brookfield White Pine Hydro LLC	27	11	38
Green Mountain Power Corp.	22	5	27
Boott Hydropower, Inc. & E.L. Field Hydroelectric Fac. Trust	19		19
Great River Hydro LLC	15		15

Table A-2. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2021–2040 and that overlap with seven species of interest (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
City of Holyoke Gas and Electric Dept.	10	5	15
Brookfield Black Bear Hydro LLC	5	8	13
Public Service Co. of NH	7	2	9
KEI (Maine) Power Management LLC	6	3	9
Merimil Ltd Partnership	6	1	7
Brookfield Power New England	6		6
Sheldon Vermont Hydro Co., Inc.	3	3	6
Central Vermont Pub Serv Corp.	4	2	6
Central Maine Power Co.	2	3	5
Consolidated Hydro NH Inc.	5		5
Total	250	68	318

Table A-3. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2023–2027 by the species of interest they overlap.

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Chinook Salmon			
California	5		5
Pacific Gas & Electric Co.	5		5
Northwest	12		12
City of Seattle – WA	12		12
Total	17		17
Rainbow trout/steelhead			
California	5		5
Pacific Gas & Electric Co.	5		5
Northwest	12		12
City of Seattle – WA	12		12
Total	17		17
Largemouth bass			
Great Lakes	104	26	130
Erie Boulevard Hydropower LP	33	7	40
Consolidated Water Power Co.	18	6	24
Domtar Industries Inc	14		14
Northern States Power Co. – Minnesota	4	4	8
Northbrook Lyons Falls LLC	8		8
Ampersand Hydro LLC		7	7
Domtar Paper Company Rothschild	7		7
Appalachian Power Co.	7		7
N E W Hydro LLC	3	2	5
Brainerd Public Utilities	5		5
Wisconsin Public Service Corp.	5		5
Northeast	9	3	12
Sheldon Vermont Hydro Co., Inc.	3	3	6
Green Mountain Power Corp.	6		6
Southeast	14		14
South Carolina Electric & Gas Company	8		8
Georgia Power Co.	6		6
Total	127	29	156
Bluegill sunfish			
Great Lakes	97	26	123
Erie Boulevard Hydropower LP	33	7	40
Consolidated Water Power Co.	18	6	24
Domtar Industries Inc.	14		14
Northbrook Lyons Falls LLC	8		8

Table A-3. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2023–2027 by the species of interest they overlap (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
Northern States Power Co. – Minnesota	4	4	8
Domtar Paper Company Rothschild	7		7
Ampersand Hydro LLC		7	7
Wisconsin Public Service Corp.	5		5
Brainerd Public Utilities	5		5
N E W Hydro LLC	3	2	5
Southeast	14		14
South Carolina Electric & Gas Company	8		8
Georgia Power Co.	6		6
Total	111	26	137
Great Lakes	48	15	63
Erie Boulevard Hydropower LP	33	7	40
Ampersand Hydro LLC		8	8
Northbrook Lyons Falls LLC	8		8
Appalachian Power Co.	7		7
Northeast	98	25	123
Great Lakes Hydro America LLC	32	14	46
Boott Hydropower, Inc. & E. L. Field Hydroelectric Fac. Trust	19		19
Green Mountain Power Corp.	9		9
New York Power Authority	4	4	8
Potomac Edison Co.	5	2	7
Brookfield Power New England	6		6
Sheldon Vermont Hydro Co., Inc.	3	3	6
Erie Boulevard Hydropower LP	6		6
PE Hydro Generation, LLC	6		6
Appalachian Power Co.	5		5
Public Service Co of NH	3	2	5
Southeast	14		14
South Carolina Electric & Gas Company	8		8
Georgia Power Co.	6		6
Total	160	40	200
American shad			
Northeast	52	5	57
Great Lakes Hydro America LLC	22	5	27
Boott Hydropower, Inc. & E. L. Field Hydroelectric Fac. Trust	19		19
Brookfield Power New England	6		6
Appalachian Power Co	5		5
Southeast	14		14

Table A-3. Nonfederal owners with 5+ turbines located at projects with FERC licenses expiring in the period 2023–2027 by the species of interest they overlap (continued).

Owner and Species	Turbine Type		Total
	Francis	Propeller	
South Carolina Electric & Gas Company	8		8
Georgia Power Co.	6		6
Total	66	5	71
Atlantic salmon			
Great Lakes	41	7	48
Erie Boulevard Hydropower LP	33	7	40
Northbrook Lyons Falls LLC	8		8
Northeast	72	19	91
Great Lakes Hydro America LLC	32	14	46
Boott Hydropower, Inc. & E. L. Field Hydroelectric Fac. Trust	19		19
Green Mountain Power Corp.	9		9
Brookfield Power New England	6		6
Sheldon Vermont Hydro Co., Inc.	3	3	6
Public Service Co of NH	3	2	5
Total	113	26	139

