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THE INCOMPLETE ECOLOGY OF HYDRAULIC FRACTURING GOVERNANCE

Gregg P. Macey*

ABSTRACT

Legal scholars respond to novel risks and technologies such as hydraulic fracturing with a wide range of governance claims. Normative claims are rendered as to whether central (federal), devolved (state and local), dual (distinct and separate approaches), cooperative (shared authority), or dynamic (overlapping and collaborative) federalism should prevail in addressing a policy problem. But the means by which scholars distinguish among governance options are often overconfident. Some accounts claim that regulators lack resources and expertise, or they enjoy economies of scale. Others argue that state or federal actors can tailor decisions and serve as testing grounds, or they are unable to get such experiments off the ground. What these claims lack is an account of how governance emerges in response to a new policy context.

This Article develops such an account. It recasts unconventional oil and gas development, which inspired a vast literature focused on abiotic impacts such as chemical contamination, as a landscape conservation problem. As fracking sites proliferated in twenty states, they were met with similarly exponential growth in scientific research, most of which was carried out in the last five years, as well as state efforts to address their ecological impacts. The parallel development of peer-reviewed research and the design of restrictions and controls in states such as Wyoming and Colorado occurred as governance emerged among unique assemblages of scientists, department officials, operators, and other groups.

Research imperatives of optimally organized landscape, management practices adapted to eco-regional effects, and oil and gas sites in the context of other forms of human disturbance can be removed from consideration, as institutions such as "best management practices," representations such as "wildlife area," and iterative permit approval and amendment formed what we now refer to as a regulatory response to an environmental impact. Before we consider normative governance claims such as state primacy in tailoring or testing knowledge, or the federal role in collecting or dispersing knowledge, we must first study these interactional responses that co-produce governance of a policy problem such as unconventional energy. This

research will allow us to refine our claims and render more nuanced proposals that respond to risks posed by novel technologies.

INTRODUCTION

They mimic invasive species. They behave as bacteria spread across a petri dish, tracing steep growth curves until their populations mature.[1] They may number ninety-four today; one year later, there may be 1010 of them. Another year hence—2826.[2] They present at once as construction sites, industrial zones, and small towns. Imagine a sloping terrain that is cleared, graded, and adorned with crushed limestone and gravel or wooden mats and settled with trucks, bulldozers, lined pits, and storage containers the size of freight cars. From the air, they appear as intermittent, clear-cut absences, each about 150 meters square or over two hectares.[3] The cells dominate from this

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1. Matthew D. Moran et al., *Habitat Loss and Modification Due to Gas Development in the Fayetteville Shale*, 55 ENVTL. MGMT. 1276, 1281 (2015).

2. Jon Paul Pierre et al., *Impacts from Above-Ground Activities in the Eagle Ford Shale Play*, 55 ENVTL. MGMT. 1262, 1263 (2015).

3. Sarah J. Thompson et al., *Avoidance of Unconventional Oil Wells and Roads Exacerbates Habitat Loss for Grassland Birds in the North American Great Plains*, 192 BIOLOGICAL CONSERVATION 82, 86 (2015).

vantage point and mask lines, conduits, and other connective tissue that join them in linear, grid, or neural networks.[4] Oddly, for much of their lives, the paved polygons resemble "nonhabitat,"[5] while the networks that they feed magnify their presence five- to ten-fold.[6] They infect every conceivable landscape, from riparian to deciduous to herbaceous to sagebrush-steppe.[7] No region is spared—they take up residence in national wildlife reserves,[8] near homes, and even above the Arctic Circle. They appear across twenty regions in the United States that span 760,000 square kilometers.[9] Yet they prefer wetlands, grass, shrubs, and forests to developed lands or open water.[10] Upon arrival, they drain, leak, gather, spill, vent, siltify, flare, fragment, suppress, and disturb for several decades. Then they die. Metallic fragments hint at where they once flourished.[11]

These new species bear unique nomenclature, depending on where they reside and the scale at which they are viewed. At human scale, they are "well pads" or "sites" with attendant tanks, containers, and pits. Pull back to a resolution of one kilometer and you discern infrastructure—pipelines, access roads, gathering lines, compressor stations, and their respective rights-of-way. At further distance, aerial views capture the geologic metes and bounds of "shale oil," "tight gas," "coal bed methane," and other plays where well pads slowly, then exponentially, emerge.[12] Collectively, the undulating well pad and infrastructure patterns are known as "unconventional" oil and gas (UOG), because the firms that mine these fuels use novel technologies such

4. Adrianne B. Brand et al., *Potential Reduction in Terrestrial Salamander Ranges Associated with Marcellus Shale Development*, 180 BIOLOGICAL CONSERVATION 233, 235 (2014).

5. Margaret C. Brittingham et al., *Ecological Risks of Shale Oil and Gas Development to Wildlife, Aquatic Resources, and Their Habitats*, 48 ENVTL. SCI. & TECH. 11,034, 11,037 (2014).

6. Jeffrey S. Evans & Joseph M. Kiesecker, *Shale Gas, Wind and Water: Assessing the Potential Cumulative Impacts of Energy Development on Ecosystem Services Within the Marcellus Play*, PLOS ONE, Feb. 19, 2014, at 7, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0089210&type=printable.

7. *See, e.g.*, Mary Beth Adams, *Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia*, 40 J. ENVTL. QUALITY 1340, 1340 (2011); P.J. Drohan et al., *Early Trends in Landcover Change and Forest Fragmentation Due to Shale-Gas Development in Pennsylvania: A Potential Outcome for the Northcentral Appalachians*, 49 ENVTL. MGMT. 1061, 1073 (2012).

8. Pedro Ramirez, Jr. & Sherri Baker Mosley, *Oil and Gas Wells and Pipelines on U.S. Wildlife Refuges: Challenges for Managers*, PLOS ONE, Apr. 27, 2015, at 1, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0124085&type=printable.

9. Brittingham et al., *supra* note 5, at 11,035.

10. Qingmin Meng, *Modeling and Prediction of Natural Gas Fracking Pad Landscapes in the Marcellus Shale Region, USA*, 121 LANDSCAPE & URB. PLAN. 109, 113 (2014).

11. Ramirez & Mosley, *supra* note 8, at 7.

12. Urs P. Kreuter et al., *State of Knowledge About Energy Development Impacts on North American Rangelands: An Integrative Approach*, 180 J. ENVTL. MGMT. 1, 5 (2016).

as hydraulic fracturing and horizontal drilling to access previously inaccessible strata.[13]

Unconventional energy poses threats that were largely ignored until ten years ago, when atmospheric, hydrogeological, environmental health, and other scientists set to work as concerns began to mount. Between 2013, when only a handful of states specifically tailored their oil and gas rules to this invasive force, and 2016, when the U.S. Environmental Protection Agency (EPA) released a final report on its threats to drinking water,[14] 80% of the known peer-reviewed literature on shale gas development was published.[15] More than 1,200 studies grapple with abiotic concerns such as water quality, economic benefits, waste disposal practices, methane leakage and natural gas's relative contribution to climate change, and, increasingly, air quality.[16] Many unanswered questions plague these matters of importance, from underground chemical migration to accident rates. Some of the more widely reported questions speak to localized impacts of a single UOG lifecycle stage, fracking in particular.[17] Results are highly anticipated yet, when the research is organized and answered by a regulatory agency, underwhelming.[18]

Tucked among hundreds of articles are dozens that take UOG production's broader threats at face value. They treat UOG as a system with biotic, as well as abiotic, effects. Their authors address everything from stream hydrology to pollutant bio-magnification to habitat loss. As these far-reaching corners of the UOG literature reach critical mass, their object of study can be described as the "ecological" impacts of energy development.

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13. John L. Adgate, Bernard D. Goldstein & Lisa M. McKenzie, *Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development*, 48 ENVTL. SCI. & TECH. 8307, 8307 (2014).

14. U.S. ENVTL. PROT. AGENCY, HYDRAULIC FRACTURING FOR OIL AND GAS: IMPACTS FROM THE HYDRAULIC FRACTURING WATER CYCLE ON DRINKING WATER RESOURCES IN THE UNITED STATES ES-3 (2016), http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=530159.

15. Jake Hays & Seth B.C. Shonkoff, *Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development: A Categorical Assessment of the Peer-Reviewed Scientific Literature, 2009-2015*, PLOS ONE, Apr. 20, 2016, at 1, 2 http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0154164&type=printable.

16. *See, e.g.*, *Physicians, Scientists, & Engineers (PSE) Study Citation Database*, ZOTERO, https://www.zotero.org/groups/248773/pse_study_citation_database/items (last updated Sept. 20, 2017).

17. *See, e.g.*, *PSE Study Citation Database, Water Quality*, ZOTERO, https://www.zotero.org/groups/248773/pse_study_citation_database/items/collectionKey/DCS54HV7 (last visited Jan. 23, 2018).

18. *See, e.g.*, DAVID LYON & TOBY CHU, ARK. DEP'T OF ENVTL. QUALITY, EMISSIONS INVENTORY AND AMBIENT AIR MONITORING OF NATURAL GAS PRODUCTION IN THE FAYETTEVILLE SHALE REGION (2011), https://www3.epa.gov/ttnchie1/conference/ei20/session6/dlyon.pdf.

Together, they tell an intriguing story. First, the ecological impacts literature coalesced just as states began to craft a regulatory response to the nascent industry. Second, the literature's findings unveil unmet research imperatives: (1) assess tradeoffs in the intensity and density of UOG site and infrastructure placement to create optimally organized landscapes; (2) develop and refine best management practices in light of their contribution to eco-regional effects; and (3) adjust decades worth of research on conventional drilling to the unique techniques, lifecycle, and materiel of UOG development, and consider a more complete range of human disturbance in build-out scenarios and other analytic treatments of the problem. Third, even states that are on the cutting edge of wildlife management at UOG sites lack mechanisms to achieve these landscape-scale imperatives. For example, processes to revise or update the ratios, thresholds, and relationships that exist in ecological impact research to account for the features of unconventional versus conventional oil and gas, forestry, and other landscape-scale stressors are absent or incomplete, and they are presented in the context of voluntary or negotiated operator conditions of approval.

The parallel emergence of state response along with a new scientific literature on UOG's ecological impacts reveal a "faulty federalism" in how legal scholars analyze the appropriate scale of environmental protection.[19] While it is productive to ask whether federal, state, or local governance is best able to share and make use of knowledge given economies of scale, dynamics such as "race-to-the-bottom," experimentation, and other factors, we must also contrast how interactions at different scales of governance produce knowledge absences through new and unique combinations of institutions, identities, and representations. When we shift our attention from UOG's specific, abiotic concerns, such as water pollution and chemical disclosure, to the landscape conservation challenge of its biotic risks, new knowledge production traps emerge, in the form of how scientists, regulators, and operators co-produce ecological protection under conditions of uncertainty. They raise questions about the confidence with which we make normative arguments about the appropriate scale of governance, in areas such as environmental protection and control of novel technologies such as fracking.

19. *See* discussion *infra* Part III.

I. FRACKING AS LANDSCAPE DISTURBANCE

A. UOG Sites and Magnified Disturbance

The ecological impacts literature is largely focused on landscape-scale disturbance. UOG production is at once a source of disturbance and its own unique landscape. Its mix of "hub" (well pad) and "linear" (e.g., pipeline, road) infrastructure introduces immediate impacts in the form of land clearing and construction that multiply in three respects.[20] The area that surrounds a well bore (hereinafter "well pad" or "fracking site") results in immediate impact.[21] UOG well pads are larger in order to accommodate horizontal drilling rigs, bulkier equipment (e.g., truck-mounted pumps), and greater fluid (e.g., drilling, fracking), and waste (e.g., produced water, flowback) storage.[22] Each of the thousands of sites that populate shale formations visits impacts on biotic systems. Land is cleared, excavated, and graded, each well pad defined by compacted gravel or crushed limestone, its sump holes excavated and soil stabilized and hydroseeded.[23] The resulting space is fitted with liner to limit the spread of spills. Well pads are the immediate artifact of forest cleared or high mountain desert graded to accommodate a new industrial landscape. Their regional presence can increase at an exponential rate.[24]

Immediate or direct land disturbance is magnified along three dimensions. First, linear infrastructure to connect and support drilling and production is laid out in certain ratios to UOG sites, depending on their configuration and whether they accommodate single or multiple wells. For example, access roads must be developed, their specifications based on life cycle stage.[25] Three kinds of pipeline connect well pad to compressor station (type 1) and compressor station (type 2) to main pipeline (type 3) and lend their own rights-of-way to total land disturbance.[26] Compressor stations have a density

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20. Isabel L. Jones et al., *Quantifying Habitat Impacts of Natural Gas Infrastructure to Facilitate Biodiversity Offsetting*, 4 ECOLOGY & EVOLUTION 79, 80 (2014).

21. Brittingham et al., *supra* note 5, at 11,037; Evans & Kiesecker, *supra* note 6, at 1; Thompson et al., *supra* note 3, at 86.

22. Meng, *supra* note 10, at 110.

23. *Id.* at 109–10.

24. Drohan et al., *supra* note 7, at 1070.

25. Alexandre Racicot et al., *A Framework to Predict the Impacts of Shale Gas Infrastructures on the Forest Fragmentation of an Agroforest Region*, 53 ENVTL. MGMT. 1023, 1027 (2014). One study found that a road width of six to twelve meters can support the drilling stage, while three to six meter rights-of-way are sufficient for the production stage. *Id.*

26. *Id.* One study found a diameter of fifteen to eighteen meters. *Id.*

informed by the maximum radius with which a station can service neighboring well pads (up to 9.5 kilometers in one region).[27] These and other constraints such as gathering line placement and stormwater system development can be integrated to estimate first-order landscape disturbance when UOG sites enter a region. For example, cumulative distance to a well pad from existing, accessible roads may be used to derive the surface area of new roads. Linear development to service configured hubs represents the physical reach of this new industrial landscape.[28]

To the scope of UOG's physical reach, which alters land cover and land use patterns, we can add biotic magnifiers of disturbance. Biotic impacts concern the interaction of existing ecosystems with the physical properties of pipes, well pads, roads, and lines, as well as local and regional water use for drilling and well completion. Biotic effects begin with fragmentation, where land clearing reduces core habitat and increases perforations and edge effects to forest, grassland, aquatic, and other ecosystems.[29] Core areas are defined as regions beyond the depth of edge effects, such as forest with native vegetation more than 100 meters from an anthropogenic disturbance.[30] Edge effects occur on land adjacent to non-native habitat, including cultivated lands and rights-of-way.[31] Perforations are smaller clearings of interior habitat; they differ from edge effects in that they are surrounded and isolated by native land. A smaller number of core areas or a greater number of edge and perforated lands results in biotic effects such as species isolation, avoidance, and altered migratory patterns as well as light, temperature, and moisture change.[32]

Disruption and avoidance varies in part based on oil and gas infrastructure type—one study found that grassland birds may avoid habitat within 150 meters of access roads and 267 meters of single-bore well pads, for example.[33] Fragmentation effects depend on linear and hub disturbance as well as species range, population size, and specialization. Another biotic impact projects the influence of impervious surfaces and sediment on stream flow, ecology, and watershed integrity. For example, aquatic ecosystems are

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27. *See id.*

28. *See* P.J. Drohan & M. Brittingham, *Topographic and Soil Constraints to Shale-Gas Development in the Northcentral Appalachians*, 76 SOIL SCI. SOC'Y AM. J. 1696, 1696 (2012).

29. *See, e.g.*, Sally Entrekin et al., *Rapid Expansion of Natural Gas Development Poses a Threat to Surface Waters*, 9 FRONTIERS ECOLOGY & ENV'T. 503, 504 (2011).

30. Brittingham et al., *supra* note 5, at 11,040.

31. Racicot et al., *supra* note 25, at 1027.

32. Karen A. Harper et al., *Edge Influence on Forest Structure and Composition in Fragmented Landscapes*, 19 CONSERVATION BIOLOGY 768, 769, 773 (2005).

33. Thompson et al., *supra* note 3, at 85.

seriously impacted as watershed impervious surface cover reaches 10%, while species declines begin at as little as 0.5% impervious cover.[34] Similar relationships exist between reduced stream flow due to water withdrawal for well completion and species loss. A 25% decline in median summer stream flow in the Marcellus shale region may lead to seven or eight species lost, with other impacts apparent as declines approach 25% (e.g., benthic community loss, increased number of habitat generalists).[35] Physical barriers, avoidance, migratory change, interrupted movement, and habitat loss from terrestrial and aquatic fragmentation and siltation are among UOG activity's dominant ecological impacts. Biotic magnifiers of disturbance also include noise, light, direct toxicity from air emissions, and ground and wintertime ozone.[36]

Biotic magnifiers of disturbance are deterministic. In other words, they will occur and must be planned for, whether they result from the physical range and density of well pad construction, the spatial configuration of well pads and their relation to supportive infrastructure, or the frequency and timing of operations. Other biotic impacts are probabilistic—they theoretically could take place at a place and time that is difficult to predict.[37] Probabilistic impacts include any practice that results in an unplanned chemical release, such as faulty cement casing, equipment failure, accidents, spills, and chemical migration from these as well as planned events, such as land application of wastewater. An example would be flowback or produced water that enters surface water through faulty wastewater handling, leaks from well casings and tanks, and transportation spills.[38]

For example, early research found that roughly 5% of all produced water or "brine" (so-called for its chloride content) generated by domestic oil and gas production is released at the surface.[39] Work dating back to the 1980s found that produced water migrates from well sites (e.g., from reserve pits

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34. Evans & Kiesecker, *supra* note 6, at 5.

35. Brian P. Buchanan et al., *Environmental Flows in the Context of Unconventional Natural Gas Development in the Marcellus Shale*, 27 ECOLOGY APPLICATIONS 37, 47 (2017).

36. *See, e.g.*, E.T. SLONECKER ET AL., LANDSCAPE CONSEQUENCES OF NATURAL GAS EXTRACTION IN ALLEGHENY AND SUSQUEHANNA COUNTIES, PENNSYLVANIA, 2004–2010, at 13 (2013); Ethan P. Barton et al., *Bird Community Response to Marcellus Shale Gas Development*, 80 J. WILDLIFE MGMT. 1301, 1303 (2016); Drohan et al., *supra* note 7, at 1073; Ramirez & Mosley, *supra* note 8, at 3; Thompson et al., *supra* note 3, at 86.

37. Sara Souther et al., *Biotic Impacts of Energy Development from Shale: Research Priorities and Knowledge Gaps*, 12 FRONTIERS ECOLOGY ENV'T 330, 331 (2014).

38. *See* Erica Johnson et al., *Stream Macroinvertebrate Communities Across a Gradient of Natural Gas Development in the Fayetteville Shale*, 530 SCI. TOTAL ENV'T 323, 324 (2015).

39. Tanita Sirivedhin & Liese Dallbauman, *Organic Matrix in Produced Water from the Osage-Skiatook Petroleum Environmental Research Site*, 57 CHEMOSPHERE 463, 463–64 (2004).

that are a common storage solution) to wetlands and shallow groundwater. From there it alters the chemical gradient of wetlands such as the Prairie Pothole Region in North Dakota, which in turn effects biotic communities.[40] Later research showed that produced water can transform a wetland from diverse plants and invertebrates to fewer, salt-tolerant species and render it unsuitable as a water source for livestock.[41] Even small land releases of produced water can kill vegetation and cause long-term damage to soils and wildlife habitat.[42] Field research with species such as rainbow trout can distinguish among the effects of salts and organic contaminants in combined produced water and flowback spills.[43] Other indicator species susceptible to UOG activity are biomarkers of the impacts of known constituents in flowback and produced water.[44] Probabilistic biotic impacts occur at the landscape scale—even limited datasets show regular, non-negligible chemical loss, from 12,863 spills in Oklahoma over a ten year stretch to 6,648 reported spills across Colorado, New Mexico, North Dakota, and Pennsylvania during a similar time.[45]

Even setting aside probabilistic effects, the reach of physical and deterministic magnifiers of UOG's biotic impact is breathtaking. A study of the maturing oil and gas industry in Pennsylvania is instructive. The goal of this research was to calculate the spatial coverage of conventional and UOG activity in the state.[46] Using a Geographic Information System (GIS), digital aerial photography, and available social and spatial data sets, the authors

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40. Max Van der Burg & Brian A. Tangen, *Monitoring and Modeling Wetland Chloride Concentrations in Relationship to Oil and Gas Development*, 150 J. ENVTL. MGMT. 120, 121 (2015).

41. *See, e.g.*, U.S. GEOLOGICAL SURVEY, U.S. DEP'T OF THE INTERIOR, BRINE CONTAMINATION TO AQUATIC RESOURCES FROM OIL AND GAS DEVELOPMENT IN THE WILLISTON BASIN 14 (Robert A. Gleason et al. eds., 2014).

42. *See* Thomas M. Harris et al., *Remediation of Oil-Field Brine-Impacted Soil Using a Subsurface Drainage System and Hay*, 12 ENVTL. GEOSCIENCES 101, 102 (2005).

43. Yuhe He et al., *Effects on Biotransformation, Oxidative Stress, and Endocrine Disruption in Rainbow Trout (Oncorhynchus Mykiss) Exposed to Hydraulic Fracturing Flowback and Produced Water*, 51 ENVTL. SCI. & TECH. 940, 944, 946 (2017).

44. Wilson H. Johnson et al., *Do Biofilm Communities Respond to the Chemical Signatures of Fracking? A Test Involving Streams in North-Central Arkansas*, 17 BMC MICROBIOLOGY 29, 30 (2017).

45. J. Berton Fisher & Kerry L. Sublette, *Environmental Releases from Exploration and Production Operations in Oklahoma: Type, Volume, Causes, and Prevention*, 12 ENVTL. GEOSCIENCES 89, 89 (2005); Lauren A. Patterson et al., *Unconventional Oil and Gas Spills: Risks, Mitigation Priorities and States Reporting Requirements*, 51 ENVTL. SCI. & TECH. 2563, 2567 (2017).

46. Terry E. Slonecker & Lesley E. Milheim, *Landscape Disturbance from Unconventional and Conventional Oil and Gas Development in the Marcellus Shale Region of Pennsylvania, USA*, 2 ENVIRONMENTS 200, 203 (2015).

calculated proximity to streams (including impaired and wildland trout streams), surface drinking water intakes, forest (including interior forest), watersheds (including exceptional value watersheds), and residential communities that already bore disproportionate exposure to pollution in the Marcellus shale region.[47] They found oil and gas development in half of the state's over 900 watersheds, close to streams (45% of the sites were within sixty meters of a stream) and surface drinking water intakes (within ten upstream acre-feet of intakes in 45% of the state's watersheds), near environmental justice communities (30% of the sites were in watersheds that hosted an already impacted residential area), and in interior forest.[48]

From occurrence rates, scientists try to calculate landcover loss through build-out scenario analysis based on permit data, where deterministic impacts come into focus. One study in Pennsylvania found that each well pad results in about twelve ha of disturbance.[49] Another found that habitat conversion alone accounts for 2.9 to 3.6 ha from the introduction of pipelines and access roads.[50] Estimates range up to twenty ha of disturbance per well pad location;[51] the level of disturbance depends on the degree to which infrastructure is optimally organized. Direct and indirect landscape disturbance might impact one-fifth or 96 million ha of western North America alone.[52]

B. *Invasive Landscape Knowns and Unknowns*

UOG's ecological impacts, when interpreted as a landscape-scale event and queried with spatial and statistical analysis tools, are gradually revealed. Mature well pad construction in a shale gas play follows a logistic growth curve.[53] Well pads are commonly placed close to wetlands and isolated rural homes, within agricultural, grass and forest lands, and at a relative distance from lakes and urban neighborhoods.[54] At build-out, newly-introduced nonhabitat disturbs a collective range of wildlife; the multiplier effects of infrastructure depend on the shale formation and host ecosystem in question.

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47. *Id.* at 205.
48. *Id.* at 200, 208–11.
49. Coral M. Roig-Silva et al., *Forest Cover Changes Due to Hydrocarbon Extraction Disturbance in Central Pennsylvania*, 12 J. MAPS 131, 131 (2016).
50. SLONECKER ET AL., *supra* note 36, at 19; Brittingham et al., *supra* note 5, at 11,037.
51. Evans & Kiesecker, *supra* note 6, at 5.
52. Clay B. Buchanan et al., *Seasonal Resource Selection and Distribution Response by Elk to Development of a Natural Gas Field*, 67 RANGELAND ECOLOGY & MGMT. 369, 369 (2014).
53. Moran et al., *supra* note 1, at 1278.
54. Meng, *supra* note 10, at 114.

Factors such as elevation, slope, land use or land cover, and distance to roads and rivers guide much of the variance in well pad disturbance.[55]

Further afield, ecosystems support indicator species that silently gather biomarkers of UOG's adverse effects. These species are specialized to or require intact habitat and thrive in unpolluted freshwater or unique soils. Examples include brook trout with habitat range from Georgia to Maine, whose tissue is an indicator of stress from low pH and heavy metals; woodland salamanders and other northeastern amphibians that are sensitive to soil changes and chloride content; macroinvertebrates that depend on certain aquatic conditions; mule deer that respond to well pad density by changing migration patterns; and forest songbirds that keep a distance from roads, pipelines, and compressor stations.[56]

After well pad construction, ecosystems endure deterministic impacts such as habitat loss and probabilistic impacts such as spills. Impacts differ according to landcover and UOG lifecycle stage. Some result from multiple stages of production (e.g., fragmentation and related habitat loss and species behavior); others stem from a single stage (e.g., water withdrawal for well completion).[57] At greatest risk are ecosystems with core forest or sagebrush habitat and stream biota.[58] Disturbance proceeds from land clearing through well abandonment thirty years later, stretching further as land recovers.[59] Disturbance propagates between local and regional scales, such as when produced water in the Williston Basin alters wetland chemistry and aquatic biodiversity.[60]

The ecological impacts invite landscape-scale analysis. Some landscape features are captured in publicly available data sets. Build-out scenarios reflect not only location but intensity of well pad development, whether single- or multi-bore and the number of wells per pad.[61] The influence of

55. *Id.* at 111.

56. Erik Kiviat, *Risks to Biodiversity from Hydraulic Fracturing for Natural Gas in the Marcellus and Utica Shales*, 1286 ANNALS N.Y. ACAD. SCI. 1, 4–6 (2013); Patrick E. Lendrum et al., *Migrating Mule Deer: Effects of Anthropogenically Altered Landscapes*, PLOS ONE, May 14, 2013, at 7–9, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0064548&type=printable; Maya Weltman-Fahs & Jason M. Taylor, *Hydraulic Fracturing and Brook Trout Habitat in the Marcellus Shale Region: Potential Impacts and Research Needs*, 38 FISHERIES 4, 10 (2013).

57. Brittingham et al., *supra* note 5, at 11,037.

58. *Id.* at 11,040.

59. *See id.* at 11,035–37.

60. Van der Burg & Tangen, *supra* note 40, at 121.

61. On federal land, build-out scenarios are informed by oil and gas leasing data and Bureau of Land Management resource management plans. Holly E. Copeland et al., *Mapping Oil and Gas Development Potential in the US Intermountain West and Estimating Impacts to Species*,

UOG infrastructure can be gauged using landscape-scale ratios.[62] Edge effect, flow-ecology, percolation theory, and other ratios can be added to UOG spatial data. Researchers build logistic regression and other nonparametric models. Each layer in a GIS represents independent variables that potentially impact a binary, dependent variable such as whether a location will host UOG activity. Inversely, predictive models estimate the impacts of UOG sites such as landcover change or stream turbidity based on watershed well pad location and density.[63] The ecological impacts literature benefits from advances in not only spatial analysis but also species-based modeling, assessments of species and habitat vulnerability, threshold toxicity evaluations of physiological changes and survival at the individual and population levels, and new ways to combine impacts at a variety of spatial scales.[64]

The research suggests several signposts for future work. First, impacts should be mapped with increasing spatial resolution, including deterministic impacts such as fragmentation and sedimentation and turbidity change in aquatic areas. In-stream flow-ecology correlations, sediment load, stream siltation, habitat loss, wildlife fragmentation, and noise and light pollution follow patterns, relations, and distances that must be studied. Landscape metrics of human impact include edges, evenness, and contagion.[65] They can be used to compare the influence of lines and polygons that appear on spatial imagery and represent cleared sites, transportation routes, impoundments, processing, and storage. For example, one county may face forest cover that drops below a critical value based on percolation theory, after which it is likely to break down; another may face a sharp rise in forest patches due to pipeline construction that present their own challenges.

Second, while ecological impacts can be assessed at the landscape scale, there must also be reciprocal movement between regional predictive metrics and localized monitoring and adjustment. Landscape-scale disturbance differs according to the mix of landcover and UOG activity within a region. The studies identify indicator species and continuous monitoring, field measurement, and survey protocols that can collect ground-truth data from

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PLOS ONE, Oct. 14, 2009, at 4, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0007400&type=printable.

62. *Id.* at 2. Buffers can be drawn to reflect indirect impacts of UOG infrastructure categories, such as avoidance of single-bore well pads by grassland birds or deer avoidance of active drilling sites. *See* Thompson et al., *supra* note 3, at 86.

63. David R. Smith et al., *Shale Gas Development and Brook Trout: Scaling Best Management Practices to Anticipate Cumulative Effects*, 14 ENVTL. PRAC. 366, 369 (2012).

64. Brittingham et al., *supra* note 5, at 11,042.

65. SLONECKER ET AL., *supra* note 36, at 10–11.

spatial models.[66] The research must move iteratively among landscapes and sites as a corrective and update to landscape-scale metrics.

Third, much of what is known about ecological impacts is derived from conventional oil and gas and other kinds of landscape disturbance, from urban development to timber harvesting.[67] Each anthropogenic disturbance represents cleared patches in a matrix of roads and impervious surfaces.[68] UOG impact studies announce a duality: indicators of deterministic, landscape-scale disturbance derived over several decades and an imperative, rarely realized, to tailor findings to UOG activity's probabilistic impacts. Examples range from how patches of land are cleared and altered to permeability differences to how long these alterations remain to chemical constituents lost through spills and other releases.[69]

The influence of conventional or "shallow gas" wells over direct and indirect habitat change is wide-ranging, from shorter vegetation and increased non-native plant species to decreased diversity of native species and changing animal behavior, as well as species abundance that varies with well density among the many ecological influences of conventional oil and gas.[70] The literature is equally broad in its analysis of probabilistic impacts, such as the sensitivity of lichens, mosses, conifers, and aquatic plants to chloride in produced water and its influence on vegetation, amphibians, and fish or mercury's "ability to persist, transform . . . [and] biomagnify," and affect organisms in acidifying streams.[71] Findings from conventional oil and gas are rarely updated to reflect UOG's distinct qualities.

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66. *See, e.g.*, Buchanan et al., *supra* note 35, at 40–41.

67. Pierre et al., *supra* note 2, at 1267–68; Slonecker & Milheim, *supra* note 46, at 214.

68. Smith et al., *supra* note 63, at 369.

69. The impacts of timber clearing and suburban sprawl are laid out in stunning range and detail: "breeding patterns of birds . . . grazing patterns of herbivores . . . [v]egetation responses . . . [and] the spread of invasive alien species." Jones et al., *supra* note 20, at 80.

70. *See, e.g.*, N. Koper et al., *Effects of Livestock Grazing and Well Construction on Prairie Vegetation Structure Surrounding Shallow Natural Gas Wells*, 54 ENVTL. MGMT. 1131, 1131 (2014).

71. Christopher J. Grant et al., *Marcellus and Mercury: Assessing Potential Impacts of Unconventional Natural Gas Extraction on Aquatic Ecosystems in Northwestern Pennsylvania*, 50 J. ENVTL. SCI. HEALTH 482, 482–83 (2015).

II. REGULATING LANDSCAPE-SCALE EVENTS

A. The Research Imperatives of Managerial Response

Ecological impacts are an afterthought among a sea of studies that respond to the fracking boom. Yet while *abiotic* impacts at the site or neighborhood scale continue to defy intermittent, costly efforts to reveal them,[72] the challenges posed by biotic impacts for land use management and landscape conservation are evident. The belated blip of peer-reviewed articles on UOG's ecological impacts concludes with unanswered questions. The implications converge, whether the focus of a paper is mule deer migration, sage grouse habitat, aquatic plant response to fracking fluids, well pad siting in grasslands versus cultivated crops, or areal extent of disturbance. The literature's points of consensus reflect chains of causation that the studies sketch in aquatic and terrestrial lands, including lower stream water pH that increases mercury bio-accumulation and decreases biodiversity. They are also informed by findings for other anthropogenic disturbance, whether the offending activity is "slash and burn agricultural practices, timber harvesting, road building, urbanization," or "extraction of hydrocarbons such as coal, oil, and gas."[73]

In response to these findings, the research (1) points to directional drilling (and, to lesser extent, well completion) as flexible tools that could facilitate optimal land use; (2) argues that best management practices (BMPs) should be adapted to landscape-scale impacts and refined in light of their contribution to eco-regional effects; and (3) calls for research to adjust findings from conventional oil and gas and other human disturbance to the unique techniques, lifecycle, and materiel of UOG development.

At the core of landscape-scale development tradeoffs are the intensity, density, and potentially shared nature of UOG production. For example, developing additional wells per existing well pad "could provide the benefit of fewer pads throughout [a] state, with fewer new roads, gathering lines, and other associated infrastructure" that result in "undeveloped, or less developed areas where ecosystem protection is maximized."[74] Tradeoffs arise from

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72. *See, e.g.*, Avner Vengosh et al., *A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States*, 48 ENVTL. SCI. & TECH. 8334, 8335–36 (2014).

73. Pierre et al., *supra* note 2, at 1262 (citation omitted). Landscape-scale disturbance "transforms heterogeneous ecosystems to more simplified homogeneous ecosystems that support less diverse wildlife." *Id.*

74. Drohan et al., *supra* note 7, at 1070.

greater intensity of development from reliance on multi-well pads, which introduce "more local disturbance such as noise pollution, air quality degradation, or vibrations from traffic."[75]

Similarly, well pad siting faces a tradeoff between more sites closer together and further from existing roads versus fewer, multi-well pads. The former presents a greater risk of landscape fragmentation. Intensity of development tradeoffs join biotic tradeoffs in the fledgling literature, such as avoiding headwater streams in forest cover versus locating closer to non-forested waters.[76] Each shale play and host landscape present a set of potential choices, from "clustering pad locations" to "maximizing the number of wells per pad" to "identifying and excluding from shale gas development areas of high quality contiguous forest."[77]

Tradeoffs are discussed in light of directionally drilled, underground bores that span 1.5 to 3.0 kilometers and are common in shale gas regions. The horizontal wells allow for the possibility of an "optimally organized landscape."[78] For example, pipelines can be routed near the periphery of core forest, away from high stream density, and apart from areas ranked high in vulnerability based on state inventories of species of concern. Infrastructure can avoid steep slopes and grades to minimize soil erosion and stream sediment. Optimality is defined in terms of variation in well pad and road configuration and its effects on surface disturbance and shale play productivity. Optimal configuration can also rely on existing development.[79] For example, wells can be sited near highways, derelict lands such as abandoned strip mines, and prior modified habitat.[80] Timing plays a role. The rate of development and scheduling of lifecycle stage should be informed by the nature of impacted watersheds and other landscapes. For example, drilling could be avoided during winter months, or construction and well completion

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75. *Id.*

76. Entrekin et al., *supra* note 29, at 509–10 (noting that natural gas development may threaten surface waters through "[e]levated sediment runoff into streams, reductions in streamflow, contamination of streams from accidental spills, and inadequate treatment practices for recovered wastewaters").

77. Barton et al., *supra* note 36, at 1310.

78. Thompson et al., *supra* note 3, at 86.

79. *See* Kiviat, *supra* note 56, at 9; *see also* Laura S. Farwell et al., *Shale Gas Development Effects on the Songbird Community in a Central Appalachian Forest*, 201 BIOLOGICAL CONSERVATION 78, 87 (2016) ("Concentration of well pads along existing road and pipeline networks, and reduction of new well pad construction by drilling multiple bores on existing well pads would further minimize impacts to core forest habitat.").

80. Kiviat, *supra* note 56, at 9. On developed lands, integrated vegetation management such as "feathered" cutbacks can decrease the impact of infrastructure borders. Farwell et al., *supra* note 79, at 87.

could be timed to "allow[] refuge habitat during the most acute periods of stress."[81] These are two among many variables that inform theoretically optimal arrangement.[82]

The literature calls for developers to engage in landscape-scale tradeoffs for optimal organization, which points to a second research imperative: BMPs, designed to avoid or mitigate small-scale effects, should be refined in light of their contribution to eco-regional effects. Historically, BMPs are site-specific or influenced by the habitat of a select number of species.[83] This assumes that site-level BMPs will be uniformly adopted, and that across a UOG field they will be sufficient to hold certain localized impacts within an acceptable range. These are flawed assumptions, given the pace of site development, proximity of infrastructure to valuable ecosystems, and known failure rates of procedures and equipment. Tailored BMPs that account for and avoid ecological thresholds and impacts is another example of the interplay between landscape-scale analysis, optimal configuration, and localized monitoring and adjustment.

There is a need to tailor ratios, thresholds, distances, probabilities, and other ecological indicators in light of a specific host landscape, whether forest, grassland, or semi-arid; refine the ecological impacts of well pads, supportive infrastructure, lifecycle stages, and unplanned events such as chemical loss; and apply these findings to site selection and create BMPs that take them into account. Occasionally, BMP refinement should rely on site-specific as opposed to landscape-scale indicators. For example, reclaiming abandoned, decommissioned sites depends on a striking mix of hyper-local land features such as soil bulk density, pH, and conductivity as well as the topography, revegetative potential, and water-holding capacity of the immediate area of an abandoned well.[84]

A third research priority would contrast UOG and other human practices in terms of their contribution to landscape-scale effects: "One of the first needs in understanding overall effects of shale resource development on ecosystems is to compare similarity of effects with those from other practices."[85] In order to adjust BMPs so they account for and limit collective

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81. Joseph M. Northrup et al., *Quantifying Spatial Habitat Loss from Hydrocarbon Development Through Assessing Habitat Selection Patterns of Mule Deer*, 21 GLOBAL CHANGE BIOLOGY 3961, 3969 (2015).

82. *E.g.*, Drohan et al., *supra* note 7, at 1073 (noting that an "organized approach to siting drilling infrastructure could help minimize the development on forest lands and potential damage to waterways, and help manage development on agricultural land").

83. Smith et al., *supra* note 63, at 368.

84. Pierre et al., *supra* note 2, at 1272.

85. Brittingham et al., *supra* note 5, at 11,041.

impacts, known mechanisms of conventional oil and gas, timber harvesting, suburban development, mining, and other land use change, each well-researched, should be compared, tested, ground-truthed, and revised.[86] The literature notes that certain paths by which land use changes affect biotic communities are similar across development categories, but the mechanisms need refinement in light of UOG's "different implementation and maintenance requirements" including "injection of fracking fluid, higher traffic levels, different well pad size, different well and road density, and varying landscape configurations."[87] Perhaps the most detailed repository of knowledge for BMP revision is conventional oil and gas research.[88] An equally important task is to consider a more complete range of anthropogenic impacts in UOG build-out scenarios, predictive models, and BMP refinement. For example, shale gas development in Appalachia impacts land that is subject to forest loss from agriculture, silviculture, urban development, mining, and conventional gas.[89] Research has yet to compare the influence of each land use as a driver of fragmentation and other deterministic impacts; rarely are they combined in spatial data sets for purposes of model building and prediction.[90]

B. State Regulation: Leading Indicators

States that intersect shale gas basins were slow to address UOG's ecological impacts. But even an aggressive response can bump up against the knowledge production challenges these impacts pose. For example, California enacted S.B. 4 in 2013 to counter growing use of hydraulic

86. *See id.*; *see also* Joseph M. Northrup & George Wittemyer, *Characterising the Impacts of Emerging Energy Development on Wildlife, With an Eye Towards Mitigation*, 16 ECOLOGY LETTERS 112, 121–22 (2013).

87. Thompson et al., *supra* note 3, at 83.

88. Fracking sites in North Dakota, Montana, and South Dakota, for example, intersect with habitat that endured conventional drilling that began in the 1950s. Ecological impacts research in the region dates back several decades. *See, e.g.*, EDWARD C. MURPHY & ALAN E. KEHEW, THE EFFECT OF OIL AND GAS WELL DRILLING FLUIDS ON SHALLOW GROUNDWATER IN WESTERN NORTH DAKOTA 8 (1984) (enumerating the purposes of the study).

89. Farwell et al., *supra* note 79, at 85.

90. Slonecker and colleagues offer questions to guide ecological impacts research, including "the level of overall disturbance attributed to gas exploration and development activities," how that disturbance has "changed over time," the "structural components (land cover classes) of this change" and how land disturbance by UOG affects "the structure, pattern, and process of key ecosystems" within each basin. SLONECKER ET AL., *supra* note 36, at 6.

fracturing in the state.[91] As part of California's first UOG-specific regulatory program, S.B. 4 included a study to be completed on "all aspects and effects of well stimulation treatments," including "potential impacts on wildlife, native plants, and habitat."[92] Published in 2015, the study found that 60% of the 33,000 ha impacted by UOG in California were natural habitat.[93] The report listed categories of ecological impact: habitat loss and fragmentation, invasive species, harmful fluids in the environment, diversion of water from waterways, noise and light pollution, vehicle collisions with wildlife, and ingestion of litter.[94] Based on a survey of the existing literature, it found that habitat loss and fragmentation was "the only impact for which . . . sufficient data to quantify impacts" within the state exists.[95] By the time California's study was released, a small number of states had amended their oil and gas laws to address ecological impacts, often in reference to wildlife. I consider two such states below, each a top UOG production center as well as a first mover in trying to limit a broad range of its ecological impacts.[96]

1. Wyoming

To glean Wyoming's response to the biotic as opposed to abiotic impacts of UOG activity, we must dig past enabling legislation that grants shared authority to oil and gas conservation and environmental quality agencies. The Wyoming Oil and Gas Conservation Commission (WOGCC) regulates much of the UOG lifecycle—applications for permits to drill or deepen wells, onsite storage of waste in pits—while the Wyoming Department of Environmental Quality (WDEQ) administers rules under air and water statutes that speak to, for example, produced water, drilling fluids, hazardous waste, and discharges

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91. S.B. 4, 2013–2014 Leg., Reg. Sess. (Cal. 2013) (codified as amended at CAL. PUB. RES. CODE § 3160 (2018)).

92. CAL. PUB. RES. CODE § 3160(a)(3)(A), (a)(4) (2018).

93. CAL. COUNCIL ON SCI. & TECH., AN INDEPENDENT SCIENTIFIC ASSESSMENT OF WELL STIMULATION IN CALIFORNIA: POTENTIAL ENVIRONMENTAL IMPACTS OF HYDRAULIC FRACTURING AND ACID STIMULATIONS 327 (2015).

94. *Id.* at 308.

95. *Id.*; *see also id.* at 309–10.

96. Wyoming ranks fourth in U.S. natural gas production and eighth in crude oil production. *Wyoming State Profile and Energy Estimates*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/state/?sid=WY (last updated Dec. 21, 2017). Colorado ranks sixth in U.S. natural gas production and seventh in crude oil production. *Colorado State Profile and Energy Estimates*, U.S. ENERGY INFO. ADMIN., https://www.eia.gov/state/?sid=CO (last updated Dec. 21, 2017).

to surface waters.[97] WOGCC rules, the most notable among them provisions for permitting and well stimulation, were amended in 2010 in response to groundwater contamination concerns.[98] Wyoming's chief response to the fracking boom was to mandate disclosure of chemical contents of fluids used in well stimulation, including Chemical Abstracts Service numbers and concentrations, subject to exemption.[99] In addition, the rules require detailed description of the mechanics of well stimulation (such as casing integrity and cement testing) and the formation where it will be carried out.[100]

Ecological impacts appear infrequently in the rules, in reference to "wildlife" or a body of water such as a stream.[101] Chapter 4, Section 1 of the rules concerns oilfield pits that endanger "human health or wildlife."[102] This is determined with information submitted in forms along with an Application for Permit to Drill—distance from surface waters, depth to useable ground water, fluid type stored.[103] Construction requirements such as liner thickness and grading kick in when a pit is proposed in a "critical area" or in certain relation to shallow groundwater, Green or Colorado River drainage environments, and other sensitive environments.[104]

"Critical areas" are itemized according to several units of measure for distance to a wellhead or well location: one-fourth mile (water supplies), 500 feet (wetlands, ponds, lakes, floodplains), twenty feet (groundwater), and pervious soils such as sands and loams.[105] In addition to engineering controls and design specifications that apply to pits constructed in these areas, WOGCC may decide that wildlife warrant protection from, say, a reserve pit

97. *See generally* WYO. STAT. ANN. § 30-5-104 (2017) (WOGCC powers and duties); *id.* §§ 35-11-201 to -214 (WDEQ Air Quality Division powers and duties); *id.* §§ 35-11-301 to -318 (WDEQ Water Quality Division powers and duties).

98. 055-3 WYO. CODE. R. §§ 8, 45 (LexisNexis 2018) (Application for Permit to Drill or Deepen a Well, and Well Stimulation, respectively). A summary of the reasons behind adoption of the 2010 regulations can be found in *Powder River Basin Resource Council v. Wyoming Oil and Gas Conservation Commission*, 320 P.3d 222, 225 (Wyo. 2014).

99. 055-3 WYO. CODE. R. § 45.

100. *Id.* § 8.

101. Wildlife appears nine times in WOGCC regulations. *See id.* § 45(j) (lined pits); 055-4 WYO. CODE. R. § 1(a) (LexisNexis 2018) (pit construction); *id.* § 1(c)(iv) (Migratory Bird Treaty Act administration in Wyoming); *id.* § 1(u) (retaining pits); *id.* § 1(bb) (fencing and netting); *id.* § 1(jj) (removal of oil and other hydrocarbons from reserve pits); *id.* § 1(qq) (reclamation of production and reserve pits); *id.* § 4(a)(vi) (access to production facilities); *id.* § 4(a)(vii) (preventing wildlife access to spills).

102. *Id.* § 1(a).

103. *Id.* § 1(j).

104. *Id.* § 1(w).

105. 055-1 WYO. CODE. R. § 2(pp) (LexisNexis 2018).

that poses a threat of communication with surface water.[106] The Commission "may require such modifications or changes in the Owner's/Operator's plans as it deems necessary" including monitoring, lining, and closed system requirements.[107] Precautions or operational restrictions may be put in place to "avoid contamination of groundwater and surface water at the well location."[108]

There are also distance-based limits with regards to ecological resources. For example, equipment such as wellheads, pumping units, tanks, and treaters may not be located closer than 350 feet from a water supply (absent a variance), and unlined pits may not be built in floodplains.[109] The applicant assists in these determinations by locating water sources within a half mile of the proposed well and its depth to groundwater.[110] Operators are also required to complete a baseline groundwater sampling and monitoring plan, and any discharge of pollutants to waters of the state must proceed through issuance of a state-administered National Pollutant Discharge Elimination System permit by WDEQ.[111] Operators must observe safety measures to prevent the direct loss of wildlife or migratory birds, such as netting or fencing pumps and pits.[112] Site reclamation is also triggered in part by threats posed by production pit areas that "contain chemicals harmful to wildlife."[113]

Concepts such as "landscape," "watershed," "fragmentation," and "sediment" fail to make an appearance in the state's oil and gas rules, with an important exception. The rules require the Commission to comply with executive orders for sage-grouse protection.[114] The State's "Core Area Strategy" includes measures similar to those stipulated by the Bureau of Land Management to protect wildlife from human activity, such as "no surface occupancy" zones and timing limits for when development may occur within a given distance from a sage-grouse lek.[115] Other wildlife programs do not find their way into the state's oil and gas laws, such as the Governor's off-site mitigation framework and several research, interagency, and industry

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106. 055-4 WYO. CODE. R. § 1(u) (LexisNexis 2018).

107. *Id.*

108. *Id.* § 1(p).

109. 055-3 WYO. CODE. R. § 22(b) (LexisNexis 2018).

110. *Id.* § 8(c)(iii).

111. *Id.* § 46(a); 055-4 WYO. CODE. R. § 1(ee) (LexisNexis 2018).

112. 055-4 WYO. CODE. R. § 4(a)(vi) (LexisNexis 2018).

113. *Id.* § 1(qq).

114. *Id.* § 1(c)(v).

115. WYO. GAME & FISH COMM'N, WYOMING STATE WILDLIFE ACTION PLAN: ENERGY DEVELOPMENT II-2-7 to II-2-11 (2017), https://wgfd.wyo.gov/Habitat/Habitat-Plans/Wyoming-State-Wildlife-Action-Plan.

partnerships.[116] These initiatives enlist the support of public resource agencies such as the Wyoming Game and Fish Commission (WGFC).

WGFC lacks direct authority over oil and gas well location, drilling, and operation. However, it is the agency most self-aware of the imperative to fit a burgeoning science of UOG's ecological impacts within ongoing development of a new industry. In notes to a slideshow given at the dawn of the fracking boom, a WGFC official overlaid maps of the Powder River, Jonah, Pinedale, and other natural gas production basins with maps of the physical range of sage-grouse, big game, and sensitive species.[117] The "energy resources" and "world-class fish and wildlife habitats" were, in many cases, "located right on top of each other."[118] The following year, the agency prepared BMPs and development guidelines for the spaces where maps of wildlife and UOG production intersect.[119] While the recommendations are nonbinding, WGFC's State Wildlife Action Plan refers to the BMPs as central to ensuring the health of biotic communities such as "big game winter ranges, sage-grouse habitats, priority watersheds, and others identified on maps available from the [Wyoming Game and Fish Department] website."[120] The guidelines were most recently updated in 2010 for several impacts of oil and gas development: habitat loss, physiological stress, disturbance and displacement, fragmentation and isolation, change in water quantity and quality, invasive species, and secondary effects.[121]

Biotic communities are defined according to species, population, or habitat.[122] The 236-page document is dominated by references and an annotated bibliography for each species. Its most impressive analytical feat is to distinguish impact according to moderate, high, and extreme levels of disturbance by oil and gas activity.[123] Levels of impact are defined according

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116. *Id.* at II-2-10, II-2-14.

117. *Current and Future Energy Development in Wyoming*, WYO. GAME & FISH DEP'T, https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Habitat%20Information/Wind%20Energy%20Development/Current-and-Future-Energy-Development-in-Wyoming.pdf (last visited Mar. 23, 2018).

118. *Energy Development Power Point*, WYO. GAME & FISH DEP'T, https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/Habitat%20Information/Wind%20Energy%20Development/Energy-Development-Power-point.pdf (last visited Mar. 23, 2018).

119. WYO. GAME & FISH COMM'N, WYO. GAME & FISH DEP'T, RECOMMENDATIONS FOR DEVELOPMENT OF OIL AND GAS RESOURCES WITHIN IMPORTANT WILDLIFE HABITAT, at i–ii (2010), https://wgfd.wyo.gov/Habitat/Habitat-Information/Development-of-Oil-and-Gas [hereinafter Wyoming BMPs].

120. WYO. GAME & FISH COMM'N, *supra* note 115, at II-2-9.

121. Wyoming BMPs, *supra* note 119, at 9.

122. *Id.* at 7.

123. *Id.* at 14.

to two quantitative measures: well pad density and cumulative area of disturbance per square mile. For example, two to four well pad locations per square mile is considered "high" disturbance for mule deer crucial winter ranges, while one to four well pads per square mile is considered "moderate" impact for blue and red ribbon streams.[124] Well pad density is used as a proxy for development impact "because it would be exceedingly difficult, based on the available literature, to factor every aspect of well field development into a comprehensive set of disturbance criteria."[125] Necessarily, a focus on well pad density and cumulative acreage "may under-represent the actual level of disturbance."[126]

Management responses to avoid, mitigate, or offset these levels of impact round out the matrix. For example, blue and red ribbon stream disturbance in a moderate-impact zone (one to four well pads per square mile) warrants the use of "standard management practices," a list of which appears in an appendix (e.g., "no drilling activity or disturbance should be permitted within 500 feet of a riparian area," "design drill pad sites to disperse storm water runoff onto upland sites," "pipeline crossings can be installed through ephemeral streams by trenching").[127] On a handful of occasions, directional drilling and clustered development are listed as a means to reduce disturbance, such as for high-impact (two to four well pad locations per square mile) zones for mule deer crucial winter range: "To the extent technologically practicable, develop multiple wells from single pads . . . [and] locate well pads, facilities and roads in clustered configurations . . . ."[128]

124. *Id.* at 18–19.
125. *Id.* at 14.
126. *Id.*
127. *Id.* at 54, 104–05.
128. *Id.* at 27.

When describing the BMPs, the guidelines and Wildlife Action Plan emphasize the challenge of setting them in light of their contribution to higher levels of biotic change:

> *Key Misconceptions about Wildlife Responses to Development*: Seasonal use stipulations, standard operating procedures, and reclamation practices are adequate mitigation for wildlife resources affected by oil and gas developments. . . . 84% of [wells and facilities in northeast] Wyoming were out of compliance with reclamation success standards and other conditions of approval. . . . [S]easonal restrictions are currently limited to exploration and drilling phases of oil field development. Oil and gas operations also disturb and displace wildlife throughout a production life of up to 40 years and longer.[129]
>
> It is difficult to establish performance indicators to evaluate the success of mitigation efforts given the diverse, changing, and incomplete understanding of the effects of energy development. There is also a lack of consensus on the timeframe or benchmarks by which success should be evaluated. . . . A significant amount of wildlife mitigation and enhancement techniques pertain to riparian areas and wetlands, which tend to be geographically limited and defined. It can be more challenging to establish effective performance indicators in habitat types that occur on a landscape scale, such as sagebrush.[130]

2. Colorado

The ecological impacts of UOG are more directly addressed in Colorado law, again with a focus on wildlife. Ten years ago, the legislature expanded Colorado Oil and Gas Conservation Commission (COGCC) authority to regulate drilling and well production.[131] It amended the Oil and Gas Conservation Act and enacted the Colorado Habitat Stewardship Act, directing applicants for permits to drill to consult with wildlife authorities and surface owners and to utilize, "whenever reasonably practicable," best management practices.[132] New rules followed every year or two for chemical disclosure, water quality sampling, setbacks, spill response, and other

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129. *Id.* at 11–13.

130. WYO. GAME & FISH DEP'T, *supra* note 115, at II-2-16.

131. Act of May 29, 2007, ch. 320, 2007 Colo. Sess. Laws 1357 (codified as amended COLO. REV. STAT. § 34-60-102 (2018)).

132. Act of May 29, 2007, ch. 312, § 3, 2007 Colo. Sess. Laws 1329 (codified as amended COLO. REV. STAT. § 34-60-128 (2018)).

concerns that appear in the 2007 OGCA amendments, including wildlife.[133] CDPHE shares authority over air quality impacts and waste discharge to surface waters with COGCC.[134]

As in Wyoming, the state first responded to UOG by indirectly limiting its ecological impacts. COGCC administers rules that cover, *inter alia*, setbacks, pit design, chemical disclosure, surface water discharge (and, with CDPHE, stormwater management), pre- and post-drilling water quality sampling, netting and fencing to protect wildlife and migratory birds, and reclaiming a site on an interim basis and when it nears the end of its productive life.[135] These rules are triggered when COGCC receives a request for permit—an Oil and Gas Location Assessment (OGLA) and an Application for Permit-to-Drill (APD).[136] COGCC reviews the application for indicators such as distance and direction from surface and groundwater, distance from building units, topography, soil type, and vegetation. Setbacks, revised in 2013, limit UOG activity within 500 feet of a building unit or 1,000 feet from a high-occupancy building (subject to exception and exemption), and the rules detail the spacing of heater-treaters and other equipment.[137]

From there, the rules diverge and lay out more focused distance- and location-based indicators than we find in Wyoming. An OGLA permit includes "over 70 individual data fields" including location, disturbance size, soil, vegetation, surface and ground water, and wildlife habitat.[138] COGCC reviews the indicators, consults with surface owners, local governments, and agencies such as Colorado Parks and Wildlife (CPW), and receives public comment, all of which result in general operating requirements and conditions of approval specific to the proposed site.

Rules for Protection of Wildlife Resources (the "1200-Series"), adopted in 2008, reference an operator's duty to consult with CPW under Rule 306(c) and base certain restrictions on a proposed site's location in a Sensitive Wildlife Habitat (SWH) or Restricted Surface Occupancy (RSO) area.[139]

133. *See* COGCC 2008 implementing regulations for, *inter alia*, well drilling requirements, COLO. CODE REGS. § 404-1:317 (2018); groundwater baseline sampling and monitoring, *id.* § 404-1:609; setback requirements, *id.* § 404-1:604; waste management, *id.* § 404-1:907; and wildlife protection, *id.* §§ 404-1:1201 to 1205.

134. COLO. REV. STAT. § 24-1-119 (2018).

135. COLO. CODE REGS. §§ 404-1:205, -1:604, -1.609, -1:902, -1:904, -1:1001, -1:1002 (2018).

136. *Id.* § 404-1:303.

137. *Id.* § 404-1:604.

138. *Environmental Unit: Oil and Gas Location Assessment Permit*, COLO. OIL & GAS CONSERVATION COMMISSION, https://cogcc.state.co.us/documents/about/TF_Summaries/GovTaskForceSummary_Environmental_OGLA.pdf (last visited Mar. 10, 2018).

139. COLO. CODE REGS. §§ 404-1:306(c), -1:1201, -1:1202 (2018).

SWH is a geographic range where a biotic activity takes place. Examples include bald eagle nests, lesser prairie chicken nesting habitat, and places where pronghorn antelope, bighorn sheep, elk, and mule deer concentrate in winter months.[140] Operating requirements for these areas are outlined in Section 1203, the goal of which is to minimize "impacts to sensitive wildlife species and habitat."[141] They are expressed in terms of general goals or choices during site and supportive infrastructure development (e.g., "minimize rig mobilization"; "reduce excessive right-of-way widths"; "limit access to oil and gas access roads"; "reduce traffic"; "install wildlife crossovers and escape ramps"; "use boring instead of trenching").[142] By comparison, RSO areas are, for the most part, defined in relation to well distance from wildlife: 300 feet from ordinary high-water mark of streams with Cutthroat Trout, a quarter mile from active bald eagle nest sites, 0.6 miles from sage-grouse.[143] Section 1205 requires operators to avoid RSO areas "to the maximum extent technically and economically feasible," subject to exemption or authorization.[144]

As in Wyoming, more specific wildlife protection requirements are found elsewhere. This time, they take the form of suggested BMPs maintained on CPW's website.[145] In Colorado, the BMPs can be imposed on an operator as conditions of approval for an APD.[146] CPW (at the time known as the Division of Wildlife) prepared a list of BMPs in 2008.[147] The list was revised most recently in 2012 for infrastructure placement[148] and 2016 for species-specific concerns.[149]

The infrastructure placement measures span thirteen pages and aim to avoid or reduce disturbance from several UOG lifecycle stages.[150] Examples

140. *Id.* § 404-1:100.

141. COLO. OIL & GAS CONSERVATION COMM'N, COGCC OPERATOR GUIDANCE, 1200-SERIES: WILDLIFE RESOURCES 2 (2016), https://cogcc.state.co.us/documents/reg/opguidance/1200%20Series%20Operator%20Guidance%20Final%20Draft.pdf; COLO. CODE REGS. § 404-1:1203 (2018).

142. § 404-1:1203.

143. *Id.* § 404-1:100.

144. *Id.* § 404-1:1205.

145. *Id.* § 404-1:1202(c).

146. COLO. OIL & GAS CONSERVATION COMM'N, *supra* note 141, at 2.

147. *See generally* COLO. DIV. OF WILDLIFE, ACTIONS TO MINIMIZE ADVERSE IMPACTS TO WILDLIFE RESOURCES (2012), http://cusp.ws/wp-content/uploads/2014/10/Colorado-Final-Oil_Gas-Wildlife-BMPs-03_16_2012.pdf.

148. *Id.*

149. *See generally* COLO. PARKS & WILDLIFE, ACTIONS TO MINIMIZE ADVERSE IMPACTS TO WILDLIFE RESOURCES (2d rev. 2016), https://nhnm.unm.edu/sites/default/files/nonsensitive/news-files/Colorado%20Final%20Species_Specific%20BMPs_Oct%2017_101716.pdf.

150. COLO. DIV. OF WILDLIFE, *supra* note 147, at 1–13.

include infrastructure layout (e.g., "[p]hase and concentrate all development activities," "[a]void low water crossings"); drilling and production (e.g., "[s]chedule construction, drilling, and completion activities to avoid particularly sensitive seasonal wildlife," "locate pipeline systems under existing roadways"); pit construction (e.g., "[a]void locating fluid pits within 300 feet of the ordinary high water mark of any reservoir, lake, wetland," "[s]kim and eliminate oil from produced water ponds and fluid pits at a rate sufficient to prevent oiling of birds or other wildlife"); and reclamation (e.g., "[r]estore both form and function of impacted wetlands and riparian areas and mitigate erosion," "[c]lose and reclaim roads not necessary for development immediately").[151] There are also measures to minimize invasive species and disturbance to aquatic habitats (e.g., "bore pipelines that cross perennial streams," "schedule necessary construction in stream courses to avoid critical spawning times").[152] The infrastructure placement measures end by noting that research may be needed "to test the effectiveness of specific Best Management Practices."[153]

Species-specific recommendations were updated in 2012 and 2016 (in a document that does not include the infrastructure measures just described).[154] The text enumerates BMPs to "provide operators guidelines to plan and manage their activities to avoid and minimize adverse impacts to wildlife resources."[155] Species-specific BMPs "are derived from the best available science and represent necessary management actions to protect wildlife," although the document does not contain citations to relevant research.[156] BMPs are listed for each of more than forty species. There is a marked uptick in specificity from the infrastructure measures in 2012 to the species-specific measures in 2016. For example, the document lists twenty-three measures to avoid disturbance to a species of sage-grouse.[157]

Unlike Wyoming's inventory of voluntary BMPs for wildlife habitat, Colorado's list of suggested BMPs does not distinguish among or tweak measures according to a proxy for level of landscape disturbance, such as well pad density per square mile. Instead, Colorado's BMPs begin with a species and build out steps to minimize or mitigate impacts to that species.[158]

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151. *Id.* at 2–3, 6–7, 10–11.
152. *Id.* at 5, 7–8.
153. *Id.* at 13.
154. COLO. PARKS & WILDLIFE, *supra* note 149.
155. *Id.* at 1.
156. *Id.* at 2.
157. *Id.* at 9–11.
158. *See, e.g.*, *id.* at 2 (Bighorn Sheep); *id.* at 5 (Columbian Sharp-Tailed Grouse); *id.* at 7 (Deer and Elk); *id.* at 9 (Greater Sage-Grouse); *id.* at 13 (Kit Fox); *id.* at 19 (Raptors); *id.* at 20 (Bald Eagle); *id.* at 21 (Mexican Spotted Owl).

They include distance- and time-based restrictions (e.g., "preclude new oil and gas operations within 0.4 mile," "operations outside the period between March 15 and July 30," "well site visitations [restricted] to X times per day"); density-based restrictions (e.g., "limit surface facility density . . . to one facility per square mile within 1.25 miles of Columbian sharp-tailed grouse leks"); noise and visual controls (e.g., "limit noise emissions from new oil and gas operations to 10dBA above pre-development background"); and equipment-specific measures to limit direct contact with wildlife (e.g., "tanks and other facilities designed such that they do not provide perches or nest substrates").[159]

Both wildlife agencies express the importance of limiting disturbance and planning for mitigation "at a landscape scale."[160] The rules make some effort to encourage this. Colorado's rules repeat the goal of siting well pads "to provide a safe working area while reasonably minimizing the total surface area disturbed."[161] They include mandatory mitigation for sites in designated setback areas. For example, parties must agree to conditions of approval for site-specific mitigation within 1,000 feet of a building unit.[162] The rules list two-dozen requirements that apply within this and other designated setback locations, including two planning tools: consolidate well pads "[w]here technologically feasible and economically practicable" and develop multiple reservoirs or completions from existing well pads "where possible."[163]

One crude means of evaluating this complex regulatory tapestry, which zeroes in on wildlife, defines it in terms of "areas" of activity, and selects practices from intermittently updated menus posted online to include in an APD, appears in a memorandum from the Director of CPW to COGCC. It updated the known acreage of each RSO or SWH area and indicated change in acreage between October 2008 and June 2013. Defined areas experienced a range of declines and gains in acreage. For example, among RSO areas,

159. *Id.* at 5–6.

160. *Id.* at 1 ("Assessing unavoidable adverse impacts and evaluating potential compensatory mitigation actions is best accomplished at a landscape scale . . . ."); *see also* Wyoming BMPs, *supra* note 119, at 6 ("'Landscape unit' means a geographic area encompassing all the major ecological components, functions, and processes that are essential to sustain species populations or biotic communities.").

161. 2 COLO. CODE REGS. § 404-1.1002(d) (LexisNexis 2018).

162. *Id.* § 404-1.604(a)(2).

163. *Id.* § 404-1.604(c)(2)(E), (V). The rules also encourage voluntary Comprehensive Drilling Plans (CDPs) for more than one proposed UOG site in a geological basin, through priority approvals and burden shifting to parties that request a hearing. *Id.* § 404-1.216.

there were declines of between 3% and 92% in nine RSO categories and gains of between 13% and 96% in six categories.[164]

III. FAULTY FEDERALISM AND KNOWLEDGE GOVERNANCE

A close read of oil and gas laws, regulations, policies, and supporting documents in two jurisdictions and their change over more than a decade reveals tensions between research on UOG's ecological impacts and state control over development. The peer-reviewed research stresses tradeoffs, reciprocal correction, and context—optimally organized landscape; BMPs adapted to eco-regional effects; and UOG as one among several forms of human impact, the effects of which depend on mix of landcover and anthropogenic disturbance. In contrast, rules and guidelines are triggered by discrete siting proposals, measure distance to or location within one of several categories of wildlife activity or range (referred to as "areas"), and list a menu of steps and goals that can be pursued in the form of BMPs.

The research imperatives that underlie the peer-reviewed literature are briefly presented as discrete choices in rules and guidance documents: "multiple wells," "clustered configuration," and "least possible infrastructure" to be selected among, rather than unanswered questions of optimal organization.[165] Available acts abound—operators might "phase" or "avoid" or "schedule," if suggested BMPs are included in an approved APD.[166] Landscapes are mentioned but key landscape metrics are not.[167] Even a proxy for landscape disturbance, defined in narrow fashion by Wyoming as well pad density or acreage, is used to suggest that operators voluntarily "disperse" runoff, "trench" rather than "bore" through a stream, or adopt any of a number of "standard management practices."[168] The limited success of seasonal use and standard operating procedures, and the uncertain efficacy of mitigation, appears as a brief admission.[169] Pre-defined "areas" ebb and flow over years,[170] perhaps in response to one or more practices that can be plucked

164. Memorandum from Steve Yamashita, Acting Director, to Colo. Oil & Gas Conservation Comm'n 4 (Aug. 29, 2013) [hereinafter Yamashita Memorandum], https://cpw.state.co.us/Documents/Commission/2013/Sept/ITEM6-COGCCmap-ruleupdateMemotoCPWCommissionSept2013.pdf.

165. Wyoming BMPs, *supra* note 119, at 27.

166. COLO. DIV. OF WILDLIFE, *supra* note 147, at 2, 4–5.

167. *See* SLONECKER ET AL., *supra* note 36; *supra* text accompanying note 65.

168. Wyoming BMPs, *supra* note 119, at 98, 104–05.

169. *Id.* at 12–13.

170. Yamashita Memorandum, *supra* note 164, at 4.

from lists and given effect as (depending on the jurisdiction) voluntary or enforceable conditions under which a UOG site can proceed.

Together, these tensions reveal an absence of infrastructure to answer foundational research questions that animate the peer-reviewed research. They stand in contrast to the claims that legal scholars make when they debate the level of governance that should address, say, healthcare or environmental impact.[171] The claims of legal scholars are often confidently expressed, and not only in terms of whether central (federal), devolved (state and local), dual (distinct and separate approaches), cooperative (shared authority), or dynamic (overlapping and collaborative) federalism should prevail for a policy problem.[172] More concerning for our purposes is how normative claims that are made to distinguish among these governance options, such as "closeness," "innovative experimentation," or "expertise," are described.

In the context of UOG development, for example, a local actor may be portrayed as "closer" to the source of an impact, or they might "lack" "resources or expertise."[173] UOG's "costs and benefits" may be best "balanced" by a state if impacts are "local," or perhaps a federal agency can "fill gaps" by taking advantage of "economies of scale."[174] Maybe states could "tailor" decisions and serve as "testing grounds," which could "lead to technical experimentation" and "foster technological innovation," while experiments at the federal level may be "less likely to get off the ground."[175] But then cumulative or boundary-spanning impacts of fracking might exceed

171. *See, e.g.*, Larry Kramer, *Understanding Federalism*, 47 VAND. L. REV. 1485, 1498 (1994).

172. *See* J.B. RUHL, STEVEN E. KRAFT & CHRISTOPHER L. LANT, THE LAW AND POLICY OF ECOSYSTEM SERVICES 282–83 (2007) (dual); Henry N. Butler & Jonathan R. Macey, *Externalities and the Matching Principle: The Case for Reallocating Environmental Regulatory Authority*, 14 YALE J. REG. 23, 28 (1996) (devolved); Daniel C. Esty, *Revitalizing Environmental Federalism*, 95 MICH. L. REV. 570, 624 (1996) (centralized); Robert Schapiro, *Toward a Theory of Interactive Federalism*, 91 IOWA L. REV. 243, 250 (2005) (dynamic).

173. Hannah J. Wiseman, *Risk and Response in Fracturing Policy*, 84 U. COLO. L. REV. 729, 813 (2013).

174. Thomas Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy*, 98 MINN. L. REV. 145, 255 (2013); David B. Spence, *Federalism, Regulatory Lags, and the Political Economy of Energy Production*, 161 U. PA. L. REV. 431, 462–64 (2013).

175. Michael Burger, Response, *Fracking and Federalism Choice*, 161 U. PA. L. REV. ONLINE 150, 159–60 (2013), https://www.pennlawreview.com/online/161-U-Pa-L-Rev-Online-150.pdf; Thomas W. Merrill, *Four Questions About Fracking*, 63 CASE W. RES. L. REV. 971, 979–80 (2013); *see* Spence, *supra* note 174, at 435.

the geographic scope of state governance and "become national-level issues," "squarely within the competencies" of federal regulators.[176]

Even dynamic federalism celebrates the "marvelous machine" and the "dialogue, and redundancy" that could result from overlapping jurisdiction.[177] And the rare, and recent, argument that states may not be such a reliable source of new regulatory options treats information as an independent variable: states "may still be laboratories," but "with no comprehensive, uniform information exchanged among them."[178] The challenge of "shared regulatory content," or information diffusion, proceeds from an assumption that the good work of state laboratories may in some policy domains be carried out in vain.[179] From there, the full range of normative federalism concerns return—"building structures for information sharing" under the Affordable Care Act; comparing state approaches to oil and gas when such work "requires substantial background expertise."[180]

To further advance the federalism literature, we must open up each of these normative claims in light of what anthropologists, sociologists, and critical theorists such as the French school of actor-network theory have learned about scientific practice itself. Bruno Latour eviscerated the divide between seemingly "immutable" scientific facts and the social and cultural practices that produce them[181] and lend them "stability and persuasive power."[182] This insight was given normative valence and relevance to how we "organize and govern ourselves"[183] through Sheila Jasanoff's co-production framework.[184] Co-production argues that we do not merely

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176. Burger, *supra* note 175, at 154; Robin Kundis Craig, *Hydraulic Fracturing (Fracking), Federalism, and the Water-Energy Nexus*, 49 IDAHO L. REV. 241, 263 (2013).

177. Kirsten H. Engel, *Harnessing the Benefits of Dynamic Federalism in Environmental Law*, 56 EMORY L.J. 159, 176, 183 (2006).

178. Hannah J. Wiseman, *Regulatory Islands*, 89 N.Y.U. L. REV. 1661, 1661 (2014).

179. *Id.*

180. *Id.* at 1673, 1703.

181. Bruno Latour, *Drawing Things Together*, *in* REPRESENTATION IN SCIENTIFIC PRACTICE 25 (M. Lynch & S. Woolgar eds., 1990).

182. Sheila Jasanoff, *A New Climate for Society*, 27 THEORY, CULTURE & SOC'Y 233, 236 (2010).

183. Sheila Jasanoff, *Future Imperfect: Science, Technology, and the Imaginations of Modernity*, *in* DREAMSCAPES OF MODERNITY: SOCIOTECHNICAL IMAGINARIES AND THE FABRICATION OF POWER 3 (Sheila Jasanoff & Sang-Hyun Kim eds., 2015).

184. In an early use of the co-production framework, Jasanoff demonstrates that epistemic closure around the impacts and root causes of the Bhopal gas tragedy—where a leak at a Union Carbide pesticide plant exposed hundreds of thousands of people to methyl isocyanate—was not reached until normative closure around notions of responsibility for the disaster was achieved. *See* Sheila Jasanoff, *The Bhopal Disaster and the Right to Know*, 27 SOC. SCI. & MED. 1113, 1121–22 (1988). A more recent example is Mahony's study of the Indian Network for Climate

"ascertain facts about the natural world," but do so in the context of problems such as social authority and credibility.[185] In this way, scientific knowledge and social order are not distinct, nor do they occur in ordered sequence where one is necessarily prior to the other. Rather, they exist in a cycle of exchange. This process is facilitated by resources such as standardization, categorization, visual representation, identities, discourses, and norms. Co-production explores the interdependence of fact and value, and "the concealment of such entangling."[186] Latour argues that the means by which such categories are brought into being as separate spheres is a distinguishing characteristic of modernity.[187]

The approach can resolve common fallacies in legal scholarship. In place of an assumed linear model of scientific development where its products are received and perhaps accepted,[188] analysis avoids scientific determinism by focusing on "the constant interplay of the cognitive, the material, the social and the normative"[189] within each of the cultural resources that emerge as knowledge and society engage in mutual accommodation. Rather than consider governance as a mix of bureaucratic institutions and procedures, co-production begins with the interactions that create a range of "organizational mechanisms, operational assumptions, modes of thought, and consequential activities involved" in "a particular area of social action."[190] Through study of these interactions, we refine our understanding of how science and

Change Assessment and the co-evolution of its "practices of territorial calculation" and "shifting norms and discourses of Indian climate politics." Martin Mahony, *The Predictive State: Science, Territory, and the Future of the Indian Climate*, 44 SOC. STUD. SCI. 109, 112 (2014).

185. SHEILA JASANOFF, STATES OF KNOWLEDGE: THE CO-PRODUCTION OF SCIENCE AND SOCIAL ORDER 29 (2004).

186. Mahony, *supra* note 184, at 119.

187. *See* BRUNO LATOUR, POLITICS OF NATURE: HOW TO BRING THE SCIENCES INTO DEMOCRACY 46 (Catherine Porter trans., 2004).

188. *See, e.g.*, Silke Beck, *Moving Beyond the Linear Model of Expertise: IPCC and the Test of Adaptation*, 11 REGIONAL ENVTL. CHANGE 297, 304 (2011); Carina Wyborn, *Connectivity Conservation: Boundary Objects, Science Narratives, and the Co-Production of Science and Practice*, 51 ENVTL. SCI. & POL'Y 292, 293 (2015).

189. JASANOFF, *supra* note 185, at 38.

190. Alan Irwin, *STS Perspectives on Scientific Governance*, *in* THE HANDBOOK OF SCIENCE AND TECHNOLOGY STUDIES 584 (Edward J. Hackett et al. eds., 3d ed. 2008).

governance co-evolve,[191] and the active work by which science is constituted alongside emergent identities and institutions.[192]

The framework offers sophisticated tools to analyze interactions among domains such as experimental knowledge (grounded in, for example, validity based on models and quality checks such as peer review), oil and gas commission regulatory change (grounded in administrative practices and institutions such as advisory panels and BMPs), and rights-based demands to permits or clean air and water (grounded in corporate practices or lived experience in relation to a context or location). Areas of focus include how ordering instruments such as identities, institutions, discourses, and representations emerge, are stabilized, allow for mutual accommodation during times of conflict, and shape how states of knowledge "are arrived at and held in place, or abandoned."[193] Before we consider normative governance claims such as state primacy in tailoring or testing knowledge, or the federal role in collecting or diffusing knowledge, we must study the interactional responses to a policy problem such as UOG development.[194] The aim of this research is to trace how the co-evolution of science and governance yields knowledge absences as well as what regulators consider relevant knowledge. A chief concern at the heart of the analysis is "how some

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191. *See, e.g.*, Jurian Edelenbos et al., *Co-Producing Knowledge: Joint Knowledge Production Between Experts, Bureaucrats and Stakeholders in Dutch Water Management Projects*, 14 ENVTL. SCI. & POL'Y 675, 675–76 (2011); Dries Hegger et al., *Conceptualizing Joint Knowledge Production in Regional Climate Change Adaptation Projects: Success Conditions and Levers for Action*, 18 ENVTL. SCI. & POL'Y 52, 53–54 (2012).

192. Kaushik Sunder Rajan, *Two Tales of Genomics: Capital, Epistemology, and Global Constitutions of the Biomedical Subject*, *in* REFRAMING RIGHTS: BIOCONSTITUTIONALISM IN THE GENETIC AGE 196 (Sheila Jasanoff ed., 2011).

193. JASANOFF, *supra* note 185, at 19.

194. Future research could, for example, consider how ecological impact knowledge and governance co-evolve at the federal level. For examples, see Federal Land Policy and Management Act, 43 U.S.C. § 1712(c) (2012) (resource management plan); BUREAU OF LAND MGMT., U.S. DEP'T OF INTERIOR, BLM PLANNING FOR FLUID MINERALS RESOURCES (2013), https://www.blm.gov/sites/blm.gov/files/uploads/Media_Library_BLM_Policy_Handbook_H_1624_1.pdf (master leasing plans); SALLY JEWELL, DEP'T OF INTERIOR, SECRETARIAL ORDER NO. 3330, IMPROVING MITIGATION POLICIES AND PRACTICES OF THE DEPARTMENT OF INTERIOR (2013), https://www.doi.gov/sites/doi.gov/files/migrated/news/upload/Secretarial-Order-Mitigation.pdf (department-wide strategic plans); *The BLM's Landscape Approach for Managing the Public Lands*, DEPT. INTERIOR, https://www.blm.gov/policy/ib-2012-058 (rapid ecoregional assessment). Landscape-scale planning for the impact of UOG infrastructure at BLM and other federal agencies such as the U.S. Forest Service is in doubt at the moment after congressional repeal of BLM's "Planning 2.0" rule. *See* Resource Management Planning, 81 Fed. Reg. 89,580 (Dec. 12, 2016) (codified at 40 C.F.R. pt. 1600); *see also* Kellie Lunney, *Trump Signs Resolution Repealing BLM Planning 2.0 Rule*, E&E NEWS (Mar. 27, 2017), https://perma.cc/3MF8-FSRW.

crucially important knowledges, practices and norms were bounded out of decision-making" and the role of ordering instruments that form and fuel these "processes of erasure."[195]

The experience of Colorado and Wyoming in dealing with the ecological impacts of UOG development shows how such research might force us to rewrite the causal claims that embody normative federalism. The interaction of ecologists, biologists, chemists, state legislators, oil and gas commission and wildlife agency officials, operators, and other parties drives the iterative approval of APDs and updating of BMPs, based not only on innovations in the peer-reviewed literature but also on the evolving condition of wildlife areas that are subject to industrial activity through combinations of operating requirements and BMPs in approved APDs and amended Oil and Gas Location Assessments (OGLAs). For example, an amended OGLA submitted by Antero Resources might disclose a change in location for some of its facilities (four condensate tanks, six water tanks, six separators, twenty-three wells, water and oil pipelines, and other equipment) in a sensitive wildlife area. COGCC and operator interaction, in consultation with CPW, might lead to the inclusion of thirteen BMPs and a claim that "directional drilling will be implemented to minimize habitat loss."[196] The design and updating of CPW's *Actions to Minimize Adverse Impacts to Wildlife Resources*, as well as its selective use in Antero Resources and other party filings, reveal significant initiative and expertise on the part of state regulatory response.

Yet either level of interaction can remove foundational research questions from consideration or render them unanswerable, including the three research imperatives described in this Article. Removal may occur through institutions such as BMPs, representations such as wildlife area, the periodicity with which an OGLA form is submitted or amended and other rules, and the formation and maintenance of identities of operators and other parties that are viewed as holding material knowledge to inform selection among menus of BMPs for a given site. These combinations in turn constitute a base of daily practice that can limit or facilitate further growth in observational or experimental knowledge of UOG's ecological impacts. We are unable to claim that one or more governance level can best tailor, balance, test, share, or foster relevant knowledge until we analyze the interactions that co-produce knowledge in a particular policy context.

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195. JASANOFF, *supra* note 185, at 39–41; Sheila Jasanoff, *Breaking the Waves of Science Studies: Comment on "The Third Wave of Science Studies,"* 33 SOC. STUD. SCI. 389, 395 (2003).

196. *COGIS—COA/BMP Information*, COLO. OIL & GAS CONSERVATION COMMISSION (Nov. 1, 2017), http://cogcc.state.co.us/cogis/COAs.cfm?facid=335538.

CONCLUSION

Invasive oil and gas landscapes were met with similarly exponential growth in scientific research in the last few years, as well as sustained efforts by states to address their ecological impacts. A close review of the parallel (and at times intersecting) development of peer-reviewed research and the design of restrictions and controls reveals inherent tensions in how fracking governance is constructed among assemblages of scientists, department officials, operators, and other groups. Research imperatives of optimally organized landscape, management practices adapted to eco-regional effects, and UOG sites within landcover mixtures and other forms human disturbance can be removed from consideration as institutions such as BMPs, representations such as wildlife area, permit approval and amendment cycles, and the identity of groups viewed as holding material information to influence the selection of operating requirements form what we later refer to as regulatory response to an environmental impact. Before we can consider normative governance claims such as state primacy in tailoring or testing knowledge, or the federal role in collecting or diffusing knowledge, we must first study these interactional responses that co-produce governance of a policy problem such as UOG development. Such research will allow us to refine our claims and render more sophisticated proposals that respond to risks at the edge of human ingenuity and understanding.