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Modeling without end: Conflict across organizational and disciplinary boundaries in habitat conservation planning

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CHAPTER 3

Modeling Without End: Conflict Across Organizational and Disciplinary Boundaries in Habitat Conservation Planning

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Practices of modeling that involve real life situations are increasingly seen as both the context for and object of mathematics teaching and learning (e.g., Greeno & Hall, 1997; Lehrer & Schauble, 2004; Lesh & Doerr, 2003). Open-ended, model-eliciting tasks are expected to provide learners with an opportunity to find relevant problems in complex situations, to develop representational tools for describing and analyzing problem structure, and to compare different approaches to solution. Negotiation over model assumptions, interpretation and explanation of model behavior, and model revision in response to evaluations of findings are highlighted as modeling practices that provide both a learning environment and an image of what should be learned. Mathematics classrooms designed to facilitate these modeling practices are expected to engage learners' interests in the real world, to resemble professional practices in ways that are meaningful for learners, and to encourage deeper conceptual understanding of key mathematical concepts for both learners and teachers.

In this chapter, we analyze a case in which modeling becomes "too real" for participating scientists, to the point that modeling goes on, it seems, without end. Participants cannot agree on what are the relevant problems to solve, representational tools are developed and discarded without a clear evaluation of progress, and cycles of model revision do not converge or terminate with findings or explanations that satisfy major stakeholders in the modeling activity. The case is drawn from a four year, ethnographic study of efforts to design a multiple-species habitat conservation plan (MSHCP) for an ecologically sensitive desert region in the southwestern United States (Goldstein, 2004). We focus on work by members of a scientific advisory committee (SAC), locating their efforts within a larger history of plan development. We also look closely at conversational exchanges between scientists, land managers, and plan

consultants in a meeting called to review additions/deletions to an existing model of occupiable habitat for an endangered lizard species.

We start by describing the history of conservation planning in the Valley (names of all participants and locations are pseudonyms), leading into the MSHCP planning effort used as a case in this chapter. We interrupt that historical narrative to present two scenes from a SAC meeting convened to identify lizard habitat that should be included in the multiple species plan. Talk-in-interaction from these scenes is analyzed closely to explore differences in professional point of view towards land in the Valley, listed or endangered species that live there, and human activities that increasingly determine the welfare of those species. Land managers in the Valley, regulatory biologists from state and federal agencies that encompass the area, and local biologists with a professional history of studying Valley species (like the fringe-toed lizard) each see the planning process and its outcome differently. A potentially volatile disagreement in the meeting is contained by a decision to fall back on prior planning models for the lizard, but as the meeting ends, this is clearly a tenuous settlement between regulatory and local biologists. We then resume the planning history, describing the fate of this effort to contain disagreement, of the SAC as an organizational entity, and of the MSHCP itself. We conclude by identifying aspects of model construction and negotiation that cross organizational boundaries and may be particularly relevant for cognitive studies of educational practice.

FROM NATURAL PRESERVE TO A "BALANCE OF TERROR" BETWEEN RACKET CLUBS AND LIZARD HABITAT

Table 3.1 shows a narrative timeline of conservation history in the Valley, starting with the region's relative isolation (because of surrounding mountains and desert). This natural isolation was opened with installation of a canal and water supply in the late 1940's (Event 2), which enabled a dramatic expansion of the human population, along with construction of golf courses, tennis clubs, and hotel and related entertainment facilities. Sand-dependent species like the fringe-toed lizard (FTL), found only in the Valley, went into an equally dramatic decline, as habitat was lost to human development. Local biologists, some participating in the SAC meeting analyzed in this paper, successfully petitioned the U.S. Fish and Wildlife Service in the early 1980s to list the FTL as an endangered species. When a new golf course development was proposed in critical lizard habitat, local biologists and developers threatened each other with legal action, creating what one biologist termed a "balance of terror" between the two sides. After a few years of standoff, both sides formed a working group they called the "lizard club" and began preparing a habitat conservation plan (HCP), a regulatory structure newly authorized by the U.S. Congress that allowed regional stakeholders (including cities, land managers, and property owners) to create plans that permit "take" of species and habitat in exchange for mitigation fees, if developers can demonstrate continuing species viability. The fringe-toed lizard HCP was approved in 1986 (Event 3).

With evidence growing that 1986 assumptions about lizard habitat were inaccurate, and in the context of a fierce debate about other listed species in the Valley (Event 4), local biologists assembled a planning group to work on a multiple-species HCP that would include (and revisit) the existing lizard plan. A scientific advisory committee (SAC) consisting of local biologists, regulatory biologists, and area land managers was established and supported by plan consultants in 1996, who expected

TABLE 3.1.
A Narrative Timeline of the MSHCP Planning Process Running up to the SAC Meeting Analyzed in this Chapter

1500s–1900	(Event 1) Mountains and desert isolate the valley from large-scale land conversion and exotic species that were introduced in other parts of California, creating a natural preserve for endemic valley species.
1948	(Event 2) Construction of a canal makes water available for a substantial increase in human development, including recreational facilities (e.g., golf courses, hotel/entertainment centers). The valley environment is rapidly impacted by human use, and sand-dependent species go into sharp decline.
1980s	(Event 3) Local biologists and developers resolve a "balance of terror" by collaborating in preparation of a habitat conservation plan (HCP) for the fringe-toed lizard. The plan is approved in 1986 by regulatory agencies and local municipalities (the second HCP prepared in the nation).
1990–1996	(Event 4) Amidst controversy over other endangered species and growing uncertainty about the viability of lizard populations in the valley (e.g., assumptions about sand sources), local biologists (several from the 1980s "lizard club") begin discussing a multiple-species HCP. The SAC is convened in 1996, and in their proposed timeline, an approved MSHCP would begin issuing permits in 1998.
1996–2000	(Event 5) Despite guidance provided by eminent external scientists (in 1996 and 1998), there is ongoing disagreement between regulatory and local biologists over assigning conservation value to mapping units in the valley and which areas to include in the plan. After meeting in private for months, regulatory biologists release a 41-page letter, calling for inclusion of new areas and contracting a new hydrology study (2000). Local biologists are furious, some concluding they have been "rejected entirely."
October, 2000	(Event 6, meeting analyzed in this chapter) With new preserve areas and a pending hydrology study still on the table, the SAC meets to discuss lizard habitat as one component of the larger MSHCP.

approval for the new MSHCP within two years. As planning proceeded, the modeling procedures for the SAC habitat preserve design were created with the advice and oversight of a panel of eminent scientists (Event 5), although internal disagreements between local and regulatory biologists became increasingly heated. Regulatory biologists, preferring a plan area that was more expansive than local biologists would allow, began meeting in private, then issued a lengthy criticism of the SAC plan and commissioned scientists from a separate federal agency to study the "hydrology" of wind-blown sand across the landscape, focusing on critical linkages between sand dunes and the mountainous areas that serve as sand sources. Local biologists and even plan consultants felt their work had been undermined by regulatory biologists on the SAC, and this trouble was still underway as they met to revisit the FTL lizard preserve (Event 6, the meeting analyzed in this chapter).

MODELING IN THE WILD: TROUBLE IN SCENES FROM A SAC MEETING

We now examine two scenes from a SAC meeting (Event 6, Table 3.1) held four years after the committee was established to develop a multi-species HCP for the

FIGURE 3–1. Seating order, participants and active map documents in SAC meeting to discuss conservation plan for an endangered lizard species in the valley. Different professional roles include plan consultants (PC), regulatory biologists (RB), local biologists (LB), and land managers (LM).

valley. As described above, there was substantial disagreement between local and regulatory biologists over which areas of the valley should be included in the plan (Events 4 and 5).

As SAC participants come to the table, they take seats in a pattern that reproduces the growing divide between local and regulatory biologists (Figure 3–1). Local biologists sit together to the left (Nick, Bert, and Dave are active participants), while regulatory biologists cluster at the upper right (Linda, Randy, and Charles). Plan consultants (Mary, Vera, and Edward) take seats that mark a boundary between local and regulatory biologists in the seating order. Land managers and representatives of other stakeholder organizations are distributed across the remaining seats. The purpose of this meeting is to identify preserve areas for a single valley species, the fringe-toed lizard (FTL), which is already protected under a habitat conservation plan established in 1986 (the second HCP approved in the nation, Event 2 in Table 3.1).

Scene 1: Using Satellite Imagery to Model Sandy Lizard Habitats

Dave, a local biologist and manager of the existing FTL preserve, has worked with plan consultants to bring a new map to the meeting. The new map shows soil types by color, and Dave proposes that he has developed a reasonably accurate way to identify areas in the valley that are either good or poor habitat for the lizards. Mary

[1]Transcripts identify speaker (Figure 3–1) with professional affiliation and show contiguous talk unless otherwise noted. Extended turns are broken at thematic boundaries. EMPHATIC speech is shown in upper case, stre:::tched enunciation is shown with repeated colons, ((*action descriptions*)) are show in italics within double parens, and [overlapping talk is marked with [matching square brackets across speaking turns.

(a plan consultant) has already placed the new soil map at the center of the table, next to a map showing the existing FTL preserve areas. Referring to the new soil map, Dave talks[1] about what a computer can "see" when analyzing data taken from a satellite orbiting the Earth.

Binding reflected light to habitat-species relations and human activity. Dave proposes using reflected light, measured by a satellite, to represent the grain size of soils, associating a particular reflectance range with wind blown sand (i.e., colored red in the new map). Loose sand with this small grain size is good habitat for fringe-toed lizards (FTL, a listed species), which "swim" in the sand as part of their daily round. Dave, in his daily round as a local scientist and manager of the existing lizard preserve, has visited these red areas and reports they have wind blown sand inhabited by FTLs.

DAVE(LB): The hot red? Um, Well, these are reflectance values that the computer sees from um, an Ekinos satellite image that's forming a resolution using color, three color infrared…um scanning and it APPEARS based on my field checking and and experience out there, that the RED areas are the areas with the most active and um LEAST compacted sand. And in areas within the preserve boundary that I have checked where it's red, there, it's virtually always occupied by fringe toed lizards.

Three measures are bound together in Dave's extended utterance: (1) A remote sensing measure of light intensity is linked to the relation between (2) grain size and compaction of soils as this provides habitat for (3) confirmed sightings of individuals of an endangered species. Dave speaks as an authority for lizards and the local terrain, and his work in the field and on the computer binds light to lizards and soil quality. The outcome, as proposed and resting on the table top, is a map of the valley with a colorized layer that sorts good ("hot red")" from poor lizard habitat (orange, yellow or brown, described below).

And the areas that are ORANGE, it's a mix. Um there's some fairly unconsolidated or un-compacted material, but some compacted material as well. And it's sort of intermediate in character and in THOSE areas, so far anyway, I've tended to find LESS fringe toed lizards although some, but um, the flat tails are more common in that particular color type.

HANK(LM): The orange?

DAVE(LB): The orange. The, that's, and I'm just speaking from within the preserve cause those are the only areas I've checked.

In the yellow area, it's MUCH more compacted, sometimes almost to the extent of feeling like cement, and tends to get coarser and then the brown, which there isn't much there, has got a lot of rocks and gravel and um boulders mixed in with it.

During Dave's visits to the mapped areas, as the sand becomes more compacted (i.e., areas colored orange and brown by satellite data), there are fewer FTLs and other lizard species ("flat tails")" begin to appear. So reflectance values do seem to represent soil type and habitat-species relations accurately. Dave's reflectance layer could provide the SAC with a defensible way to identify current FTL habitat, including areas that have become more or less suitable for lizards since the 1986 plan was approved.

So, one COULD um…figure that if you were just to map the red stuff, that would show you the extent of currently occupied habitat and it, it, at least in the little field checking I've done, which is…just the preserve and the areas I'm familiar with it seems pretty consistent.

You can see over there by Terry's dune area that it's, that's, if it wasn't for the off-road vehicles I'm sure it would be occupied and I'm sure it still has a few lizards in it.

But it also shows the area in front of Stove Top as being bright red and that's an area that just gets hammered by off-road vehicles, so the image may be picking up the fact that it's loose fluffy material because of that and whether or not it would ever be occupied if the um…vehicles were removed, I can't say.

Dave cautions that reflectance values, alone, are not sufficient. Some areas within the selection threshold for fluffy sand (i.e., red areas) do not currently have lizards because of human activity (e.g., off-road vehicles), and that soil quality may even be a result of human activity. In this sense, level of human activity (e.g., terrain "hammered by off-road vehicles")" is added as a fourth measure to the emerging model of suitable FTL habitat.

For a study of modeling in the wild (following Hutchins, 1995), Scene 1 looks like a moment of rapid progress in work by the SAC. The area and relations Dave wants to model are already captured by earlier modeling efforts (the 1986 plan), yet assumptions behind those prior efforts may no longer hold. Dave proposes they displace that earlier model (and its settled agreements) with another, in a way that can be shown to be consistent with the existing preserve but more accurate. To do this, Dave proposes a new representational layer that binds satellites to lizards, linking four measures (light intensity, soil quality, lizard activity, and human activity) to show what has changed since the prior modeling effort.

Regulatory biologists question accuracy and coverage for their anticipated use. Dave's proposal to identify lizard habitat as the correspondence between reflected light and confirmed lizard/human activity seems like a reasonable set of model assumptions. Designated habitat (i.e., what the plan seeks to preserve) would be found by combining objective measures (reflectance imagery) with local, expert judgment in the field (Dave's efforts to "ground truth" soil quality and species sighting). However, regulatory biologists scrutinize the new map (and in-progress model) closely as the conversation continues.

CHARLES(RB): Does the, do the colors comport at all with grain size? Can you tell coarse from wind blown? [Is the red basically wind blown?]

DAVE(LB): [Well, all of those] colors have a degree of aeolian character to them. They all, um the red as I said is the most active, the um, probably has the most consistently, I'm trying to think of the right word, that the the LEAST variation in grain size.

A regulatory biologist (Charles) asks whether the red reflectance class corresponds to coarse or "wind blown" sand, making a distinction between the physical state of soils (fine or coarse) and processes that produce this state (wind sources or human activity). Wind sources are good for sustaining lizard habitat because they require no human intervention. Charles's question cuts through Dave's efforts on the ground and local expertise to ask a more fundamental question. Does the reflectance layer tell them anything about sand sources that will operate over longer periods of time?

Another regulatory biologist (Randy) then asks if the entire multiple-species plan area has been covered with satellite reflectance data. Sand sources or even conservable habitat may lie outside the area Dave has mapped, these areas are linked dynamically to what is inside the preserve, and the SAC will want comparable imagery and soils classification for the entire plan area.

RANDY(RB): So its, have you uh, don::e ((*L hand sweeps over white space on map*)) the rest of the sand areas?

DAVE(LB): [No.

MARY(PC): [But just for information, ((*hands sweep over smaller map*)) this is the area that that image covers, overlaid on the whole…um [potential habitat.

DAVE(LB): [I only paid for the preserve and the sand sources to the preserve, so that's all I have, now. I have just recently REQUESTED, and they said it's about a ninety day guaranteed turnaround so it could be sometime next year, an image that would take all the way from Chipper's Finger to the eastern edge of the preserve, so then I can take it all in one image and look [at it that way.

CHARLES(RB): [Um hm.

Dave reports that the larger imagery set will not be available for another three months. Over the history of the SAC planning effort, money to collect map-able data has been scarce, and this creates recurring problems for their planning horizon. Raising money to map the valley, then waiting for additional studies to be completed, pushes a scientifically defensible conservation plan further into the future. Unfortunately, demands from developers (of golf courses, hotels, etc.) and local communities to "take" lizard habitat continue to operate in the present.

As conversation in the SAC continues, regulatory biologists return repeatedly to a distinction between finding areas to preserve, as one function of the plan, and regulating which of these areas land developers might be allowed to "take," as a different function. For example, FTL habitat that is good today (i.e., fluffy sand, populated by lizards) may disappear if regulators allow land developers to take a sand source that maintains that area.

Running Dave's soil classification layer over time. Another local biologist (Nick, a lizard expert) asks if Dave can define reflectance class thresholds consistently so they can compare sand quality over time. He worries that trusting the GIS system to assign color classes will lead them to compare "apples and oranges" across years.

NICK(LB): Can you define:: what frequencies the red um covers so you can compare ((*hands flatten over table*)) between r among years, um [so you're not comparing…apples and oranges?]

DAVE(LB): [In terms of s, its,] Well, you mean in terms of the the the image, ((*hands pull up from table*)) [the reflectance value?

CHARLES(RB): [The year to year image.

NICK(LB): Yeah, so the red this year is the same frequency [range as the red next year.] ((*hands grasp in successive locations*))

Nick's question, completed by Charles, is not just about the validity of computed classes. He proposes extending the reflectance layer from a snapshot of present conditions into a representation of changes in habitat over time. A more dynamic model could show how habitat suitability changes over time, perhaps even addressing the regulatory biologists' questions about the model's capacity to identify FTL habitat that is still maintained by active sand sources. To answer Nick's question, Dave digs into the computational machinery of GIS threshold definitions, contrasting more and less "objective" approaches (below).

DAVE(LB): [Right.] I think you can do that.

Um what we…we tried it a couple of different ways. One was we just asked the computer to divide the image into ten separate, um, reflectance types. And those are four that were representative of blow sand types or aeolian types of some kind.

The other six were mountainous and vegetation and things like that so we didn't color those, so that's why there's so much gray in that image.

Um, so that's one approach and that is more or less, um, the computer is being more or less objective about that because the computer is making that selection.

((*describes other technical strategies through which a GIS user can set reflectance thresholds that apply over successive years*))

I mean that would be the best way to make sure that each year you were looking at the exact same thing.

RANDY(RB): USGS might be interested in questions like that.
(3 sec) ((*Dave and Nick looking at Randy*))

DAVE(LB): Well, when I showed this to, I always forget his name =
((*SAC members jointly recall name of a USGS scientist from a neighboring state*))

DAVE(LB): He said he'd been trying to use this kind of imagery to look at grain size for the last ten years and never been successful with it. And I said, well, this may not be grain size per se, but it it's definitely CONSISTENT with grain size. And he was very impressed that it was that consistent.

Dave's new map layer, under questioning by another local scientist, is extended towards a more dynamic model of sand processes that create lizard habitat. A static model of what exists now (the current landscape) might become a model of how things work over time (how sand processes may maintain the current landscape). This will be critical if the plan is to allow developers to take existing habitat that has little future value, to protect areas that are sustainable as lizard habitat, and to protect sand sources for those sustainable areas.

Randy's observation that USGS might be "interested" in Dave's more dynamic model seems out of place, marked (as we hear it) by a slight pause in ongoing talk among committee members (above). Why would a regulatory biologist, explicitly positioned as a recipient of Dave's in-progress soils model, and even a contributor to insuring its scope and referential adequacy (Randy's earlier questions about areas not yet mapped), allocate the new model to an entirely different organization? Dave, after the slight pause, responds that another scientist, a geologist working for the USGS and not on the SAC, is "very impressed" with his reflected light approach to classifying lizard habitat. But there is no responsefrom Randy.

Why is interest by the USGS a relevant contribution in the SAC meeting at this point? A possible answer, which gains support as the meeting progresses, is that Randy is trying to terminate or defer Dave's model proposal, in light of the fact that he and Charles have recently commissioned a hydrology study (i.e., a map and analysis of sand flow) for the plan area from USGS (Event 5 in Table 3.1). Under this interpretation, Randy withholds assent (or even sustained interest) in Dave's model by referring it to another organization that he and other regulatory biologists have already engaged to provide external scientific advice to the SAC. Several moments later in the meeting (turns not shown), a plan consultant (Edward) follows up on Randy's seemingly off-handed comment, and the regulatory biologists reveal that their external hydrology study will not be delivered for another five months. This is met with incredulity by plan consultants and land managers, who anticipate a

significant delay in the SAC planning horizon. What might have been settled in today's meeting is pushed five months into the future.

Scene 2: Conflict and Containment within Coincident Boundaries

What looked like a productive episode of model building at the beginning of Scene 1, where Dave (local biologist) described how to bind satellite imagery to lizard and human activity in different types of soil, now is being pulled apart by the questions and extra-curricular activities of regulatory biologists. Particular mapped areas are disputed, the coverage of Dave's reflectance layer is too small, and his analysis is not dynamic enough both to identify preserve areas and to regulate what developers can "take" when the HCP is actually used. We have selected Scene 2 to show (a) how this tension between model construction and deconstruction spills over in face-to-face interaction during the SAC meeting, and (b) how the conflicts made explicit in this eruption are contained, at least temporarily, within decisions made by the committee.

A plan consultant's effort to bring closure leads to overt accusation and historical retreat. After 40 minutes of further discussion about specific preserve areas, "sand lenses" that supply fluffy sand to lizards, and human structures that act as barriers in these dynamic processes, the lead plan consultant (Edward) tries to bring SAC members to a decision about what should be in the model.

EDWARD(PC): Well, in terms of what we can accomplish uh today, are we all clear now as to what the model is going to represent when finished? [((*looking at Bert*))

BERT(LB): [((*shaking head, negative*))
((*general laughter*))

CHARLES(RB): ((*laughs, throws hands up, slumps over table*))

BERT(LB): ((*points to Nick and Dave*)) These guys are. I'll work with them, but I'm not. [Do you understand it?] ((*pointing to Dave*))

DAVE(LB): [Well…] I, I know what they want. But this is, when we put this together we had the same discussion, and it was clear that we weren't of one mind completely. And that's why we created what we did.

HANK(LM): I think what you, what we really need to do is have a written statement that everyone can agree, what the model is intended to represent.

General laughter at Bert's response suggests that SAC members are anything but clear about what will or should be in the model. Charles, in what looks like a show of desperation, slumps over the table. Bert asks other local biologists if they understand what the SAC is proposing, and Dave remembers that the lizard club agreed on the previous FTL model after a similar disagreement over what areas were required to pay the mitigation fee. Hank, who has consistently pointed out that his land management decisions will rest on scientific consensus, asks the committee for a written agreement. But given the circumstances, what would biologists (local or regulatory) agree to write down? Bert and Nick, both local biologists, are next to speak.

BERT(LB): And that's got to come from them. ((*points at Charles*))

NICK(LB): Based on all of the models that we've done [so far.

RANDY(RB): [You know maybe we should back up a little bit and ask the question whether it's worth opening this Pandora's box? It would be far easier and more expeditious to just make a simple assumption and accept the fringe-toed lizard HCP model. And…move on. Because I'm not sure it's going to have LOTS of consequence to the end result.

Randy earlier allocated a local biologist's modeling effort to another organization (USGS), and now Bert allocates responsibility for lack of agreement directly to the regulatory biologists across the table. As Nick (also a local biologist) confirms, the regulators need to agree to some version of their model proposals before the SAC can advance the planning effort. By deconstructing model proposals, withholding agreement, and commissioning external scientific studies, the regulatory biologists have blocked the ability of the SAC to provide scientific advice to valley municipalities just as surely as interstate highways have blocked lizards from dispersing to new habitat.

Randy's proposal to "back up a little bit" (above) pulls the committee back from the brink of what may have turned into a heated disagreement, both at the level of interaction in this moment and the level of their collective advice as scientists. What is in "Pandora's box" is both the current accusation by local biologists and the prospect of reworking the 1986 lizard HCP, which reflects both scientific opinion (at the time) and a long-standing (14 years) set of agreements between local land owners, developers, and regulatory agencies. The valley has literally come to resemble the plan, since regulators have performed its entailments over years of negotiations with property owners. Randy proposes they avoid opening both fights (current and future), since the effort will not have "LOTS of consequence" for the multi-species plan under development.

Consensus by coincident boundaries…political and scientific justification as different orders of work. Randy's proposal, at least for the moment, sidesteps Bert's accusation. As the meeting continues, regulatory biologists and land managers discuss areas in the original (1986) plan that need to be removed because of subsequent development, but leave in other areas like quarries that might collect blowing sand. Once minor edits to the 1986 plan have been identified (the local biologists are largely silent during three minutes of further discussion), Edward, the lead plan consultant again seeks consensus from the SAC.

EDWARD(PC): Okay, so landfill and quarry stay IN. ((*typing*))
((*hands spread out to encompass entire table*)) Is our…Linda how do you react to Randy's suggestion?

LINDA(RB): I like it. It's…

EDWARD(PC): ((*looking at local scientists*)) How about you guys?
(3 sec)((*Nick pushes back from table; all 3 local biologists look back, silent*))

HANK(LM): Well, I think it's workable and defensible.

RANDY(RB): I think we just need some logic. And the logic would be continuity with the past. And there's high acceptance for the existing HCP. It's probably not going to have a big result or ch, make a big difference in the end result.

CHARLES(RB): No.
(3 sec)((*local biologists remain silent*))

Edward tries to get a spokesperson from each side of the conflict, allocating his second question to the local biologists. After a brief silence, Hank (land manager) answers the question, and then Randy calls for "some logic" that could be used to

justify their decision to adopt a model that coincides with the 1986 lizard HCP. Local biologists are again quiet, and Hank (below) begins a new topic. As he has done repeatedly during this meeting, Hank asks for advice about a particular land management decision he faces in the valley. Overlapping with the beginning of Hank's speaking turn (below), Bert (local biologist) begins to criticize Randy's historical logic.

HANK(LM): Would it [be permissible at this point to bring up a specific example, another specific example?]

BERT(LB): ((*looking at Edward*)) [Those, those are political (inaudible) That's not the role of…

EDWARD(PC): ((*looking at Bert*)) Well,] but it is a science question. I mean, [do you think that the HCP model is still valid?]

HANK(LM): [And I have all the brains in the industry] ((*looking at Randy, who laughs*))

EDWARD(PC): ((*looking at Bert*)) Given two things. Given, one that as we just said we'll take out stuff that's actually been developed. And two, recognizing that we each DO have the sand source transport, or ecological process OVERLAY, which becomes a part of this.

Edward ignores Hank, instead asking Bert about the scientific merit of going forward with a slightly edited version of the 1986 plan, including new information about sand sources. Hank and Randy stop talking as Bert responds (below).

BERT(LB): And I think the answer to it is yes. Now the justification that, you know, it's historic continuity of the planning process, et cetera. That's not a science question, or an answer. That's political JUSTIFICATION.

DAVE(LB): But you can =

EDWARD(PC): = But you're saying it's scientifically justifiable, too.

BERT(LB): [In my opinion, yes.

DAVE(LB): [Well, all you have to do is…you look at a map like this ((*holds up small map*)), and you look at a map like that red orange and yellow map over there, and you can see that it's pretty defensible scientifically from that standpoint.

EDWARD(PC): Ok.

DAVE(LB): From…if you're looking at historically occupied, occupiable habitat. We're talking within the last hundred years, type stuff.

Bert contrasts two types of justification, scientific and political, complaining that the SAC has adopted the latter. Edward persists, asking if the edited 1986 plan can also be justified scientifically. Bert thinks so, and Dave agrees, pointing to the correspondence between 1986 preserve boundaries and his (currently stalled) reflectance model as "pretty defensible" scientific backing. This correspondence, crafted by local biologists earlier in the meeting, is exactly what regulatory biologists are setting aside in proposing to reuse (with slight edits) the 1986 HCP model.

CONTAINING DISAGREEMENT AS PLAN HISTORY RESUMES

By reusing the 1986 HCP model, edited to reflect undisputed changes in property value (e.g., landfills) over the prior fourteen years, SAC members adopted a tenuous agreement to defer talking about potentially volatile differences between local and

TABLE 3.2.
A Narrative Timeline for the MSHCP Planning Process, Continuing from the SAC Meeting Analyzed in this Chapter

Winter, 2001	(Event 7) Regulatory biologists arrange an external review by a group of scientists, many of whom are unfamiliar with the planning process, and they impose strict rules on interaction between reviewers and SAC members. External reviewers criticize the lizard model (e.g., edits to the 1986 HCP) and caution that the SAC has been too conservative in identifying preserve areas. Regulatory and local biologists reject many of their recommendations.
Summer, 2001	(Event 8) The USGS hydrology survey, contracted 11 months earlier by regulatory biologists, is received. Regulatory and local biologists cannot agree on whether findings in the USGS survey are relevant for preserve areas in the MSHCP.
Fall, 2001	(Event 9) After complaints by municipalities to regulatory agency directors, the SAC is disbanded and the planning process is taken over by these agencies. Regulatory and local biologists continue to give advice, but the SAC plays no further role in the planning process.
2004	(Event 10) A MSHCP for the valley area is released for public review. In planning documents, the SAC is described as giving advice "throughout the planning process," organizing "workshops" for external scientists, and visiting mapped areas in the field. There is no mention of protracted disagreements or disbanding of the SAC.

regulatory biologists. By allowing the committee to move forward without opening a "Pandora's box" of disputed classifications and scientific uncertainty, the prior plan might provide a "coincident boundary" (Star & Griesemer, 1989) that could contain both the committee's trouble and resolve the "balance of terror" that motivated the 1986 plan approval process. If so, local and regulatory biologists on the committee could continue to coordinate their work in the larger plan without needing to reach full agreement over a model of lizard habitat. But would the container hold into the future and outside the committee?

Table 3.2 resumes the conservation planning timeline that we interrupted to look closely at scenes from a SAC meeting four years into the planning process. As planning continued, regulatory biologists carefully arranged the membership and format of a third external scientific review (Event 7), in which local biologists were not allowed to talk directly with external scientists, and both groups of biologists submitted sets of carefully crafted technical questions for external reviewers. The reviewers' report found use of the 1986 lizard plan scientifically indefensible, on the one hand, but also criticized the SAC for being too conservative when identifying Valley land to preserve in the multiple species plan. In follow-up SAC meetings, neither group of biologists accepted the external reviewer's recommendations, arguing these academics were insensitive to local political and financial realities. After almost a year of waiting, the USGS hydrology study commissioned by the regulatory biologists was delivered, but the SAC factions couldn't agree on how (or whether) to use these findings (Event 8). Reflecting a growing sense that the SAC would not be able to reach agreement, agency managers disbanded the SAC, five years after it was organized by local biologists (Event 9).

Neither the coincident boundary of the 1986 lizard HCP nor the committee that adopted it to avoid further trouble survived the planning process in this case.

MSHCP planning continued inside sponsoring agencies, and as we write this chapter, a completed plan is finally under public review in the Valley (Event 10), 14 years after the planning process began, which is a longer preparation period than any of the other approximately 50 large-area HCPs approved over the last twenty years (Goldstein 2004).

PERFORMING DIFFERENCES IN SCIENTIFIC PRACTICE THROUGH MODELING

We began this chapter by describing a case in which modeling, as it is usually understood by design-oriented reformers in mathematics education, became "too real" even for professional modelers. After years of entrenched scientific conflict, with mutual accusations of self interest and bad science traded between local and regulatory biologists, local governments paying for plan development disbanded the SAC. A MSHCP was subsequently developed without formal participation by either group of scientists. How could conservation biologists, whether local scientists or professional regulators, fail to reach agreement when the stakes were so high? How could they abandon the lizards and other endangered or listed species, even as pressures to develop land for human use continued to accumulate? From the perspective of mathematics or science education research, are these people terminally "off task" or resistant to progress?

It is tempting to choose indifference on the part of regulatory biologists (the local biologists' preferred accusation) or overly narrow scientism on the part of local biologists (the regulatory biologists' preference) as explanations, but these simply force us, as analysts, to take sides in a controversy that was not resolved in favor of either professional group (see Latour, 1987, on how to conduct a "tribunal of reason" for settling accusations of irrationality). For example, as evidence against a conjecture that regulatory biologists were insufficiently interested in local species and their habitats, the following excerpt from Goldstein's field notes describes a field trip with the regulators:

The degree to which the regulatory biologists shared the local biologists' passion for the […] Valley was impressed upon me in May of 2001 when I accompanied two of the regulatory biologists on a morning visit to the "fault dunes", a series of sand dunes that lay along [an earthquake] fault in the northern end of the valley. We walked over trash-strewn rocky and sandy terrain, looking for a small rare shrub called the Mecca Aster. We were buffeted by thirty mile-per-hour winds, and temperatures soon rose to over one hundred and ten degrees. The dunes were so hot that the sole of one of my Teva sandals melted and separated from the upper part of the shoe. While I was hobbling across the sands, the regulatory biologists were racing around me, identifying the tracks of lizards and flipping over plywood boards and old tires to find the burrows of pocket mice and ground squirrels. After three hours of this we headed back to [the city] to catch a quick lunch before the SAC meeting that afternoon, where the regulatory biologists engaged in heated debate over the disputed additions to the habitat preserve with the local biologists, who may have been the only other people who shared their enthusiasm for the desert ecology of the Coachella Valley (Goldstein, 2004, p. 320).

Even as Goldstein's plastic shoes were cooling, regulators who had enthusiastically followed lizard tracks in the desert were back at it, tooth and claw, arguing with local scientists who felt that only they were adequately concerned about these species.

From the perspective of mathematics education research, it might also be tempting to decide that the planning effort failed because information needed for the model (e.g., digital map layers with adequate precision across multiple measures) could never be obtained. But conservation planners like those on the SAC are regularly faced with cobbling together information of varied quality from heterogeneous sources, while the plans of developers proceed apace, making claims on the landscape even as the regulatory models are being constructed. The problems of modeling in this case were complex, but not unusually so. Species-habitat relations would never be known with fine precision, and ongoing human projects were, themselves, part of what SAC members were trying to locate in the model. For our analysis, contaminating social interests and inadequate information are poor candidates for explanation.

But what could account for years of intense work in which it appeared modeling would go on without end? It was not, we will argue, bad will or poor communication on the part of either group of professional biologists. Instead, each group participated in the SAC by performing aspects of distinctly different professional practice, and these differences (along with their consequences in the plan under development) led to an inability to construct a model that would be compatible with either group's image of work and professional identity in the future. In a sense, neither group would let modeling end without being able to imagine a viable future for themselves, and through their efforts, the valley itself.

PERFORMING DIFFERENCE BY ENACTING PROFESSIONAL VISION

Chuck Goodwin (1994) argues that professional groups like archeologists bring objects of their work into existence by orienting to the world in ways that reflect years of participation in distinct professional practices. They notice particular objects and relations (and not others), "high light" these in ways that enable coordinated work with others in their field, and encode what they see and talk about in conventional representational forms that (over the history of their practice) structure the intentionality of individual participants. In this sense, practitioners of a discipline actively experience their world of work through historically distinct forms of "professional vision" (Goodwin's term), even as their activity brings that professional world into existence as an ongoing technical practice.

In this case of conservation planning, as we have demonstrated in Scenes 1 and 2, differences in professional vision led to trouble both in ongoing interaction and in the possibility (or not) of creating a scientifically defensible model. In the following paragraphs, we focus on differences in professional vision between land managers, local biologists, and regulatory biologists as the SAC meeting was in progress. We examine an exchange involving participants from each group to explore how different points of view are produced in ongoing talk as SAC members work with map layers. These differences matter, we argue, when setting model assumptions, evaluating proposals for what should be in/out of the model, and for reaching agreement on these matters.

Showing "give and take" in order to "pitch and sell" during plan approval (Land Managers and City Official). In the following excerpt, two land managers (Hank and Kurt) complete a joke about the SAC's planning process as an example of "fuzzy habitat work," referring to the 2000 US Presidential debates, in which Texas Governor George Bush repeatedly accused Al Gore of using "fuzzy math" to

explain how he would pay for new government programs. As laughter dies down, Ernie, a local city official, observes that removing habitat areas from the old HCP will show city managers and local land owners ("thousands of people")" that conservation biologists are willing to "give and take." In turn, this will allow him to "pitch and sell" the new conservation plan as they seek public approval.

HANK(LM): This is…this looks like fuzzy habitat work. ((*general laughter*)) One percent of the lizards are getting…

KURT(LM): Are getting ninety nine percent of the feed.

ERNIE(CO): It's not a scientific issue, but a, anyway if you see areas that should not be modeled habitat and they're in the old HCP boundary, that shows give and take. And I think, you know, Hank's been talking about talking to managers, you know and trying to be able to pitch and sell? And eventually we got to pitch and sell this to…thousands of people. You know as long as moving those boundaries don't get people sideways with the existing HCP? It SHOWS:: a positive effect of this analysis, to have some give and take.

All three SAC members orient strongly to the near term process of plan approval, in which a proposed conservation model will be presented for public hearings and, shortly after, submitted for approval by local governments and state agencies. The joke completed by Hank and Kurt positions land managers as stewards who "feed" habitat to species, but they must do so fairly under public scrutiny. Ernie's contribution is given in a more serious tone, and he identifies specific areas in the plan that will show to the public and city officials that conservation biologists are willing to "give and take" land when it comes to human use. In turn, this will allow him to "pitch and sell" the plan to the public and others involved in the plan approval process. Taken together, the point of view expressed in this excerpt enacts a near term time horizon, concerned with particular areas (and human projects) in space, with contemporary non-specialists as the most significant actors.

Shifting the map and its information into a broader regulatory context (Regulatory Biologists). In the following exchange, Edward (plan consultant) has asked whether there is enough information to preserve habitat in the proposed map, and the response from two regulatory biologists (Linda and Charles) shifts the map into a different regulatory context.

LINDA(RB): But to answer your question Edward. Is there enough information to do the conservation areas? I think…the information is there. But to do the TAKE…that's a diff, ((*leans over, looking at Charles*)) is that, would that be a… Do you agree with that Charles? [Is there enough information?

MARY(PC): [Could you elaborate on that Charles?

CHARLES(RB): I'm not sure what Edward said, but what I said earlier was if we were gonna analyze ta::ke and we had a project, like a dam up here, this is not occupiable habitat but it would still be part of the take issue.

When they look at the map, Linda and Charles see tradeoffs between conserving and taking areas that are valuable to land developers. Their temporal horizon extends out well beyond that of the land managers and county officials (above), to the complexity of managing relations between different organizations as the plan is actually put into practical use (a period of 50 or more years, extending into the

future). Mapped plan areas are not simply allocated to needy species (the stewardship approach, above), but enter into a complex managerial relation that balances conservation against the need to "take" habitat and species for human use and development. Charles illustrates this point of view by describing a hypothetical development project ("a dam up here")" that does not involve lizard habitat, but which still should be considered as part of the plan, since developers will be required to apply for a take permit when building the dam. Unlike land managers, time extends well into the future (and their professional career), the relevant terrain is not only soils and species, but also a complex social landscape of competing organizations and commercial interests, and they are central actors who manage this complex natural and social terrain.

Planning with apocalyptic dimensions (Local biologist). In the following excerpt, Hank, a land manager who regularly asks SAC biologists for advice on current land use proposals, begins to explore "the theory" that plan areas might turn into lizard habitat if left alone by humans. When Hank looks at the map, his sense of time is tied to a stack of developers' requests waiting on his desk (i.e., his insistent requests for advice). But Dave's response stretches out over a radically different horizon of activity.

HANK(LM): So, the theory there is what we were talking about in the beginning of the meeting, that if you don't have some structure there, eventually Mother Nature is going to deposit suitable substrate and the lizards could =

DAVE(LB): = Well, our discussion, and Bert brought this to the head was, we're not looking at the next ten years or the next hundred years. From the standpoint of the green line we're looking at geologic processes. So people die out, buildings go away, lizards maintain what happens over the long haul? And so…If we're talking thousands of years, yeah.

When Dave looks at the map, he imagines an apocalyptic future in which "people die out, buildings go away, lizards maintain." Time, which was anchored to plan approval and particular projects for land managers, then at a scale that included careers and organizational life for regulatory biologists, now extends forward and backward into scenes where humans have either not yet arrived or have (for reasons not disclosed) disappeared. In terms of space, what currently shows as human habitat in the map could return to lizard habitat, as sand lenses bring sheets of sand over human structures, these structures crumble, and animals species once threatened by human activity take center stage in an unfolding, apocalyptic narrative. Perhaps surprising, land managers and city officials do not ask who will conserve the golf courses. Most interesting, in the point of view enacted by this local biologist, humans (including authors and users of conservation plans) disappear as part of a broadly encompassing natural order.

The points of view produced in (and used to produce) these conversational exchanges show distinctively different orientations towards time, space, and agency as SAC members who inhabit different professional trajectories look at maps, imagine their reception and use, and judge whether current efforts are adequate for varied purposes. We think it is unlikely that SAC members (or members of any professional group) explicitly orient to these dimensions of experience as they conduct interaction. But differences across professional perspectives may help to explain which proposals lead to agreement or disagreement, and why. For example, when Randy (regulatory biologist) allocates Dave's reflectance imagery model to another organization (USGS), he enacts a version of the ongoing planning process that is made out of and for the work practices of a regulatory biologist.

Both at the level of talk-in-interaction (e.g., topic projection) and collective action (e.g., commissioning a parallel study by the USGS), Randy shapes the prospects for a model under development by re-arranging what will count as adequate science, who will give it, and when it will arrive. Dave, in contrast, positions himself (and scientific peers on the SAC) as a spokesperson who binds together satellites, soils, lizards, and off road vehicles without the help or involvement of other organizations. In doing so, he enacts a version of the planning process that is built out of his own scientific expertise and local experience, something that Randy and his professional peers evidently find insufficient. Each biologist contributes to the model in ways that are consistent with his professional vision and expectations about future work.

CREATING DIFFERENT ORGANIZATIONAL FUTURES THROUGH MODELING[2]

Since both regulatory and local biologists felt that no MSHCP at all was better than a dysfunctional MSHCP that undermined their capacity to perform effectively as scientists and conservationists, each refused to give way. Instead, they deadlocked the planning process, causing a controversy that threatened their professional reputations, and endangered the prospects for adoption of the MSHCP. What was at stake in the dispute was their capacity to act effectively as scientists in the valley both now and into the future, and ultimately their ability to realize their conservation vision by setting into motion a natural ecology and a social dynamic that was amenable to the particular way they did science.

For the local biologists, the institutional and ecological setting for the MSHCP would be a kind of "peaceable kingdom". The leadership of the desert cities and surrounding county would predictably abide by the terms of the plan, so the regulatory agencies would never have to intervene to enforce it. Development interests would cooperate with the planning effort, since violating it would only expose them to political and economic turmoil, and the loss of take permits would stop their work altogether. Nature would also obediently play its part in the planning effort, as species lived and died in predictable ways within the habitat preserve. In contrast, for the regulatory biologists the natural and social dynamics of the MSHCP could be characterized as "red in tooth and claw." The cities and counties would have to be closely watched and held to the conditions of the take permits, which they surely would seek to covertly violate. Both environmentalists and developers would defect from the agreement when it suited them to do so. The natural world would also resist compliance with the terms of MSHCP, as new scientific paradigms undermined the theoretical basis of the plan and predictions based on scanty field data turned out to be false. Fortunately, new opportunities to conserve habitat would also arise, as new development proposals in the valley provided the regulatory agencies with opportunities to modify and adapt the MSHCP.

Both groups tried to bring their different conceptions of the social and natural world into being. The actions of both sides can be understood in terms of sociologist Brian Wynne's observation that, "Validity depends upon whether the world—natural and social—can be restructured and manipulated to accord with and thus

[2]Material in this section is drawn from Chapter 10 of Goldstein's dissertation (2004, pp. 317–352, available from the author).

'validate' the tacit models embedded in the technology or knowledge claim" (Wynne 1992, p. 276). For their part, the regulatory biologists chaffed under the organizational regime established by the local biologists, which relied on consensual and trusting social relationships established since the negotiation of the 1986 lizard HCP a decade before. In turn, when the regulatory biologists altered this organizational dynamic to something more harmonious with their understanding of the uncertainty of the natural and social world, the local biologists were bitterly resistant to the change.

DISCUSSION

We have now come a good distance from the optimistic gloss on modeling that we used to open this chapter. Participants indeed could not agree on what were the relevant problems to solve, representational tools were developed and discarded without a clear evaluation of progress, and cycles of model revision did not converge or terminate with findings or explanations that satisfied major stakeholders in the modeling activity. Modeling, in the case of this SAC, did not actually go on "without end," but it exceeded the patience of Valley stakeholders and even Goldstein's fieldwork stamina. Modeling ended because the advisory committee, itself, was broken apart as an organizational container in order to let the planning process reach a conclusion. The MSHCP was eventually delivered for public review, but its local history of production was messy.

Who needs modeling like this, a reader might ask, if we seek empirical images of what should be taught to provide a foundation for the future? Inside the mess, we argue, we can learn a substantial amount that is relevant for teaching and learning when modeling crosses organizational boundaries, something that is now ubiquitous in high stakes technical and scientific work. Our analysis supports several observations:

1. Models of broad consequence are not self-contained mathematical puzzles with single authors and docile readers. What is in/out of a model is an organizational question as much as a question for individual cognition. Model negotiation across organizational boundaries is, we argue, an increasingly common form of scientific/technical work.

2. Model construction and use usually happens against a history of prior modeling efforts. New models, when adopted, displace old models and their negotiated assumptions. Displacements are a disruption to existing representational infrastructure and the work it supports (Hall et al., 2002). As a result, conflict and different perspectives should be expected, and these are important phenomena for further research in mathematics and science education. The relation of Dave's (local biologist) reflected light model to the 1986 lizard HCP is a particularly clear example of this.

3. Members of different professional groups see models and what they represent in different ways. In this case, the underlying ontology of time, space, agency and their relations can be quite different, even among a group of people who self-identify as conservation biologists. Conflicts around model displacement appear to be strongly influenced by these ontological differences (see also Eisenhart, 1996). Distinctly different professional points of view held and enacted by land managers, regulatory biologists, and local biologists appeared to be critical in this case.

4. Anticipating downstream reception and use of models is an important aspect of their design. When modeling and displacement involve negotiation across organizational boundaries, differences in disciplined perception are compounded by different organizational objectives and accountabilities.

5. By studying differences and how they are resolved, we can identify modeling strategies that operate at collective (not only individual cognitive) levels of analysis. Regulatory biologists' successful efforts to re-arrange the SAC's authority and planning timeline provide a particularly clear illustration of this, even if in the negative.

In a larger collection of case studies of math at work among professionals (Hall, 1999), participants (civil engineers, architects, field and conservation biologists) report that learning to work across organizational boundaries is highly valued but rarely taught in school. This has consequences for what students should experience as they move towards professional careers that involve modeling. If negotiation over what is in/out of models is the typical context of using mathematics to model complex systems (i.e., mathematics plays a supporting role in a larger, leading activity), then cognitive studies of modeling as self-contained mathematical problem solving may have little relevance for what work demands of schooling. On the other hand, studies of individual mathematical problem solving in simulated modeling tasks may continue to have great relevance for how mathematical reasoning or application is assessed in schools. This is a larger problem of alignment between schooling and professional practices that this book is organized to address.

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