Environmental Review

A Monthly Newsletter of Environmental Science and Policy

Volume Six Number Twelve

December 1999

Does Fire Suppression Make Fires Worse ?

Introduction:

California shrubland fires are increasingly destructive and it is widely thought that fire suppression has made the problem worse; that is, by putting wildfires out we allow fuel to build up, making the next fire even larger. However when Jon Keeley, C.J. Fotheringham and Marco Morais analyzed California's fire history back to 1910 they found that fires have not increased over that time[1]. They also found that the total area burned in southern California has stayed about the same as it was ninety years ago. This in spite of major efforts at fire suppression. Dr. Keeley calls this the Red Queen effect: we keep running faster to stay in the same place with respect to wildfires. We spoke with him about his work over the years studying the fire ecology of southern California.

ER: Professor Keeley what is your training?

JK: My undergraduate and masters degree were from San Diego State University, and Ph.D. was from the University of Georgia. I spent the first twenty years of my career as a college professor of biology, and then I spent a year with the National Science Foundation as program director, and I just started this job about a year ago with the US Geological Survey as a research ecologist in Sequoia/Kings Canyon National Park.

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ER: Why is your paper considered controversial?

JK: Much of the controversy around my paper is probably due to the fact that people haven't generally appreciated that the role of fire can be very different in different ecosystems. In forested ecosystems in the Western U.S. there is good evidence that major fires occur on the order of one fire every one to two decades in most of the mid-elevation forests, for example in the Sierra Nevada.

But the records also indicate that since the turn of the century these forests have had almost no fire. There has been nearly complete fire exclusion due to fire suppression.We also know that there's been an accumulation of fuels.

And so far, that's what we know: we know that fire suppression has been successful in these forests; and fuels have accumulated. Scientists have projected that one consequence will be larger, more catastrophic fires in these forests in the future but this is an area that we don't know quite as much about.

For example in Sequoia National Park, we've had few large catastrophic fires, and the one large fire that occurred in the park was early in the century, so we have no evidence that fuel accumulation has gotten to the stage where we see larger fires. But it's reasonable to expect in the future that will be the case as long as fire is excluded from the forest.

Starting in the early 1970s Sequoia National Park started a program of reintroducing fire into these forests. It's a successful program; they've done a lot in terms of getting fire back into these systems. This program has received a great deal of publicity and I think a lot of people have heard about fire and fire exclusion and fire suppression impacts and fuel hazards.

What my research has focused on is brushland ecosystems, known as chaparral, which occur at lower elevations and are more coastal and represent the bulk of southern and central coastal California ecosystems.

In the 1970s shrubland researchers transferred this forest model to chaparral; that is, they hypothesized that fire suppression caused the vegetation to get older and allowed fuels to accumulate. Further, it was argued that these older stands with unnaturally high levels of fuels would lead to larger and more intense fires than what one would get under natural conditions. At least that was the hypothesis that was put forth in a fairly influential paper in *Science* in 1983[2].

The evidence for this hypothesis was a comparison of fire sizes over a nine-year period taken from LandSat imagery in southern California and south of the border in Baja, California. This paper found that fires were smaller south of the border and it was argued that this was due to the fact that there was no fire suppression south of the border. In other words, without fire suppression fuels did not accumulate and this reduced the chances for large, catastrophic fires.

In brief what that 1983 paper primarily demonstrated was that there was some difference in fire size between north and south of the border. However what that paper failed to demonstrate was that the cause was due to differences in fire suppression policy.

So that was the model that resource managers have been working with in southern California for the last twenty years basically, that fire suppression is responsible for our large catastrophic wildfires.

So my colleagues C.J. Fotheringham and Marco Morais and I set out to test a number of assertions that were made in Minnich 1983. In a nutshell the primary assertion that we tested is that fire suppression has been effective in excluding fire for long periods and this has led to an increase in size of fires in recent decades.

If there's any message that I think people ought to get out of our paper, it's that we've demonstrated that fire suppression has not excluded fire from brushland ecosystems like it has in montane systems. In montane systems the effect is dramatic. It's the difference between night and day when you compare fire regimes prior to 1900 versus after. There's almost no fire in coniferous forests like the ones here in the Sierra.

But in brushland systems we found that there has been no reduction in the number of fires or increase in size. In fact, if there has been any change, it is towards more fires and more area is being burned by smaller fires.

ER: The change is one of perception more than anything else.

JK: I think that's right. The perception that fires are getting larger is tied to the fact that there are more people moving into the interface zone between brushland systems and urban environments, and as a result more people are at risk, more property is at risk. The interface perimeter is increasing and actually becoming more of a mosaic with fuels, and as a result there is not just an increased perception that fires are different today, it's the amount of damage they cause, the dollar amounts are going up every decade.

If you look in the literature closely, early on, like in the 1940s, 1950s, people started looking at the question of why we were losing so much property from chaparral fires, the conclusion by a number of investigators at the time was it was because people are putting developments at the interface of these wildland areas.

In the 1970s, though, scientists changed their view, I think in part because poor land planning was the crux of the problem, and this was not politically or economically popular.

There were researchers who developed some powerful models of

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Gifts and donations to help support the *Environmental Review* are tax deductable.

The Environmental Review (ISSN 1080-644X) is published the first business day of each month. Address correspondence to 6920 Roosevelt Way N.E. STE 307, Seattle, WA. 98115. Copyright by Environmental Review Educational Services. Douglas P. Taylor, Publisher. Domestic subscriptions (12 issues) $30.00 in U.S. currency. For Canada and Mexico add $10.00. All other foreign add $21.00. Libraries, teachers and students in the U.S. may subscribe for $15.00 per year. Email subscription is $15.00 per year. Change of address: allow 4 weeks, giving old and new address. email dtaylor@igc.apc.org - Web site URL = http://www.igc.apc.org/envreview

fire spread. One, which was very influential at the time, showed that as fire suppression goes up you should expect an increase in the size of fires. This seemed to many people to be an explanation for why it was costing more and more money to put out fires; that is, because we were putting fires out, that was causing fuels to accumulate more, stands were getting older and that drove this pattern of more larger fires.

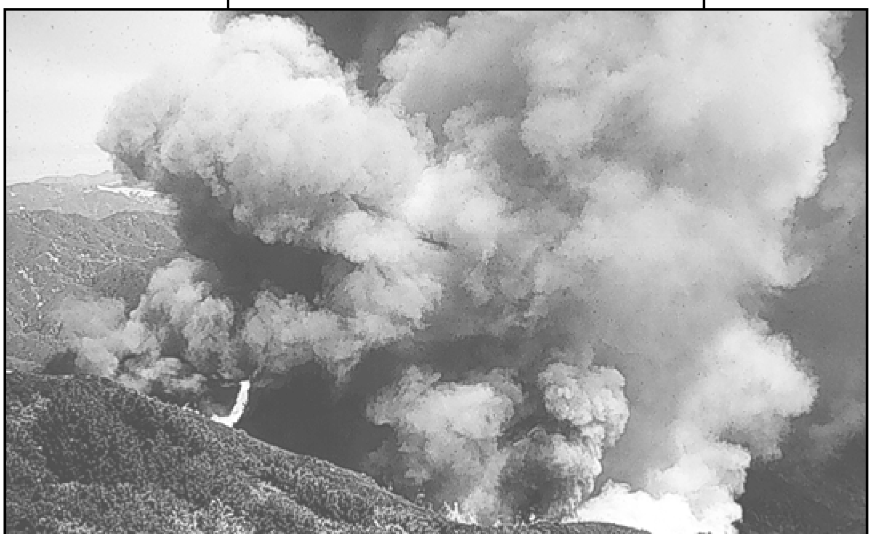
ER: Same old story: more fuel, bigger fires.

JK: Right. But what many people have not appreciated is that this model starts with the basic assumption that fire suppression is effective; then it says as fire suppression increases, we should expect larger fires. What we were in effect testing is the assumption that fire suppression has been effective, and what we found is that it has not been effective at all. We've got as much fire, more fire in fact, than we ever have had.

ER: How did you figure that out?

JK: State, county, and federal land management agencies in the state have been collecting records on fire occurrence and fire size since the turn of the century. It varies from county to county. Los Angeles County for example, has the best records; some other counties may not be quite as detailed. This data has been around in records ever since they started collecting data, but starting a few years ago the California Division of Forestry started to assemble all of these disparate data sources into one electronic data file. So the data was finally all in one place and we could test these ideas.

I'd been thinking about the effectiveness of fire suppression for a long time. Having worked in chaparral for the last twenty-five years I've been convinced that fire suppression has not eliminated or excluded fire from these systems.



A Chaparral fire, California, 1968.

Photo courtesy U.S. Forest Service

So when I heard about this data base I decided it was time to write this paper and test this idea, and the results were clear: out of the nine counties that we studied, none had a decrease in fires, and a couple of them, like Los Angeles and Riverside, had highly significant increases in numbers of fires. So the number of fires hasn't gone down, and the amount of area burned has not gone down. It's actually increased in those two counties, and in other counties it's more or less stayed the same. So the bottom line conclusion is that fire suppression has not excluded fire from the system.

What it does tell us is that fire suppression has been effective; in my mind fire suppression is very effective because the dramatic increase in numbers of fires over the century parallels the growth in population. That's not too surprising because in these coastal and southern California ecosystems people are the primary source of fire.

When people weren't around, fires were almost certainly started by lightning. There are a small number of lightning fires every year that are started in southern California, but not at all like in the forests up here in northern California, or even other parts of the western U.S. like Arizona where they have massive numbers of lightning fires every year. In Arizona for example, in those forests lightning accounts for perhaps 90 percent of all the fires; in southern California people start 95 percent of all the fires.

Over this century, as there's been an exponential increase in population there's been an exponential increase in numbers of fires, and when we look at the total area burned, by and large it hasn't changed. That tells me that fire suppression is doing a pretty good job of keeping up with increased ignitions. The reason that we have to spend more and more money every year on fire suppression is because we have more and more fires.

I like to describe it as the Red Queen phenomenon after Alice in Wonderland's Red Queen where she describes having to run just to stay in place, and that's essentially what fire suppression has to do. We have to keep dumping more and more money into fire suppression just to stay where we are.

Now, the other component of what we were looking at in the study has to do with fire management philosophy. Based on these studies comparing Baja California and southern California by Minnich (1983), it was noted that fires were smaller south of the border in Baja. It was hypothesized that fires were smaller in Baja because they would burn into another area that had burned earlier and it would burn out. However it needs to be recognized that in Baja there are about five times more fires than north of the border, and they're largely due to people. Why? Because they not only don't practice fire suppression; they don't practice fire prevention to the same degree we do. So they have many more fires on their landscape, and when a fire gets started it's likely to run into a younger age class and burn out.

It was argued that this mosaic of different age classes, particularly young age classes, is what kept fires small. This has been what some have termed the age mosaic or age class mosaic model of a landscape that does not have large fires. To put it another way, fire managers have contended that if they can go out and do enough small prescription burns and keep the landscape in a mosaic of different young age classes, we could prevent large fires.

ER: Is there any evidence for that?

JK: We tested that idea in the Santa Monica mountains, which have had some very catastrophic wildfires in the past: the Bel Air fire in the 1960s and the Green Meadow fire in the 1990s, as well as a number of others in between. We took advantage of a very nice database that the National Park Service has accumulated for the Santa Monica mountains where all the fires since 1925 have been mapped. Because of that map, one can ask the question, What age classes of vegetation have burned in these large catastrophic fires? We just took all fires over 12,000 acres as being large fires and went back as far as thirty years and examined what age classes burned. We found that the large fires were not burning old age classes; they were burning actually fairly young age classes because the mountain range burns so frequently. In fact the majority of what burns is between eleven to twenty years of age.

In Arizona forests lightning accounts for perhaps 90 percent of all the fires; in southern California people start 95 percent of the fires.

So just having a young age class out on the landscape does not mean you have a barrier to a large fire spread. These fires can spread through any age class, it would appear. The main reason is because the only time you get these catastrophic fires is when you have a fire ignition coinciding with Santa Ana winds in the fall. When you get these winds blowing at 50 miles an hour, it doesn't matter how old the vegetation is, fire will blow right through it.

It's not that young age classes necessarily prevent fire spread, it's just that they allow fires to die down enough so that fire crews can go in and extinguish them in the young age classes. When there's a Santa Ana wind blowing a fire, you won't find fire crews standing in front of it trying to put it out because it's too dangerous, they just stand on the side and let it go.

So the conclusion from that part of the work was that young age classes per se are not a barrier to fire spread, and therefore these management agencies might want to rethink this philosophy of trying to broad scale burn the entire landscape in small patches because it's probably not going to be a barrier to fire spread under large fire conditions.

The controversy that these conclusions have generated is that many of the agencies, particularly the California Division of Forestry, are interested in doing prescription burning, in large part because it's one of the few things they can do that might actually have some impact. A management agency is in a bad position when they don't have tools to use, and prescription burning is one of the few tools they have. So I don't think they particularly want people saying that prescription burning is not solving the wildfire problem.

What I would say about all this is that our study does not say that prescription burning doesn't have a role. What it says is that under the severest conditions it's probably not going to be an effective barrier to fire spread. However, many of our fires do ignite under moderate weather conditions, and under moderate weather conditions prescriptive burning seems to actually be effective. So the conclusion that I would draw is that prescription burning has a role: it can assist in preventing fire spread under moderate conditions. But when the worst conditions come, it's probably not going to be an effective strategy.

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ER: Where do the Santa Ana winds come from?

JK: The Santa Ana winds begin in the Great Basin when cold air sinks rapidly and creates a high pressure cell. If it coincides with a low pressure cell off the coast of California, you'll get high winds blowing from the Great Basin to the coast. The Santa Ana winds tend to be fairly warm, they're dry, they blow from the interior to the coast. Southern California usually has on-shore breezes, and the Santa Ana results in off-shore winds.

ER: Is it seasonal?

JK: Yes, typically Santa Anas will occur between September and November.

ER: How has the landscape changed since people have come to dominate southern California?

JK: Our landscape is closer to being natural than a lot of people suppose. Many people have argued that large wildfires driven by Santa Ana winds are an artifact of modern fire suppression, and I think we've shown clearly they're not. In fact I believe that they're quite a natural phenomenon, and they actually don't appear to have changed over time.

There was a recent paper published in *Quaternary Research*, that looked at charcoal deposition in sediment cores off the coast of Santa Barbara. They documented the frequency of large Santa Ana-driven fires over the last 500 years, and concluded was that there has been no change in the frequency of Santa Ana fires in southern California over the last 500 years. So it does not appear that there's been any change in the probability of large fires here.

The primary thing that has changed is the source of ignitions, and that is the number of people in southern California. I think the major ecological change in southern California and coastal California is that some areas have burned so many times that they've eliminated the natural shrub vegetation and it's been replaced with exotic grasses from Europe.

Most of the grasslands in California are dominated by non-native invasive plants from Europe. In some areas, like the Central Valley, they replaced the native grasslands that were there originally.

In southern California and in central coastal California, exotic grasses have replaced a lot of coastal sage scrub and chaparral. Repeated burning started with the Spanish period; they burned the shrublands repeatedly and eventually eliminated it to make foraging areas. That's the primary change in the landscape: the loss of native vegetation because of too frequent fires.

ER: What would be a natural fire regime?

JK: In my mind a natural fire regime for coastal California, for example, would be one where lightning would ignite fires, but fairly infrequently. For example, in the Santa Monica mountains in the official records they have no lightning-ignited fires recorded since 1925. Lightning isn't very common there, but there are some reports of lightning-ignited fires in those mountains.

My guess is that fires were probably not very common there, probably a few times a century and ignited by lightning. Usually lightning is concentrated in the month of August, and those fires might burn at fairly low intensity for a few weeks or a month or more; when the Santa Ana condition picks up, then they would be carried and burn like a Santa Ana fire does today.

ER: What does an old chaparral stand look like? If it's burned, how long does it take to grow back up and become fuel again?

JK: The question of senescence in chaparral is something that's captured the imagination of many people for a number of years, but I think the evidence is pretty good at this point that it's not a very accurate description of what happens in chaparral. I've not seen any stand of chaparral I'd describe as senescent.

There are some species that are relatively short-lived and they die out, but almost invariably the stand is taken over by other shrubs which are quite long-lived. There's a great many shrubs in chaparral that can easily live one hundred years or more and don't exhibit any evidence of senescence.

The topic, though, has been raised in conjunction with the issue of fire because people have argued that if you exclude fire from a fire-adapted system like chaparral, there's a senescence risk; that is, the vegetation gets so old that it can't regenerate after a fire.

But there is absolutely no evidence that senescence risk is a real concern. I've seen no evidence in the published research or my own observations that any stand of chaparral suffers a risk from getting too old. Most of these systems are capable of regenerating after a hundred years without fire. In fact, a good deal of what comes up after a fire are species that are present as a dormant seed bank, and these dormant seed banks can readily live a hundred years in the soil.

In fact the alternative risk is what we might call immaturity risk; in other words, burning too frequently, because many of the shrubs have to regenerate from seed, and if they don't have a decade or two without fire they can't build up the seed bank and they can go extinct locally. Immaturity risk is a real phenomenon, and there are at least three documented cases of species going extinct at a site because fires were too frequent.

ER: Is that what's going on when frequent burning causes a shrub system to change over to grassland?

JK: Yes, that's exactly what happens. A good majority of the shrubs in chaparral can't vegetatively regenerate, like sprouting from the base. The grasses are all annuals and so they are present as dormant seeds at the time of fire; if you burn up the grass stalks, you're not burning up anything alive anyway.

Fire suppression has not excluded fire from brushland ecosystems like it has in montane systems.

The annual grasses are well adapted to frequent fires and they'll withstand them much better than the shrubs. So if you get fires more frequently than once a decade, you're likely going to start converting it to grassland.

ER: When will chaparral burn?

JK: When a stand of chaparral will burn is in large part a function of the weather at the time of the fire. If it's windy conditions, Santa Ana or other high winds, say thirty or forty miles per hour, young and old stands will burn. In fact, in the Santa Monica mountains the records show that even stands one or two years since the last fire will burn under high winds.

If the winds though, are lighter, then age has a real effect. This is well documented in the literature on prescription burning. There have been many studies on the right sorts of formulas in terms of relative humidity and wind speed to do prescribed burning in chaparral, and they've found that stands that are less than say, fifteen years of age are hard to get to burn under wind conditions that would be acceptable — nobody wants to do a prescribed burn unless the winds are twenty miles per hour or less — and under those conditions, stands less than fifteen years of age are hard to burn.

So it's an interesting problem here because if you have stands that are fifteen years of age, Santa Ana-driven winds will blow the fire right through those. If you're going to do a prescribed fire, however, if you burn more than once every fifteen years you're going to displace the natives and introduce invasive grasses.

ER: How can we better address the problem of increasing economic losses in the face of this fire cycle?

JK: At this point I don't know what we're to do because we have already created a difficult problem. In California we have a large perimeter between the wildland and the urban environment, and in many cases it's not just a perimeter but a mosaic with patches of development scattered throughout massive fuels. And solving the problem is not even the right approach, it's probably more a matter of learning how to live with the problem. The one thing that I have suggested (and this is not my original idea, but it's a focus that some researchers from the US Forest Service, Riverside Fire Lab have proposed), and that is that since there is no evidence that doing massive prescription burning across the landscape is going to solve the catastrophic fire problem, funds ought to be focused on the interface between the urban areas and the wildland areas and maybe trying to look at corridors where fires tend to spread into urban areas and concentrate the effort there. As a philosophy, I think that makes the most sense.

What that effort should be has not been clearly articulated. On the one hand you can reduce the probability of fires spreading into urban environments if you were to displace the native shrublands and replace it with invasive grasses. That's one possible solution.

I'm not advocating that for a couple reasons. One is this will tend to increase the frequency of fire because the interface zone is an area where fires go both ways. They burn from the wildland into the urban environment, but just as often they get ignited in the urban environment and burn into the wildland environment.

The fires that get ignited at the urban interface from people are much more likely to spread into the wildland area if the urban environment is surrounded by grasslands. That's one downside of grasslands: you put grasses in there and you're going to get more fire moving out away from the urban environment into the shrublands.

ER: Why?

JK: The difference in the fuel structure. Grasses have a very different fuel structure than shrubs. Shrubs are up off the ground and it's harder to get a fire started. But once it gets started in a shrubland system, particularly if there is wind, it has no problem spreading. You could actually take a match and throw it out in a stand of chaparral and much of it wouldn't light, whereas in a grassland that's not the case, it'll light rapidly. By converting chaparral to grasses you increase the spread of fire into the system, and you increase fire frequencies by doing that.

The other downside to type converting a buffer zone is that people move to the wildland interface because they want to be closer to natural environments, and if you type convert it and remove all the shrublands and the trees, you're basically producing an artificial environment, which is not what people wanted in the first place.

If there has been any change, it is towards more fires and more area being burned by smaller fires.

Then in addition to that, just about everything that comes into this grassland will be an invasive non-native plant. Very few native plants will establish. So that exacerbates another major concern today which is invasive plants. And the more habitat you create for them, the greater sources there are for invasion of other areas.

You reduce your options when you don't plan ahead, and that's a lot of what has happened in southern California: there has not been careful planning of placement of developments and houses relative to flammable ecosystems.

In large part I think it's driven by a philosophy that there are technological solutions to all our problems. And in this case I don't think there is a technological solution. I think what people have to do, and probably people have been doing this in their own minds anyway, is they just factor that into the cost of living there.

ER: John McPhee wrote an article in the *New Yorker* a couple years ago about land development in southern California, where people ignore the flood history of the place and hope to somehow not be affected by it.

JK: I heard an interesting talk a few years ago on flood control problems in the Los Angeles basin, where they were describing a study that had been done on the cost of flood damage over the last fifty years in the L.A. basin and compared that to the costs of land planning that would have prevented development in high risk areas. They found that better land planning would have had minimal economic costs for the region and would have saved huge amounts of money. I'm sure it's the same with fire: if we had just put up with some economic costs due to restrictions on developments, we would have saved money in the long run.

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Environmental Review

Volume Six Number Twelve
December 1999

Seven Wonders
Everyday Things for a Healthier Planet

Introduction:

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Northwest Environment Watch is an independent, not-for-profit research center based in Seattle. Its mission is to foster a sustainable economy and way of life in the Pacific Northwest. NEW can be reached at 1402 Third Avenue, Suite 1127, Seattle, Washington 98101. Their website is located at http://www.northwestwatch.org.

A human's food consumption is similar to that of a common dolphin, about 2,500 calories a day. But adding in all the other energy we use, mostly from fossil fuels, the average North American consumes about 180,000 calories a day, the daily appetite of a sperm whale.

The following article is adapted from John's most recent book, *Seven Wonders, Everyday Things for a Healthier Planet*[1].

Nowhere else do humans place nearly as many demands on the Earth as we do in North America. In energy terms, a human's food consumption is similar to that of a common dolphin about 2,500 to 3,000 calories per day. But adding in all the other energy we use (mostly from fossil fuels), the average North American consumes about 180,000 calories each day the daily appetite of a sperm whale.

A world of six billion North American-style consumers cannot come to pass. But pondering such a world can help us see our own in a different light. How can people get the nutrition, shelter, knowledge, recreation, and community they need without placing insupportable demands on the world?

The flip side of our economy's current destructiveness is that opportunities abound to lessen our impacts on the Earth, and improve human welfare as well. Our economy is so inefficient at using what it takes from the Earth that most of the appalling environmental damage we do can be avoided without hardship. In agriculture, industry, transportation, and all realms of daily life, workable alternatives superior to and usually less expensive than business as usual already exist.

Seven Wonders is about seven of them, the seven sustainable wonders of the world. Unlike the wonders of the ancient world, the seven sustainable wonders are notable not for grandeur or antiquity but for their ability to get jobs done at minimal cost to the Earth. They are wondrous because, unlike most artifacts of our modern economy, everyone on Earth could use them without overtaxing the planet's finite natural wealth.

The items portrayed in *Seven Wonders* can help us bring our gargantuan impacts down to a level the Earth can support. All seven of these simple, sustainable wonders are exceptionally powerful at improving human life at little or no cost to nature arguably the central challenge of the twenty-first century.

The Bicycle:

The bicycle is the world's most widely used transport vehicle. Worldwide, bicycles outnumber automobiles almost two to one, and their production outpaces cars three to one. Rush-hour traffic in China is dominated by human-powered vehicles; even in the wealthy cities of Europe and Japan, large shares of the populace get around by bike.

Despite its popularity elsewhere, the bicycle gets little use or respect, except as a plaything, in North America. About 50 million American adults (and 40 million children) ride bikes at least once each year, but only about 2 million are regular bike commuters. Of all trips in the United States, just two-thirds of 1 percent are made by bicycle.

Bicycles are sustainable wonders because of what they *don't* do to the world. A bicyclist's breathing (the closest a bike comes to exhaust) doesn't acidify the rain or kill people with carbon monoxide and particulates; neither does it alter the global climate. A bicyclist fuels up on carbohydrates, not fossil fuels and imported oil. Bicycles don't cause traffic jams or require paving over whole landscapes at the expense of croplands, government coffers, and livable neighborhoods. And bicycles are not the leading killer of Americans and Canadians 2 to 24 years old or, worldwide, of men 15 to 44 years old.

That distinction is reserved for the automobile.

Nearly half of all trips in the United States are three miles or less; more than a quarter are less than a mile. While advertising sells cars and trucks as tools for the open road, they most often help us inhabit a small daily realm Errandsville defined by home, store, job, and school. Many of these trips are easily bikable or walkable, even on roads designed without bicycles or pedestrians in mind. A bicyclist can easily cover a mile in four minutes, a pedestrian in 15.

Short car trips are, naturally, the easiest to replace with a bike (or even walking) trip. Mile for mile, they are also the most polluting. Engines running cold, at typical urban speeds, produce four times the carbon monoxide and twice the volatile organic compounds (VOCs) as engines running hot. And at the end of a trip, smog-forming (and carcinogenic) VOCs continue to evaporate from an engine until it cools off, whether the engine's been running for five minutes or five hours.

The Condom:

The condom is a remarkable little device: weighing in at a fraction of an ounce, it simultaneously fights three of the most serious problems facing humans at the end of the twentieth century: sexually transmitted diseases (STDs), unwanted pregnancies, and population growth. Pretty good for a flimsy tube of rubber.

Unwanted pregnancies fuel population growth and all of the associated ecological harm, but their toll is heaviest among women themselves. The United States has a much higher rate of unintended pregnancy than most other developed nations higher even than dozens of developing nations. More than half of all U.S. pregnancies, and 44 percent of births, are either mistimed (too soon) or unwanted. Inadequate contraception is not just a Third World issue, as some people think. Especially since a baby born in North America will use roughly 25 times more resources over the course of its life than a baby born in the developing world, population growth is a problem here at home as well as overseas.

The Ceiling Fan:

Until fairly recently, fans were the favored cooling device in the United States as well. In 1960, 12 percent of U.S. homes were air-conditioned; as recently as 1973, most American households used only fans and open windows for summertime cooling. Today nearly every new house in the nation comes with forced-air climate control. With its low energy prices and three-fourths of homes chilling their air, the United States may be the coldest nation in the world each summer indoors, at least.

Cooling has not come cheap. Air-conditioners use up one-sixth of electricity in the United States; they tie with refrigerators for demanding the most electricity in U.S. households. On hot summer afternoons, air-conditioners consume 43 percent of the nation's peak power load enough to occupy (and require the construction of) 200 giant power plants each costing over a billion dollars.

Electricity is so familiar that it is easy to forget that the invisible juice flowing out of small sockets in our walls causes acid rain, global warming, salmon extinction, nuclear waste, and various human health problems. Roughly half of North America's electricity comes from burning coal, the dirtiest fossil fuel. In 1994, electricity generation emitted 35 percent of the United States' climate-changing carbon dioxide and 70 percent of its acid rain-forming sulfur dioxide. According to the Rocky Mountain Institute, air-conditioning an average U.S. household sends about three tons of carbon dioxide up power plant smokestacks each year. Cold comfort indeed.

Better energy efficiency doesn't necessarily mean investing in new technologies. It often simply means adopting the ones already at hand. The gentle air circulation from a ceiling fan can make a room as comfortable as one where motionless air is 9 degrees Fahrenheit colder. Resorting to air-conditioning only when fans can't handle the job alone can shave a third of your cooling—and global warming—bill.

The Clothesline:

By letting the sun and wind do for free what dryers need electricity or gas for, clotheslines save consumers money. Diehards avoid the expense of a dryer, but even dryer owners save money by hanging clothes on the line whenever time and weather permit. In a typical home, the clothes dryer uses much less electric-

The 7 billion chicken, turkeys, cows, and pigs in the United States alone produce almost 4 million tons of manure per day, about 130 times more than the nation's humans produce.

ity than central air-conditioning or a refrigerator but more than any other appliance. Feeding the dryer electricity will cost about $85 annually, and $1,100 over its lifetime. Because clothes last longer when they're spared a tumble dryer's heat and wear and tear, clotheslines protect the $1,400 that the average American household invests in new clothing each year.

The decline and fall of the clothesline have come at an environmental price. With the mix of fuels burned to generate U.S. electricity, the average household dryer puts almost a ton of climate-damaging carbon dioxide into the atmosphere per year.

By drawing on the wind and sun, the clothesline avoids all the environmental impacts of electricity and natural gas. The clothesline is one of an array of technologies from the ancient to the avant-garde that fight global warming, acid rain, nuclear waste, and a host of other ills. These pervasive energy-related problems have twin solutions: using energy more efficiently and shifting as quickly as possible to renewable energy sources. If investors and energy users had to pay through taxes or other mechanisms for all the pollution, health problems, and climate change caused by fossil fuels, renewables would quickly take over the world energy market.

Pad Thai:

Pad thai is a sustainable wonder because, like most Asian food, it consists mainly of rice and vegetables, is nutritious and low in fat, and has less environmental impact than the typical American meal. Most Asians are meat eaters, but as a whole, they eat far less of it than Americans do. The average person in Thailand eats less than a fifth as much meat as the average American.

The huge demand for meat in North America and increasingly around the world has transformed livestock raising from a sideline niche into the main event. Today, most meat, milk, and eggs in industrial nations are produced by resource-intensive agribusinesses that funnel huge amounts of energy, water, and crops into factory-like facilities that emit both food and waste on an industrial scale.

Agriculture is the leading source of water pollution and the biggest water consumer in North America, as well as the main force behind soil erosion and the loss of wetlands and grasslands. And livestock are the leading agri-culprit: they eat most of the continent's grain harvest and graze on or eat feed from most of the land area in the United States outside Alaska. Livestock production consumes almost half the energy used in American agriculture. About seven pounds of grain are needed to produce a pound of boneless, trimmed pork; about three pounds for each pound of chicken; and, depending how much time cattle spend grazing before entering a feedlot, about five pounds for a pound of beef.

It's not surprising that the livestock economy has outgrown its habitat, considering that livestock outnumber humans on this planet more than three to one. The 7 billion chickens, turkeys, cows, and pigs in the United States alone produce almost 4 million tons of manure per day about 130 times more than the nation's humans produce. Manure and feed fertilizers together probably contribute a third of the nitrogen and phosphorous released into American waters, nutrients that cause harmful algal blooms and often make well water unsafe to drink. One giant hog farm under construction in Utah will generate more waste than all 2 million people in the state.

The Public Library:

Libraries are great places for saving salmon. Nobody ever built a library to save an endangered species, but that's one of the things libraries do best. By making books, periodicals, and other materials available for an entire community to share, a library makes thousands of personal copies unnecessary. By reducing the demand for paper, a library saves forests from logging and rivers from logging-road erosion; it saves the places where salmon swim and spawn from pulp mill effluent and the electricity demands of paper mills and printers. The average North American library lends out 100,000 books a year but buys fewer than 5,000, saving nearly 50 tons of paper and 250 tons of greenhouse gas emissions in the process.

Books, of course, are wonders in themselves: if more people could and would read, the world would undoubtedly be a better place. But the substance that the printed word arrives on paper carries a high ecological price tag. Growth in packaging, advertising, office paper, and various forms of publishing has doubled global paper consumption in the past 20 years, sending more chainsaws into the world's forests and a witches' brew of chemical pollutants into its rivers and bays. Despite increased paper recycling, pulp and paper mills digest about 40 percent of the global timber harvest. A relatively small number of consumers in wealthy nations use most of the world's paper: the United States alone, with less than 5 percent of world population, consumes 31 percent of the world's paper production.

There's no reason the library

concept can't be expanded to include a whole variety of useful items. The liberal outposts of Berkeley, California, and Takoma Park, Maryland, even have tool libraries where local residents can borrow hedge trimmers, ladders, table saws, and more. Business at thrift stores and other sellers of used goods is growing by 15 to 20 percent a year in the United States, much faster than other retail sectors. Once limited mostly to unsavory pawn shops and charity stores full of barely salable merchandise, secondhand stores have become popular among middle-class shoppers who love bargains, even if they don't realize that used goods cost the Earth next to nothing.

Reuse gets little attention as an environmental strategy, but it is one of the overlooked shortcuts that can help us quickly find our way toward an environmentally sound way of life. While industry and government spend millions on recycling campaigns, refillable bottles fight pollution and waste without fanfare and more effectively. Even as cutting-edge clothing manufacturers advertise their organic cotton and recycled fleece, unassuming thrift stores keep on selling the most ecologically friendly clothing of all.

The Ladybug:

Ladybugs are members of a beetle family with an estimated 4,000 species found all around the world. All but two of the 450 or so species in North America are considered beneficial because they feed on aphids and other destructive soft-bodied crop eaters. And they feed voraciously. In three to four weeks of life as a larva, a ladybug will eat 350 or more aphids. A typical adult ladybug will consume 40 to 75 aphids a day, or about 5,000 in its lifetime. While worldwide sales of pesticides total about $30 billion annually, the pest control services provided by the pests' natural enemies are worth an estimated four times that amount.

Yet most farmers have lost their faith in omnipresent, benevolent beings like predatory insects and turn instead to heavy doses of pesticides for their crops' salvation. Unfortunately, pesticides usually work either too well indiscriminately killing beneficial and harmful organisms alike   or not well enough, since short-lived species like insects often develop resistance to a given chemical in only a few generations. Farmers victories against targeted pests are frequently overshadowed by the secondary pests they create: formerly innocuous species whose populations explode in the absence of their usual predators. The farmers then end up on a pesticide treadmill, chasing one newly created pest after another.

Air conditioners use up one-sixth of the electricity in the U.S.; they tie with refrigerators for demanding the most electricity in U.S. households.

Predators are not the only life-forms harmed by pesticides. By killing the organisms that disperse pollen, decompose wastes, and build soil, pesticides can even harm the plants they are supposed to protect. Soil is a complex ecosystem whose organisms help produce about a ton of new soil annually per hectare (2.5 acres) of cropland. The fertility of the soil, as well as most plants' ability to draw nutrients from it, depends on the survival of the fungi, bacteria, and animals in it. Many soil organisms are highly sensitive to agricultural chemicals. In the U.S. Midwest, it takes about five years for healthy populations of earthworms to return to crop fields tilled and heavily sprayed with pesticides.

In the United States, more than 500 insects, 270 weeds, and 150 plant diseases are now resistant to one or more pesticides, and farmers have to apply pesticides two to five times to achieve what one application accomplished in the early 1970s.

Conclusion:

Tremendous obstacles must be overcome if humanity and the rest of life on Earth are to thrive in the twenty-first century. What we forget is how much our voices and our choices matter. Although the sustainable wonders themselves deserve praise, it's the steps *we* take   simplifying our lives and advocating for change   that make all the difference. Reaching for organic produce instead of the conventional stuff next to it at the grocery store, you can stop pesticides from being sprayed hundreds of miles away. By putting one foot in front of the other, walking or biking to a neighborhood shop instead of driving to the megastore on the far side of town, you can stop oil from being drilled in some place like Nigeria or the arctic slope of Alaska. You'll also stop heat-trapping pollution from damaging an entire planet's climate. All the tools we need to solve the world's pressing global problems already exist. We just need to use them.

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Environmental Review

Volume Six Number Twelve
December 1999

Marine Reserves: An Alternative to Traditional Management

Introduction:

Marine reserves have been proposed as a remedy for overfishing and declining marine biodiversity. But putting marine reserves in place has been resisted because of concerns that they would reduce fishery harvests. In a recent paper in Science magazine, Hastings and Botford show that managing fisheries by setting aside no take zone can produce the same harvest as traditional effort control management strategies[1]. In fact for populations in which adults don't move around, such as reef fishes and invertebrates like clams and mussels, reserves can provide the same yield as traditional management while providing the additional benefits of protecting biodiversity and by reducing the variability of populations.

This important theoretical paper shows that marine reserves are a reasonable alternative to effort control. The burden of proof has been shifted: those who argue against marine reserves will now have to demonstrate the effectiveness of their management strategies or allow marine reserves to be used as part of the management effort. We spoke with Alan Hastings about the results and implications of this paper.

AH: Professor Hastings, what is your training?

AH: I got my Ph.D. at Cornell in Applied Mathematics a little over twenty years ago, but working on ecology and population genetics. Now I'm in the department of Environmental Science and Policy at the University of California at Davis where I was Chair for six years, ending a year ago.

ER: How would you characterize using mathematics to studying ecology?

AH: I'd probably say it would be using mathematical tools to investigate questions in population biology, because I've worked on everything from population genetics to some community issues, spatial spread, a variety of different aspects. The marine reserve work was spurred by a working group at the National Center for Ecological Analysis and Synthesis that was organized by Jane Lubchenko, Steve Gains and Steve Palumbi.

The Center provides funding to bring researchers together, typically for several days to a week at a time, and then meet a number of times over a year or a two-year interval. The National Center is funded by the National Science Foundation primarily, but also gets money from the state of California and some other sources. It's a way to bring a wide variety of individuals together to focus on a particular ecological problem.

... any fisheries that we've managed, we've managed to extinction because there's always pressure to harvest more and more fish.

ER: Did the working group include fisheries managers or fishermen?

AH: No. The working group right now is focusing on the scientific issues and not necessarily dealing yet with the stakeholders. We're going to have forums to interact with stakeholders beginning this November, but they've not been involved so far.

Rather than focusing on the political issues to begin with, we are trying to clarify the scientific basis of management decisions.

ER: Is applied math and ecological problems a new approach?

AH: Well, there's been a long history of mathematics in environmental and population problems. In some sense, the first mathematical model could be thought of as Fibonacci's modeling of rabbit reproduction in the 13th Century. The reason that mathematics has such a long and important history in ecology is that ecology is a science where we count things, count populations, count individuals. So if we're going to understand ecological systems, we're going to have to use mathematics. That's become more and more prominent in the 20th century, and though not in this work in *Science*, but in other areas it's been helped by advances in computers.

Modeling is a tool or approach to try and use information to make predictions and to understand how complex systems will work. Often in collecting information, modeling is important in suggesting which information to collect.

ER: By talking about no-take zones for fisheries, isn't that an implied criticism of traditional fisheries management?

AH: Many fisheries are typically quite intensively managed, and unfortunately — I wish I could remember who said this — but someone said that any fisheries that we've managed, we've managed to extinction, because there's always pressure to harvest more and more fish. If you try to maximize the harvest, and if you're harvesting a little bit more than it can stand, the population will start to decline. And given the environmental uncertainties, uncertainties in understanding what population levels really are, it's almost certain that we will tend to overharvest.

So traditional management approaches have the danger of leaning to overharvest. There have been a number of well-known examples, ranging from the problems at George's Bank to the fact that even the California sea urchin fishery has been in big trouble. So yes, economics tends to lead to overfishing. That's the well-known tragedy of the commons.

ER: What are the two approaches to fisheries management you are comparing?

AH: The traditional management techniques, of which we've looked at one kind which is to say fishers are limited to catching a certain fraction of the fish that are available.

I should interject here that the species that we're thinking of here actually would not be fish. There's a curiosity that you can find the word fishery is used to harvesting marine invertebrates like crabs, mussels, oysters and so on. The species that will meet the characteristics that we're thinking of are primarily going to be invertebrates.

So under these conditions ... the maximum sustainable yield is the same with no take zones as it would be with management techniques based on harvesting a fraction of what's available.

ER: Things that don't move around as much?

AH: Things that don't move around as adults. Coral reef fish don't move too much as adults, there are some fish where the adults are relatively sedentary, but that's less common. So for these kinds of sedentary animals, one way to manage them would be to say that of those individuals which are say, sexually mature, you can harvest a certain fraction, and that fraction is adjusted so as to maximize the yield. In particular, the fraction that ends up being picked is the one for which there is the largest number of new individuals maturing at some time in the future. Then you fish the population down to a level at which this will happen.

An alternative would be to set aside certain parts of the coastline where you're not allowed to fish. We don't explore them in the paper, but there are many various side issues in terms of ease of enforcement, of byproducts of fishing. So if you're allowed to fish everywhere, fishing tends to have various side effects which typically are bad.

ER: Habitat destruction.

AH: Habitat destruction, by catch or incidental harm to other species and other issues. So one would think that there would be some advantages to thinking of setting aside some areas where you do not catch fish, so-called no-take zones. In those areas, for that system, the question has been, well, does this still give you the same kind of yield?

We tried to determine conditions under which the yield would be the same. We looked at a system where we said that if the adults are completely sedentary and the larvae are widely dispersed so that they are uniformly distributed over the coastline. For those kind of species, it turns out that we can analyze what the yield would be adding a couple more assumptions. The other assumption we add is that there is density dependence; that is, that there is some effect of the species on its own survival or reproduction.

ER: Density dependence means that

the number of survivors would decrease as the population density increases?

AH: Perhaps, but we don't need to specify exactly how that works, which is useful, because that's something that we know almost nothing about. People have tried to do stock recruitment curves which would provide this information, and they basically don't look much different than a shotgun blast on a piece of paper.

So under these conditions of widely dispersed larvae, sedentary adults, and all density dependence occurring after dispersal, the maximum sustainable yield is the same with no-take zones as it would be with management techniques based on harvesting a fraction of what's available. That's our major result.

We then put in some caveats, for example, that if any of these conditions are violated, things change. So particular larvae may not be dispersed necessarily this widely. This would tip the balance towards, in terms of sustainable yield, toward traditional harvest approaches. If there's density dependence before dispersal, this would also tip the balance in terms of yield towards traditional harvest approaches.

There is one factor we didn't include which would tip the balance towards reserves, which is if fecundity goes up as individuals get older, then that gives an advantage towards reserves because in reserves you get more older individuals.

The first two caveats are obviously things that occur. And this last one, which people might not think of, is also something which occurs because invertebrates typically have indeterminate growth: they get bigger as they get older, and the older individuals have higher reproduction, often it goes up dramatically.

ER: Are you arguing for more reserves?

AH: We've provided a baseline that can be used at least as an initial justification for seriously considering no-take zones. The other aspect of why this approach works is that in some sense you can set aside a fraction of individuals to reproduce either by not harvesting them or by leaving them in no-take zones. The no-take zones are a more permanent and more careful way of doing this. We didn't put it in the calculation, but if in fact you set aside less than you should, you can then apply traditional management techniques to what's going on outside the reserves and still get the same yield.

We also come up with a figure for what the optimum set-aside area is. Heuristically, if there were no survival of adults after reproducing, the set-aside area should be equal to the escapement. If there is survivorship of adults, the set-aside area should be equal to the escapement fraction minus a factor which depends on the year-to-year survivorship of adults in the no-take zones.

ER: Are there reserves available where this can be tested?

AH: Right now there are some no-take areas established in the U.S., the one in the Dry Tortugas for example. Many of these have been established for conservation reasons, much to the objection of fishers.

Our work provides at least some argument that for species where the adults are not mobile, that this would not be so bad for fishing. Some of the reviewers of our the paper said, they were just discussing ideas of no-take zones at a National Research Council forum and wished they had these results to look at then. So people are currently looking very seriously at no-take zones, and this paper provides ammunition for justifying them from a scientific basis.

ER: This doesn't address the issues of biodiversity.

AH: One of the reasons it does not address biodiversity is that reserves for biodiversity and reserves for fisheries may have somewhat different design issues. In particular, for fisheries you want to sustain the population, but given that, you want the maximum export, you want as many individuals as possible to leave. Whereas for biodiversity, in some sense you're not worried about that, and you might actually want in your reserve network as many individuals to end up back in it.

ER: The purpose of a biodiversity preserve would be to either restore or keep a more or less natural ecosystem intact, and that's not the same as trying to maintain maximum fisheries.

AH: Ideally one would want to see

... fishing tends to have various side effects which typically are bad: habitat destruction, by catch, or incidental harm to other species for example.

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how you could achieve both, and so that's something that we're starting to explore now, at least from a fairly abstract point of view again.

ER: that there are going to be some field tests or practical application tests down the line as a result of this work?

AH: We ourselves are not going to be directly necessarily involved in that. As I said, this is one paper coming out of this very large group that's meeting at the National Center for Ecological Analysis and Synthesis. So despite the fact that Lou and I are both at Davis, we did this work under the auspices of that program and basically did it while we were in Santa Barbara. Almost any aspect of this problem from a scientific point of view is going to be addressed by this group, and then we're going to be trying to get the information out to the public in a big way.

This is something we think is important to get the scientific basis well understood as a first step, and it really hasn't been. People have spent much more time and there's a much better developed approach to looking at terrestrial reserves and their impact on things like biodiversity or even hunting, but the way marine systems work is very, very different.

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NEXT MONTH

SOIL EROSION IN THE UPPER MISSISSIPPI: Stanley Trimble

EMERGING MARINE DISEASES: Drew Harvell

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