Title: How to identify win–win interventions that benefit human health and conservation

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Preface:

To reach the Sustainable Development Goals, we may need to act on synergies between some targets while mediating trade-offs between other targets. But what, exactly, are synergies and trade-offs, and how are they related to other outcomes, such as "win–win" solutions? Finding limited guidance in the existing literature, we developed an operational method for distinguishing win–wins from eight other possible dual outcomes (lose–lose, lose–neutral, etc.). Using examples related to human health and conservation, we illustrate how interdisciplinary problem-solvers can use this framework to assess relationships among targets and compare multi-target interventions that affect people and nature.

Interdependency has been hailed as a curse and a blessing for achieving the United Nations' Sustainable Development Goals (SDGs), which encompass 169 sustainability targets.[1–3] On the one hand, historical advances toward some sustainable development targets (e.g., SDG 2: Zero Hunger, SDG 8: Decent Work and Economic Growth) have caused declines in others (e.g., SDG 6: Clean Water and Sanitation), highlighting trade-offs that might impede achieving all SDGs by 2030.[2,4–6] On the other hand, synergies between SDG targets are often proposed as our best hope for getting back on track to reach the 2030 goals; if multiple SDGs can be advanced at the same time, progress may be faster and more cost-effective.[7,8] To that end, research and policy pieces often focus on interdependent targets, aiming to maximize synergies, avoid or mediate trade-offs, and ignore other possible outcomes.[5,9–11]

Acting on interdependent SDGs requires that decision makers can first distinguish among all possible interdependent and independent outcomes. However, terms like "synergy", "trade-off", "co-benefit", and "win–win" are rarely defined in the sustainability or ecosystem services literatures.[1,12] At best, synergies are defined as causal positive relationships and trade-offs as causal negative relationships,[1,11] where correlation strength is sometimes given a nominal score (e.g., +1 is "creates conditions that further another target" and +3 is "inextricably linked to the achievement of another target").[1,9] These scores have been applied differently by different teams,[1] highlighting how difficult they are to use consistently in practice. Furthermore, they do not clarify how synergies and trade-offs relate to specific outcomes. For instance, an action that degrades two target indicators will create a positive correlation (i.e., synergy), but not a win–win. What, then, is the difference between a synergy and a win–win? And can win–win solutions ever be created from trade-offs? After finding limited published guidance for navigating these terms, our working group developed an explicit framework for one early step in the SDG implementation process: assessing relationships among intervention targets and distinguishing among desirable and undesirable outcomes.[11]

Researchers, practitioners, and decisionmakers can use the framework described herein to compare interventions with just a few targets, such as the pairs proposed under the International Union for the Conservation of Nature's Nature-based Solutions Global Standard,[10] or to complete all pairwise comparisons within the full SDG target network—an increasingly common exercise.[5,11,13] With three possible outcomes per target (win, neutral, lose), there are nine possible correlated or uncorrelated joint outcomes for two targets (lose–lose, lose–neutral, etc.; Fig. 1). Unlike prior frameworks, this comparative process retains uncorrelated, neutral outcomes, which can be valuable management options to consider during multi-criteria decision making. Below, we illustrate how to use our framework using examples related to human infectious disease control and conservation.

Start with baselines and outcome directions

To define the relationship between any two targets, one must know how each target has changed, is changing, or will change. This is accomplished by first defining the spatial and temporal baseline for each target. Baselines are usually defined as the conditions that exist before an intervention, such as the prevalence of parasites in a community before a school deworming program begins. Some baselines will be considered relatively "healthy" and thus worth maintaining, such as a lake that already has high quality water before an intervention. Other baselines will be considered relatively "unhealthy" and worth improving, such as a eutrophic and polluted lake that receives a high volume of agricultural runoff. Stakeholders might have different perspectives on what the baselines are, and these differences are important to document and discuss. From chosen baselines, we can then define the observed or expected trajectories through time or space (win, lose, or neutral), where a decline from relatively healthy conditions indicates *degradation* (lose), no change from baseline indicates *stasis* (neutral), and an increase from relatively unhealthy conditions indicates *improvement* (win; Fig. 1). A "win" can occur even when starting conditions are "healthy" (e.g., what starts as acceptable water quality becomes pristine water quality; Fig. 1a) and a "loss" can occur even when baselines are "unhealthy" (e.g., what starts as moderate disease burden becomes high disease burden; Fig. 1b); it is the relative change from baseline that determines the outcome direction. The outcome directions for any two targets determines where the intervention falls within the nine-panel outcome space in Fig. 1.

In this direction-based framework, neutral outcomes do not have an inherent value judgement, where we define "values" as "reference points for evaluating things as good or bad."[3] There are many types of values (e.g., economic value, societal value), and value judgements often differ among stakeholders.[3] For instance, along the Senegal River in West Africa, dam construction extirpated native, migratory prawns. Before the dam, prawns ate the snails that are intermediate hosts for human schistosome parasites, so prawn extirpation contributed to high human disease burdens that persist to this day[14,15]—a lose–lose scenario for ecosystems and human health (but a win for local agriculture, because the dam supported agricultural irrigation). Any interventions that preserve the current, high disease burdens (an "unhealthy" baseline) would be called "neutral" scenarios for human health in our framework, even though those interventions might be negatively valued by people living near the Senegal River (red neutral-neutral panel; Fig. 1b). In contrast, schistosomiasis has been eliminated in Japan,[16] so neutral interventions in Japan that preserve the contemporary, "healthy", disease-free baseline would be positively valued (blue neutral-neutral panel; Fig. 1a). These examples show that the inherent values associated with neutral outcomes depend on the values associated with the baseline conditions (Fig. 1).

If desired, value judgements for baselines can be used to determine a "level of urgency" for any given pair of targets.[11] The most urgent targets might be those that are below standards ("mutually unhealthy") and declining. For these scenarios, any neutral outcomes will be negatively valued, and thus only interventions with win–win outcomes will be positively valued (one blue panel in Fig. 1b). In contrast, targets that are above standards ("mutually healthy") and increasing might have low urgency, and neutral–neutral, win–neutral, neutral–win, or win–win outcomes will be positively valued (Fig. 1a). In the first case, neutral outcomes might be best avoided, whereas in the second case, considering neutral outcomes expands management options for positively valued outcomes. Again, these examples show that the values associated with outcomes depend on the values associated with the baseline conditions (Fig. 1).[17]

Neutral outcomes may often be ignored in the sustainability and ecosystem services literatures because most contemporary baselines are considered mutually unhealthy, but mutually healthy baselines do exist (central panel in Fig. 1a; dashed lines in Fig. 2b). For instance, it is far more efficient to prevent a disease vector from invading than it would be to control or eradicate an established vector (e.g., the mosquitoes that spread Chikungunya virus in Italy[18] or avian malaria in Hawaii[19]). Neutral–neutral interventions that prevent degradation are analogous to "preventative healthcare", where "an ounce of prevention is worth a pound of cure".[20]

Unfortunately, many systems are already degraded and need "sick care" to return to historical, mutually healthy baselines. For instance, restoring logged forests might increase ecosystem integrity and improve human health, because increasing upstream forest cover is associated with reduced downstream childhood diarrhea risk (Fig. 2)[21,22]—a win–win if measured from mutually unhealthy, degraded baselines. This scenario would be a net neutral–neutral outcome if the baselines were intact forests and low childhood diarrhea ("mutually healthy" baselines), which were degraded by logging forests (a lose–lose) and later restored by reforestation to "healthy" baselines (a win–win; solid lines in Fig. 2B). Although this net neutral–neutral scenario has the same baselines and outcomes as would a "preventative healthcare" neutral–neutral scenario (i.e., never unsustainably logging forests in the first place), it involves ecosystem degradation, lost human lives, and resources spent on reforestation and healthcare. As in this example, many win–win solutions are sick care for degraded systems, and thus represent corrective actions for when preventative care has failed.

Positive correlations suggest win–win potential

In the sustainability literature, synergies are often defined as causal positive relationships between two targets or outcomes.[9,11] Such relationships can exist either because one outcome causes the other (e.g., an improved conservation outcome reduces human disease burdens, or reduced human disease burdens improve ecosystem integrity) or because a shared driver affects each outcome (e.g., invasive rat control benefits both human health and native wildlife populations through different processes, with rats being a common driver; see below). Given this definition and our framework, all lose–lose and win–win scenarios are synergies, and some neutral–neutral scenarios are also synergies—all outcomes that occur on the positive diagonal in Figure 1. For example, all three synergistic dual-outcomes (win–win, lose–lose, and neutral–neutral) are possible when forest restoration reduces diarrheal risk, depending on the specific baselines and outcome directions considered (Fig. 2). This results in an important corollary: lose–lose scenarios have win–win potential, and thus practitioners and decision makers seeking win–win solutions could start by searching for lose–lose scenarios.

In contrast, win–lose and lose–win outcomes represent trade-offs between conservation and human health, where the outcomes are linked by causal, negative relationships, or a shared driver affects the two outcomes in opposite directions. For example, in some parts of Africa, declines in water quality can extirpate freshwater crabs and the larval black flies that attach to them. Reduced black fly larvae abundance causes fewer adult black flies to transmit onchocerciasis to humans, such that a loss for freshwater biodiversity can be a win for human health (lose–win). Because the biodiversity and health outcomes are negatively correlated, acting on this existing relationship cannot produce a win–win scenario.[23] For instance, restoring the freshwater crabs (a conservation improvement from an "unhealthy" baseline) could cause black flies and onchocerciasis to increase again (a health decline from a "healthy" baseline), creating the opposite trade-off scenario (win–lose). Given the difficulty in changing underlying correlations in such trade-off scenarios, the sustainability and ecosystem services literatures often recommends avoiding or mediating trade-offs.

However, the best—but perhaps most difficult—solutions might be those that re-engineer, bypass, or break negative associations between conservation and human health.[5,6] For instance, in the example where damming the Senegal River extirpated prawns and increased schistosomiasis in humans, there is a lose–win trade-off between prawns and agriculture and a lose–win trade-off between human infectious disease control and agriculture. To break these negative associations, efforts are underway to design a prawn ladder for the dam that can restore prawn migration upstream from dams. This technological solution would maintain the dam and agricultural gains while also restoring prawns and human health, turning a trade-off scenario into a win–win.

Finally, there are conservation and health outcomes that are consistently uncorrelated, where an intervention could affect one sector but not the other (win–neutral, neutral–win, lose–neutral, and neutral–lose; Fig. 1, middle column and row). For instance, consider regions where malaria burdens are high ("unhealthy" baseline) and freshwater ecosystems are either degraded or pristine ("unhealthy" or "healthy" baseline). From these baselines, insecticide-treated bed nets have produced exceptional reductions in malaria burdens at low cost,[24,25] with negligible environmental consequences on non-target species (when bed nets have not been co-opted for fishing[26]). This is a win–neutral scenario for health and conservation relative to baselines, and a preferred conservation outcome over other possible interventions, such as wetland draining. These neutral outcomes are often overshadowed by win–wins within SDG target networks,[11] but once identified, win–neutral interventions implemented by only one sector may promote rapid progress toward achieving SDG goals.

Adding complexity to pairwise comparisons

An intervention might have several conflicting or complementary effects on ecosystem integrity, human health, or other sectors. To understand and make decisions in these complex systems, it is common in the SDG literature to create networks of all targets and then to evaluate the relationship between each pair.[5,11,13] For example, in Table 1, we show how 9 out of the 17 SDGs might have been impacted in India by a national policy banning diclofenac, a veterinary medicine that caused widespread vulture declines when vultures fed on toxic livestock carcasses (Fig. 3).[27,28] The diclofenac ban was primarily implemented to conserve vultures (SDG 15: Life on Land), which was expected to reduce carrion availability, free-ranging dog populations, and human rabies risk from dog bites (SDG 3: Good Health and Well-being; Fig. 3a, Table 1). Banning diclofenac was also expected to have positive impacts (wins) on many other SDGs, including reducing poverty and improving water quality (Table 1).[29–31] The diclofenac ban was not expected to create any trade-offs among SDGs, except perhaps by increasing airplane collisions with vultures.[27] Of course, it is unlikely that any intervention in a complex system will improve everything, and there were several neutral outcomes that would likely maintain "unhealthy" baselines (Table 1). Therefore, in this example, all pairwise comparisons are expected to be win–wins or win–neutrals. Though neutral outcomes are often ignored, retaining them helps to identify interventions that make improvements in some sectors without creating or exacerbating problems in others.

In addition to comparing many targets or SDGs, decision makers might compare many interventions using tools like multi-criteria decision-making analyses. When comparing intervention options in this way, it is useful to consider not only their qualitative outcomes, but also their effect sizes. To do this with our 9-panel framework, the baseline condition can be represented by the plot origin, and neutral outcomes can be placed along the axes that measure impacts on each target (Fig. 4). Associations between targets can be represented as vectors, and points along vectors are possible endpoints for interventions acting on those relationships. Endpoints can be constrained by some budget or other limited resource pool (Fig. 4). Therefore, intervention ranking and subsequent selection will depend on the priorities and resources available to decisionmakers or practitioners. Our framework makes it easier to define and compare these options.

Finally, the relationships between two targets might be nonlinear (Fig. 4, Intervention Options 2 and 3) or involve other complexities, such as time lags. For instance, forest restoration can only increase native biodiversity until the historical baseline is achieved. After that point, improvement or restoration—a win in our framework—is no longer possible and the conservation outcome direction switches to neutral; the outcome saturates with intervention intensity (e.g., Fig. 4, Intervention Option 2). Furthermore, forest restoration might take decades, and resulting ecosystem services (e.g., water purification) might not be achieved quickly, creating a large temporal lag in the correlation between forest restoration and human health benefits. Long-term outcomes are often the most cost-efficient, but they can be difficult to fund or implement if they require large initial buy-ins or long delays before benefits manifest. Because definitions based on short-term correlations alone might miss these complexities, our directions-based framework encompasses historical conditions and long-term futures.

An example with invasive rats in Hawai'i

Intervention planning, monitoring, and evaluation are often accomplished using the "theory-of-change" approach.[32,33] Using this process, practitioners and stakeholders collaboratively describe project activities, short-term outputs, long-term outcomes, and the causal relationships linking these entities in an explicit theory-of-change (TOC) diagram that illustrates what a successful intervention will look like (Fig. 5a). By making a few small changes to this workflow, practitioners can adapt this approach to our multi-outcome framework (Fig. 5a). In particular, after defining their baselines in time and space, all parties can think through their intervention options while considering multi-sector outputs and outcomes, like those for both human infectious disease control and conservation. Outcomes can then be compared to baselines, and outcome directions (win, neutral, or lose) can be recorded on the TOC diagram. To illustrate this process, we show example TOC diagrams for two possible interventions that should reduce rat-associated diseases infecting people in Hawai'i, where both interventions involve a "win" for human health, but the conservation outcomes differ between the interventions (Fig. 5).

Invasive rats cause problems for many stakeholders in Hawai'i (Fig. 3b).[34–36] Each year, several people become sick with rat-associated infectious diseases, such as rat lungworm disease, toxoplasmosis, and murine typhus. People can become infected via several transmission routes, such as parasite-contaminated vegetables or bites from flea vectors.[35] Invasive Polynesian, black, and Norway rats (*Rattus exulans*, *R. rattus, and R. norvegicus*) also eat endemic Hawaiian flora and fauna that evolved without rat predators (e.g., a forest bird called the Oahu elepaio [*Chasiempis ibidis*] and a flowering plant called the superb cyanea [*Cyanea superba*])[37,38] and agricultural crops such as sugarcane and macadamia nuts. This example shows the complexity in coupled human and natural systems where practitioners are seeking win–win solutions: there are multiple invasive rat species, conservation targets (one for each endemic species), human infectious disease targets (one for each parasite), targets in other sectors, and affected islands/habitats. We simplify the example below by summarizing all outcomes into two outcome categories: one for rat-borne human infectious diseases and one for rat-impacted endemic flora and fauna.

To use our framework, we first select appropriate baselines in time and space. We could select the historical human health and conservation baselines that existed 200 or 800 years ago, before black and Norway rats invaded and before Pacific rats invaded, respectively. From those historical baselines (no rat-associated disease, no rat predation), both human health and endemic species have declined: a lose–lose scenario. However, to compare potential present-day intervention options, we will instead use present-day human disease incidence and endemic species population sizes as our baselines. In particular, we consider these baselines to be mutually "unhealthy" (Fig. 5b-c), because human disease incidence is above acceptable levels and many endemic species are threatened with further declines and/or extinction due to rat predation. Therefore, this example is one where "sick care" is required.

Human health alone could be improved through educational campaigns to teach people about rat-associated disease risks and personal prevention measures, such as washing vegetables (Fig. 5b). Within weeks, practitioners could use surveys to measure self-reported changes in behavior (Fig. 4b, Outputs). These behavioral changes should reduce human infection risks (Fig. 4b, Outcomes) and human disease burdens (Fig. 4b, Human Infectious Disease Direction=Win), but would need to be maintained indefinitely, because potential transmission pathways from rats to people would still exist (e.g., infected rats and slugs would still persist). Similarly, because neither educational campaigns nor human behavioral changes would reduce rat population sizes, this intervention would have no effect on rat predation intensity on wildlife or crops (Fig. 4b, Conservation Direction=Neutral). This win–neutral intervention would be easy to implement and might save lives, but it represents a mixed-value dual-outcome scenario: the outcome value for human infectious disease control is positive (bad to better; win), whereas the outcome values for conservation and agriculture are negative (bad to equally bad; neutral from an unhealthy baseline). Therefore, educational campaigns alone are not the most beneficial intervention option.

Instead, there is at least one intervention that would be a mutually positive, win–win–win solution: invasive rat control or eradication (Fig. 5c). Rat control efforts use rat poison or traps,[36] and practitioners monitor success by measuring rat mortality or rat population sizes (Fig. 5c, Outputs), because rat populations are the shared driver linking human health, conservation, and agriculture outcomes. In particular, over months to years, decreasing rat populations should reduce human disease (human health "win"), increase endemic species population sizes (conservation "win"), and increase crop production (agricultural "win", not shown in Fig. 5c for simplicity). However, this potential win–win–win could have non-targets effects, which could be anticipated and mitigated. For instance, rat poison can be eaten by other wildlife and accumulate in the food web, and thus poisoning might need to be substituted with rat trapping in some contexts.[39] If non-target effects are avoided or minimized, rat control has the potential to be more broadly beneficial than educational campaigns alone.

Conclusions

Whether evaluating an intervention with a few multi-sector targets or making many pairwise comparisons within an SDG target network, deciding whether two targets represent a synergy, a trade-off, or independent outcomes requires explicit definitions that can be shared within interdisciplinary teams. Here we present a nuanced guide for identifying and comparing nine possible interdependent and independent outcomes using a process that defines baselines, outcome directions (win, lose, or neutral), and associated values. This framework can be used to identify and prevent lose–lose scenarios before they occur (akin to "preventative care") or to identify good opportunities for win–win solutions where damage to human health and to ecosystems has already occurred (akin to "sick care"). However, acting on the positive links between people and nature is just one way to safeguard future human well-being while preserving ecosystems and biodiversity; opportunities for positively-valued multi-sector outcomes might also be found where people and nature are *not* interconnected and/or where negative, trade-off links can be avoided or re-engineered. Comparing and contrasting the nine possible dual outcomes reveal more ways that funders, policymakers, researchers, and practitioners can intervene to accelerate progress towards the SDGs.

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Table 1. Banning diclofenac in India and surrounding nations after widespread vulture declines was expected to impact 9 out 17 Sustainable Development Goals, all of which had relatively unhealthy baselines in 2008. For a detailed cost–benefits analysis, see Markandya et al. (2008).

Sustainable Development Goal	Baseline (in 2008)	Expected direction of change	References
1. No Poverty	Unhealthy: 31% below poverty line in 2009	Win: Fewer free-ranging dogs and fewer rabid dogs should lead to fewer bites, reducing lost wages due to sickness/treatment and money spent on post-exposure treatment.	Markandya et al. (2008), World Bank (2020)
2. Zero Hunger	Unhealthy: Food insecurity and undernourishment rates were too high.	Win: Food security might increase with reduced expenditures on dog bite treatments and reduced livestock losses due to dog attacks, rabies, and potentially other diseases transmitted by carcasses not eaten by vultures (e.g., anthrax). *Note: replacement livestock NSAIDs might be more expensive than diclofenac at first, potentially reducing livestock output for some people, but government subsidies for new NSAIDs would be cost–effective.*	Markandya et al. (2008), World Bank (2020)
3. Good health and well-being	Unhealthy: Millions of people bitten by dogs annually in India required post-exposure treatment. India also had the highest burdens of rabies infections and rabies-associated deaths in the world.	Win: Hypothetically, vulture population restoration would reduce free-ranging dog populations, leading to fewer bites, fewer rabies cases, and reduced premature death. Vultures might also reduce burdens of other diseases, such as anthrax, by faster carcass removal. *Note: vulture restoration might increase air accidents, which would be a loss for human well-being, but it is unclear how large this risk is.*	Markandya et al. (2008)
4. Quality education	Unhealthy: Fewer girls than boys in school at all levels of education.	Neutral: Vulture conservation is not expected to affect education, unless indirectly through wealth or well-being.	World Bank (2020)
5. Gender Equality	Unhealthy: Women held a relatively small proportion of parliament positions, composed <50% of the work force, etc.	Neutral: Vulture conservation is not expected to affect gender equality, unless indirectly through wealth or well-being.	World Bank (2020)
6. Clean Water and Sanitation	Unhealthy: E.g., in 2012, hundreds of millions of people living in India practiced open defecation.	Win: Vultures provide sanitation services by consuming carcasses (sources of some diseases), garbage waste, and human and livestock feces.	Gangoso et al. (2012), WHO/UNICEF (2012)
7. Affordable and Clean Energy	Not applicable	Neutral: not applicable	
8. Good Jobs and Economic Growth	Unhealthy: Some livelihoods that were dependent on vulture services were experiencing hardships due to vulture declines.	Win: Beyond the livestock industry, waste removal by vultures benefits some livelihoods (e.g., livestock butchering, tanning, and bone collecting for fertilizer). Vultures can also provide ecotourism opportunities.	Gangoso et al. (2012), Markandya et al. (2008)
9. Industry, Innovation, and Infrastructure	Not applicable	Neutral: not applicable	
10. Reduced Inequalities	Unhealthy: The poor are disproportionally burdened by dog bites, rabies deaths, and lost economic benefits from vultures.	Win: Domestic dog management (e.g., vaccination) is considered the gold standard rabies intervention by the WHO because it is likely the most effective and equitable intervention. Vulture conservation to control dog population dynamics might similarly reduce inequalities.	Hampson et al. (2015)
11. Sustainable Cities and Communities	Unhealthy: People living in lower income neighborhoods feel unsafe due to bite risks from domestic dogs with rabies. Additionally, in some places, sky burial practices used by the Parsis religion were impeded by vulture declines.	Win: If vulture restoration works to reduce dog populations (especially of feral dogs) through competition, dog bite risks should decline. Vulture restoration might also restore cultural/religious values associated with vultures, such as sky burials.	Markandya et al. (2008)
12. Responsible Consumption and Production	Not applicable	Neutral: not applicable	
13. Climate Action	Not applicable	Neutral: not applicable	
14. Life Below Water	Relatively Unhealthy: No specific relevant indicators were available, but waste reaching waterways might have been relatively high when vultures declined.	Win: By consuming garbage waste and feces, vultures might reduce pollution reaching waterways.	Gangoso et al. (2012)
15. Life on Land	Unhealthy: More than 95% of populations of three vulture species died from diclofenac poisoning in roughly a decade, altering ecosystem structure and functions.	Win: Restored populations of three threatened vulture species; restored nutrient cycling through scavenging; reduced wildlife contacts and wildlife disease transmission at quickly removed carcasses. Might also reduce impacts on wildlife that dogs depredate or compete with.	Markandya et al. (2008), Ogada et al. (2012), Buechley and Şekercioğlu (2016)
16. Peace, Justice, and Strong Institutions	Not applicable	Neutral: not applicable	
17. Partnerships for the Goals	Not applicable	Neutral: not applicable	

Figures & Captions:

Fig. 1. A framework for evaluating intervention outcomes and their associated values. Given any two intervention targets (e.g., one related to human health and one related to conservation), there are nine possible joint outcomes that can be differentiated by defining changes from baselines ("win", "neutral", or "lose") using data or logic. The joint outcomes on the positive diagonal are positively correlated synergies, and joint outcomes on the negative diagonal are negatively-correlated trade-offs. The values ("good" or "bad") associated with outcomes are subjective and depend on the values associated with their baselines; here we show the values associated with changes from (a) mutually "healthy" baselines and (b) mutually "unhealthy" baselines.

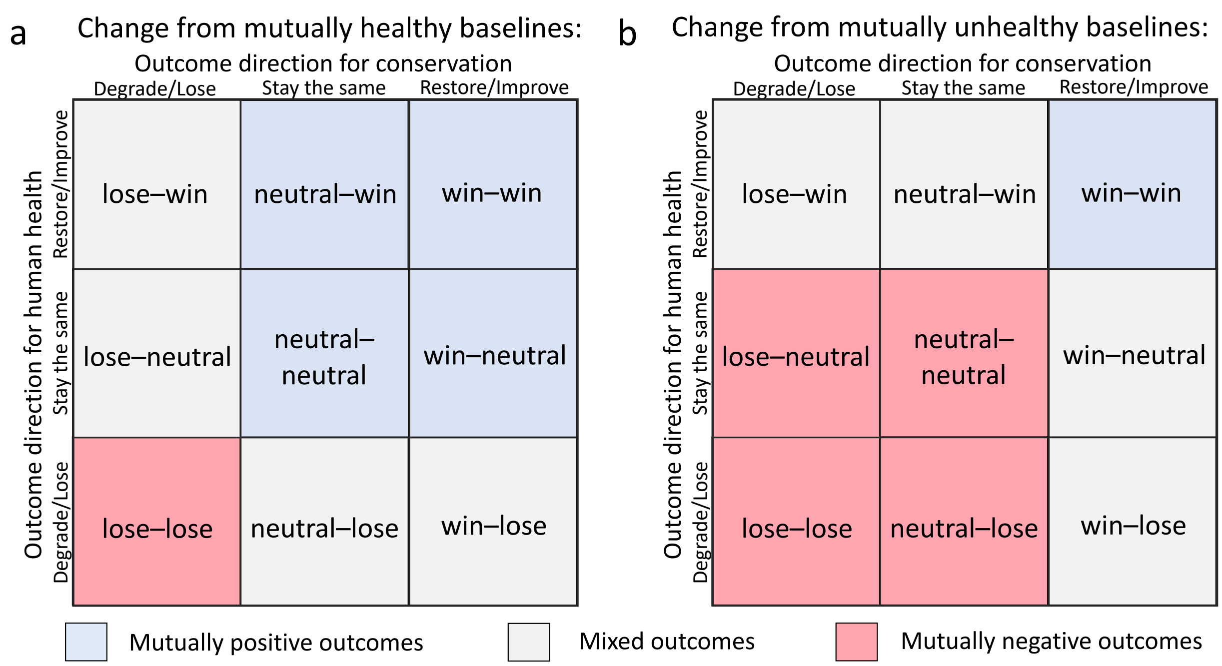


Figure 2. "Sick care" and "preventative care" within coupled human and natural systems can each create neutral–neutral outcomes. (a) Starting from pristine historical baselines, deforestation increases runoff containing human enteric pathogens and decreases biodiversity, creating a lose–lose for people and nature. From those degraded baselines, reforestation efforts to restore biodiversity, improve water quality, and reduce human disease risk would be a win–win solution.

(b) When comparing pristine historical baselines to final restoration end-points, the degradation–restoration scenario is a net neutral–neutral outcome (i.e., “sick care”, solid lines). In contrast, if deforestation were prevented, this would be a preventative neutral–neutral outcome (dashed lines).

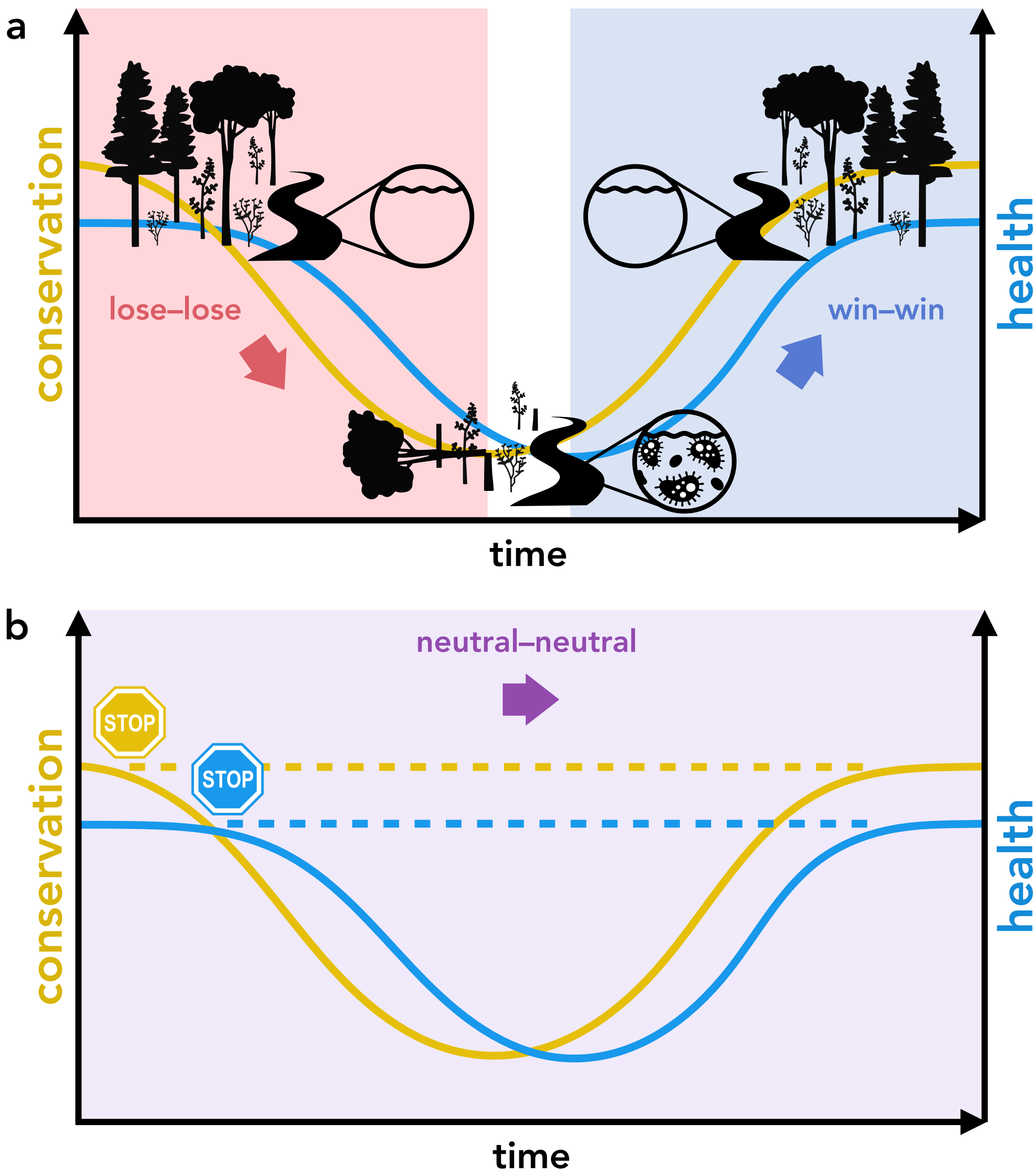


Fig. 3. (a) Vultures play important roles in nutrient cycles and carrion/refuse removal in India (1). When vultures are poisoned by the veterinary medicine diclofenac (2), free-ranging domestic dog populations might increase with food availability, leading to increased circulation of rabies within dog populations (3). Increased dog populations can lead to increased dog bites and rabies deaths in humans (4). Humans might also experience increased risk of environmental pathogens (5), which accumulate faster in ecosystems without carrion/refuse removal by vultures. (b) Larval rat lungworms are excreted from rats (1) in their feces (2), which are then consumed by slugs (3). Infected slugs can infect rats and contaminate vegetables (4) consumed by humans (5), leading to human infection. In addition to causing human diseases, invasive rats are also problematic on Hawai'i and other islands because they consume human crops (e.g., macadamia nuts, 6) and endemic species (e.g., bird eggs and seedlings, 7 and 8). This figure has been designed using some resources from Flaticon.com.

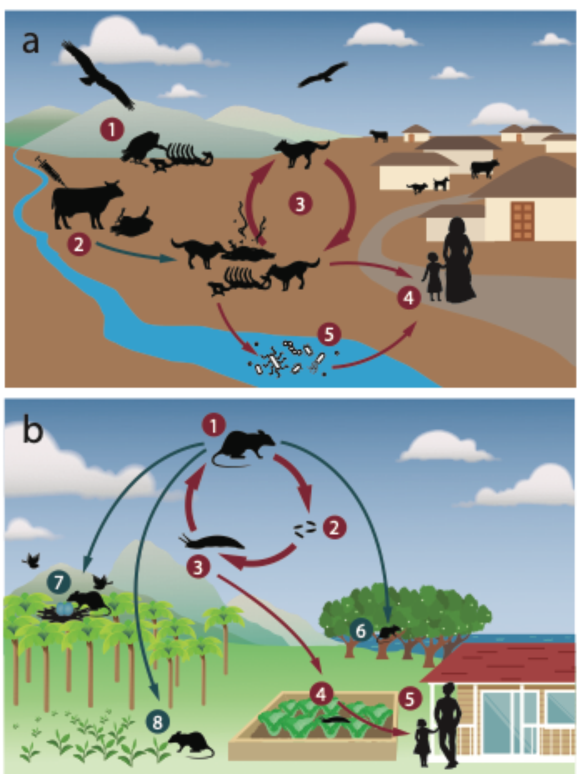


Figure 4. Multiple interventions can be compared based not only on their qualitative outcomes, but also on their effect sizes and cost-effectiveness. The baseline conditions are the origin of this plot, and vectors indicate trajectories that result from investing in an intervention. The blue points show three win–win interventions with the same cost that vary in conservation and human health outcomes, compared to a lose–win intervention with the same cost. Neutral outcomes are on the plot axes.

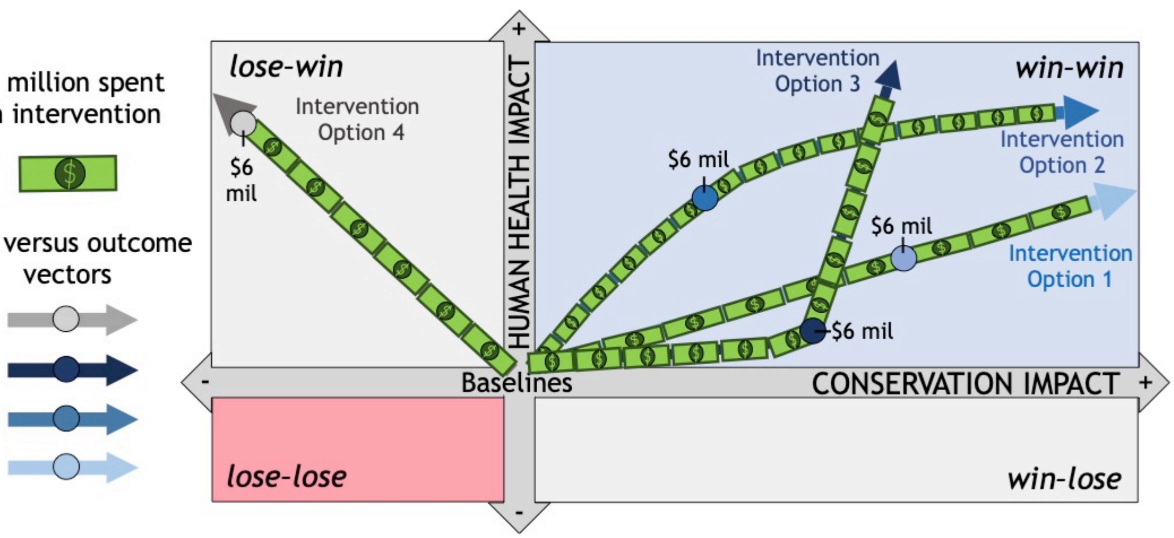
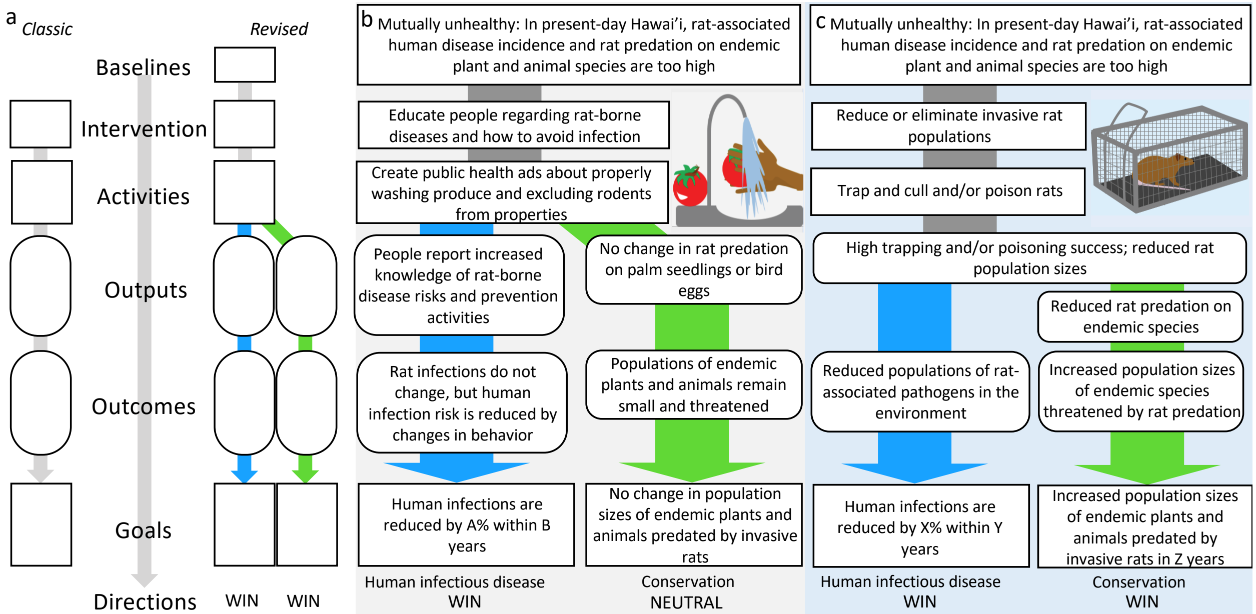


Figure 5. From mutually unhealthy baselines, we use (a) a revised, multi-outcome, baseline- and direction-explicit theory of change (TOC) approach to illustrate how two possible interventions would represent future (b) win–neutral and (c) win–win solutions for human health and conservation in Hawai'i. Further details could be added to these TOC diagrams to capture other outcomes (e.g., poisoning wildlife, reduced rat predation on agricultural crops).


a Classic
Revised
Baselines
Intervention
Activities
Outputs
Outcomes
Goals
Directions
WIN
WIN
b Mutually unhealthy: In present-day Hawai'i, rat-associated human disease incidence and rat predation on endemic plant and animal species are too high
Educate people regarding rat-borne diseases and how to avoid infection
Create public health ads about properly washing produce and excluding rodents from properties
People report increased knowledge of rat-borne disease risks and prevention activities
No change in rat predation on palm seedlings or bird eggs
Rat infections do not change, but human infection risk is reduced by changes in behavior
Populations of endemic plants and animals remain small and threatened
Human infections are reduced by A% within B years
No change in population sizes of endemic plants and animals predated by invasive rats
Human infectious disease
WIN
Conservation
NEUTRAL
c Mutually unhealthy: In present-day Hawai'i, rat-associated human disease incidence and rat predation on endemic plant and animal species are too high
Reduce or eliminate invasive rat populations
Trap and cull and/or poison rats
High trapping and/or poisoning success; reduced rat population sizes
Reduced rat predation on endemic species
Reduced populations of rat-associated pathogens in the environment
Increased population sizes of endemic species threatened by rat predation
Human infections are reduced by X% within Y years
Increased population sizes of endemic plants and animals predated by invasive rats in Z years
Human infectious disease
WIN
Conservation
WIN