metals such as copper. Once the manganese protein has folded, the metal-binding sites are inaccessible to other metals, and the protein can be safely exposed to the periplasmic environment. In other words, the metal that binds to the protein is selected by the compartment in which the protein folds.

Tottey and colleagues suggest[2] that cytoplasmic metal insertion might be crucial not only for periplasmic proteins that bind individual metal ions, but also for the numerous Tat substrates that bind to other kinds of metal-containing cofactors, such as clusters of metal and sulphur atoms or complexes of metals with organic molecules. They propose that cytoplasmic insertion prevents the misincorporation of tightly binding metals into such cofactors; once ensconced within the folded protein, the cofactors are shielded from any interference by competing metals. For example, the authors note that iron–sulphur clusters are susceptible to the misincorporation of transition-metal ions such as cobalt and copper[6,7], and that periplasmic proteins that contain iron–sulphur clusters are always transported to their site of action by the Tat pathway. Strikingly, and consistent with the authors' proposal, the only periplasmic protein that has a copper–sulphur cofactor receives this cluster in the periplasm, rather than in the cytoplasm[8].

Eukaryotic cells (such as those of animals, plants and fungi) might also control the metal loading of their secreted proteins by a variation of the protected-compartment strategy. In these cells, secreted proteins fold in the endoplasmic reticulum — an intracellular organelle that controls the concentrations of metal ions in its interior — before they reach the extracellular milieu. But in contrast to the mechanism described by Tottey *et al.*, these folded proteins are transferred to the outside world in vesicles that release their contents on fusion with the cell membrane; no physical transport of the protein across a membrane is required.

Some transport of folded proteins into organellar compartments does occur in eukaryotic cells — across the membranes of peroxisomes (ubiquitous organelles involved in metabolism) and across the photosynthetic thylakoid membranes of chloroplasts (which possess a Tat apparatus). It will be interesting to see whether these systems, like the bacterial Tat pathway, are exploited to control metal binding in organellar proteins. More generally, Tottey and colleagues' work[2] reminds us that different cellular compartments have their own distinct metal compositions, which are vital in determining which metals associate with their resident macromolecules. ■

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ECONOMICS

Sustainable fisheries

Geoffrey Heal and Wolfram Schlenker

Fishermen's aims of increasing their catch seem at odds with preserving fish stocks by limiting catch. A study of more than 11,000 fisheries shows that 'individual tradable quotas' can reconcile these goals.

The destruction of the world's major fisheries has been widely documented, with a general consensus that the biomass of top marine predators is now some 10% of what it was half a century ago[1]. Many of these species — such as the bluefin tuna, Atlantic cod, and swordfish in the Atlantic and Indian oceans — are expected to be extinct within decades. There is therefore great interest in finding ways of managing fisheries that ensure their sustainable use, allowing a fish population to return to earlier levels and providing a secure basis for a healthy and profitable fishery. Writing in *Science*, Costello, Gaines and Lynham[2] present a convincing and thorough analysis of this issue. They suggest that a particular management approach, the use of 'individual tradable quotas' (ITQs), has had dramatically beneficial impacts on many of the fisheries in which they have been implemented.

The destruction of the world's fisheries is a classic illustration of the 'tragedy of the commons'. With open access, all boats are competing for the same fish: the more fish one catches, the fewer there are for others. Everyone rushes to catch as many as possible. There is no point in leaving fish untouched so they can breed, as competitors will catch them. Economists have developed formal models showing that the outcome is a massive overuse relative to the policy that would generate the greatest economic value from the fishery.

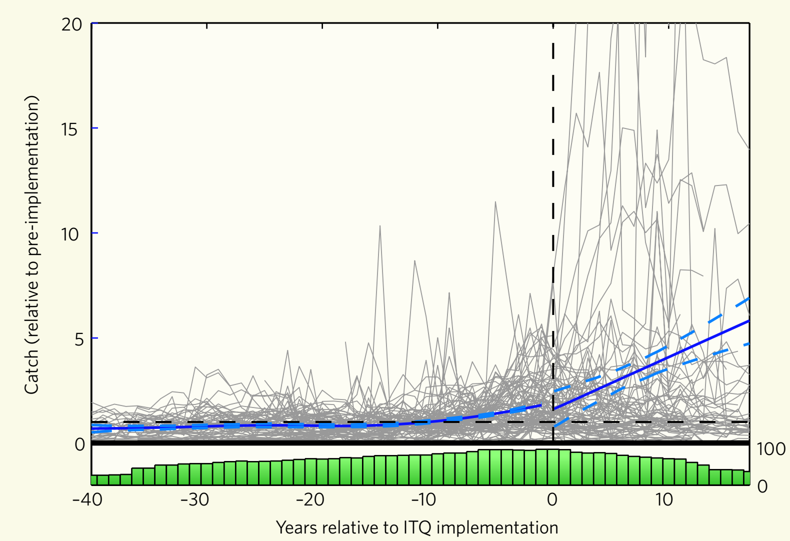

Figure 1 | Benefits of individual tradable quotas (ITQs). This figure uses catch data for all fisheries that had implemented ITQs by 2003, and for which there were at least five observations before ITQ implementation. (Two fisheries that had increases of more than a factor of 200 after ITQ implementation are excluded, as these could be outliers; the graph is thus a conservative estimate of the benefits of ITQs.) The *x* axis shows the time relative to ITQ implementation (time 0 is the year ITQs were implemented; time 1 is the first year after implementation). Upper panel, time series of individual fish species, shown as grey lines, where average catches before implementation are normalized to 1. The blue solid line shows the result from a non-parametric regression; blue dashed lines are the 95% confidence band. Lower panel, a histogram of how many fisheries had catch data available for each time period. (Catch data from refs 1 and 2, used to compile this figure, were kindly supplied by Costello *et al.*)

Introducing ITQs gives exclusive access to fishermen who work a fishery. A total allowable catch (TAC) is set and an ITQ entitles the owner to a fraction of this, so the TAC translates into a catch limit for each boat. ITQs can be traded, and their value of course depends on the productivity of the fishery: shares in a collapsed fishery are worth as little as shares in a collapsed bank. But shares in a thriving fishery command high prices and represent real wealth for their owners. Suddenly, fishermen have an incentive to preserve a fishery for the future, as preservation will be reflected in a higher value of which they 'own' a share. Each fisherman has an incentive to lobby for the optimal TAC. In theory, ITQs are a win–win solution: they align incentives for fishermen with the good of a fishery ecosystem, leading to reduced pressure on the fishery as well as higher profits for fishermen than under open access.

The innovation by Costello *et al.*[2] is a thorough statistical analysis of the impact of introducing ITQs on the status of a fishery, using a database covering 11,135 fisheries from between 1950 and 2003, of which 121 had instituted ITQs by 2003. Ecosystems with the largest number of ITQs include the New Zealand shelf (example species being squid, jack and blue mackerel); the Iceland shelf (capelin and herring, but also species with lower average catch, such as monkfish); and the Gulf of Alaska (for example, pollock and Pacific cod).

Costello and colleagues use the definition of collapse applied in an earlier paper by Worm *et al.*[1], and they show that introduction of an ITQ system reduces the probability of that outcome by about 14%. The fraction of ITQ fisheries that collapsed was about half that of the non-ITQ fisheries that collapsed. Because both Costello *et al.* and Worm *et al.* define a fishery as collapsed when the catch drops below 10% of the historic maximum to date, a policy that stabilizes catch by definition reduces the probability of collapse. (If catch is a random process with a constant mean, a one-time positive outlier equal to 10 times the mean would imply that, once catch reverts to the mean, it is now considered collapsed. Our Figure 1, which shows the win–win situation of ITQs, hence presents the entire catch series to emphasize that the results are not driven by outliers of the historic catch.)

The upper panel of Figure 1 displays the catch history for fish species for which ITQs were implemented. The *x* axis is the time from when the ITQ was implemented (ITQs are phased in over several years, and hence time 1 on the *x* axis corresponds to different years for each fish species; because we group together catches from different years for each time period, the results are less likely to be driven by year-specific environmental shocks). The *y* axis shows relative catches that are normalized to 1 before the ITQ was implemented. Grey lines display the time series of individual fish species. The blue line shows the results from a non-parametric regression (including a 95% confidence band shown as dashed lines). Note how several fisheries (grey lines) show remarkable improvements above historic levels after the ITQ was implemented. Similarly, the smoothed overall line shows an upward trend. Sustained higher catches imply that the fishery is less likely to collapse and that the fishermen are reaping the benefits through higher catches.

In Figure 1, the 95% confidence band of the non-parametric regression starts to broaden towards either end, which is not surprising given the limited number of fisheries that have such long time series. The lower panel displays the number of observations we have for each time period. We truncated the graph after 17 years, as the number of observations drops sharply from 36 in time period 17 to 12 in time period 18. Continued monitoring and improved catch data for longer time periods will hence be crucial to assessing the continued sustainability of ITQs.

If ITQs work, why haven't they been more widely used? Undoubtedly, this is partly because, until Costello and colleagues' paper, we have not had unambiguous evidence that they do work. This study should give ITQ implementation a boost. But there are also some political, ideological and regulatory issues in the way. Some environmental groups are opposed to anything based on market principles. Others feel that ocean fisheries are common property — that everyone should be free to use them, and that it is wrong to establish ownership rights in the sea. It is to be hoped that clear evidence of the effectiveness of ITQs will lead their opponents to think again. Finally, ITQs work best when a fish species resides exclusively within the waters of a particular country. Fish species in international waters, or migratory species, would require international agreements, with the complication that individual countries might have an incentive to cheat. ■

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INORGANIC CHEMISTRY

Confirmation of the improbable

Craig L. Hill

Certain transition-metal complexes are thought to exist only fleetingly, perhaps as intermediates in reactions. So the discovery of one such complex that is stable at room temperature is provocative.

During the past 40 years, few inorganic compounds have been more discussed or sought after than a curious class of transition-metal complexes. Known as late transition metal oxo (LTMO) complexes, these compounds are thought to be intermediates in all sorts of oxygen-dependent processes. For example, they could be involved in reactions promoted by copper-containing enzymes; in catalytic-converter processes; in reactions at the cathode of fuel cells; and in industrial oxidation reactions that use 'noble metal' catalysts (such as gold, platinum and silver) on solid supports. But for a long time, there was no evidence for their existence because LTMO complexes are intrinsically unstable. However, a few have recently been isolated and characterized[1–4]. The surprising stability of these compounds might be due to the ligand molecules that bind to the metal, which lower the electron density in the metal–oxygen unit.

On page 1093 of this issue, Poverenov *et al.*[5] report the first example of an LTMO complex in which the ligands are not electron-withdrawing. The complex undergoes reactions that provide insight into how the above-mentioned catalytic processes might work.

LTMO complexes are characterized by a multiple bond between the metal and oxygen atoms (Fig. 1a, overleaf); in this context, the oxygen atom is known as a terminal oxo ligand. The metal–oxygen bond is destabilized by repulsion between the bonding electrons from the oxo ligand and the '*d* electrons' on the metal. The amount of repulsion depends on the number of *d* electrons. Those transition metals on the left-hand side of the periodic table (the early transition metals, such as vanadium and tungsten) have few or no *d* electrons, so terminal oxo complexes are stable and common for these elements. The transition metals in the middle of the periodic table (such as manganese and iron) have more *d* electrons, and their terminal oxo complexes are highly reactive. The late transition metals (such as platinum, silver and gold) are found towards the right-hand side of the periodic table, and have the most *d* electrons of all; their complexes are therefore generally so reactive that, for many years, none could be isolated.

But in 1993, the first LTMO complex[1] — an iridium complex — was isolated. Iridium,