

A close-up, front-facing photograph of a white rhinoceros. The focus is on its single, large, pointed horn, which is covered in a dense, brown, fibrous texture. The rhino's face is visible on either side of the horn, showing its thick, wrinkled skin and dark eyes. The background is blurred, suggesting an outdoor setting.

SYNTHETIC BIOLOGY, PRODUCT SUBSTITUTION AND THE BATTLE AGAINST ILLEGAL WILDLIFE TRADE

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Innovation to strengthen the battle against illegal wildlife trade is being nurtured across a range of disciplines, including criminology, forensic science, economics, behavioural sciences and remote sensing. Amongst the emerging ideas are a range of proposals from the private sector to employ synthetic biology to develop substitute products, such as “horn” powder produced from synthetic keratin and rhinoceros DNA, which might match or even improve upon some of the product attributes valued by rhinoceros horn consumers in Asia (Corbyn, 2015; Nuwer, 2015). This paper examines whether disruptive marketing of such substitutes might reduce the pressure on wild populations of species under threat from illegal trade or whether the risks of perverse effects that reinforce or increase demand for the “real thing” outweigh the case for experimentation with synthetic alternatives. Weighing evidence of the opportunities and risks of such decisions in future will clearly require in-depth understanding of the dynamics of specific wildlife trade chains. There is also a clear need for policy attention to how public and private sectors might best interact in deciding when and how any releases of synthetic substitutes should proceed.

Framing the issue

Illegal trade in wild animals and plants is a persistent conservation threat for high profile animals such as elephants *Elephas maximus* and *Loxodonta africana*, Tigers *Panthera tigris* and rhinoceroses *Rhinocerotidae*, along with a wide range of others that do not usually make the news headlines: Radiated Tortoises *Astrochelys radiata*, abalone *Haliotis* spp. and Red Sanders *Pterocarpus santalinus*, to name just a few (Broad *et al.*, 2003). Negative social and economic consequences of this illicit business for communities at source include loss of resource value, conflict, governance failure and exposure to wider problems associated with organized crime (Lawson and Vines, 2014; CITES, 2013). Considerable regulatory and enforcement effort has been invested worldwide in addressing this challenge, particularly since the development in the early 1970s of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). However, demand for some wildlife commodities, especially those sought during periods of high economic growth and increasing disposable income in key consumer markets, has proven to be a formidable driving force for illegal trade (Milliken and Shaw, 2012).

Theories of product substitution

In economic terms, substitute goods are products that a consumer perceives as similar or comparable, so that obtaining more of one product makes them desire less of the other product (or vice versa). By the same principle, economic theory suggests that if the price of the first product increases, demand for the substitute will increase (referred to as a positive cross elasticity of demand). Often quoted examples are tea and coffee, and butter and margarine. The degree of perceived similarity in what is usually termed “utility” (the satisfaction received by the consumer) between the two goods dictates how perfect or imperfect the substitution may be expected to perform (Nicholson and Snyder, 2011).

To use a simplified wildlife trade example, wild-harvested and farmed crocodile skins would be viewed as

substitute goods if their perceived utility for the manufacture of luxury leather products were taken to be roughly equal. An economist might predict that an increase in price of farmed skins, for example because of a rise in farming input costs, would lead to an increase in demand for wild-harvested skins. Similarly, an increase in the price of wild-collected skins, for example owing to scarcity of supply, would lead to an increase in demand for farmed skins. In reality farmed and wild-harvested crocodile skins are not perfect substitutes, since there is a significant difference in perceived quality between these two goods (farmed skins tend to have fewer flaws and are readily and legally available), but the basic relationship described here remains valid (Macgregor, 2006).

By contrast, there are wildlife trade examples for which evidence indicates that goods that may appear at first to be substitutes are in fact rather loosely related in the market. Wild-caught salmon and farmed salmon, both destined for use as food, demonstrate rather imperfect substitution, for example, because they are nowadays perceived to have significantly different utility. Although farmed salmon was initially a close substitute for wild-caught salmon, over time parallel markets for distinct products have evolved, with changes in price for each commodity having a declining degree of impact on prices for the other (Knapp *et al.*, 2007). Similarly, the markets for natural pearls from different oyster species and from artificially cultured supplies remain rather strongly differentiated and evidence indicates that this is at least as much a result of business promotion of distinct segmented markets as it is a reflection of real differences in the intrinsic qualities of pearls from different sources (Tisdell and Poirine, 2007).

Product substitution in the wildlife trade

As availability of supply owing to resource depletion and/or regulatory restrictions has decreased for many wildlife goods in trade and as tastes and consumption trends have changed, traders and consumers have often moved to substitutes.



Fresh salmon for sale at Puerto Montt market, southern Chile.

MEREDITH KOHUT / WWF-US

These include:

- products of the same species from other source countries;
- products of the same species from captive production or artificial propagation;
- products of different wildlife species with similar utility/quality;
- products of already domesticated animal or plant species with similar utility/quality;
- products of inorganic origin with similar utility/quality (such as alternative carving materials used instead of ivory);
- products of synthetic origin with similar utility/quality.

In many cases the shift towards substitutes has arisen through business innovation within the trade chain. The move towards alternative supply countries or similar species has been a common reaction to regulatory restrictions on original supply. Shifts to captive production have also often been triggered by regulation of wild-sourced supply, but have also been driven by basic business imperatives such as improved quality, lower production costs and risk management benefits of vertical supply chain integration. However, there are also cases in which strategic intervention from regulators or NGOs has taken place to encourage use of substitute supply in the hope that pressure of over-harvest on wild populations would reduce.

A regulatory example is the mechanism adopted through CITES that facilitates trade in captive-bred or artificially propagated specimens of wildlife species for which trade in wild-sourced specimens is subject to greater restriction. This has played a significant role in the shift towards “farmed” sourcing of crocodile skins, live parrots, orchids and a wide range of other wildlife goods. Similarly, national government law and policy in some countries—China’s being the most notable—has encouraged other shifts to commercial ex-situ wildlife production of bears, musk deer and other species.

Non-regulatory examples of strategic substitution efforts are less common. Perhaps the most notable examples relate to efforts during the late 1980s and early 1990s aimed to reduce poaching of African and Asian rhinoceroses. Saiga

Antelope *Saiga tatarica* horn was promoted as a substitute for rhinoceros horn use in traditional medicines and a variety of alternative raw materials (including domesticated Water Buffalo *Bubalus bubalis* horn and inorganic substances) were promoted for the manufacture of carved ceremonial dagger handles in Yemen, a market that had previously been a primary driver of illegal rhinoceros horn trade for the same purpose. However, in neither of these cases is it clear that substitution played a pivotal role in the eventual decline of these markets (Milliken, 2014).

Challenges of strategic substitution

Strategic substitution of a wildlife product, as considered in this paper, is an active intervention aimed to shift demand away from an original source of supply that is of conservation concern owing to over-harvesting for trade. In order to have a significant conservation impact, such a substitution needs to be accepted by the market and the level of that acceptance needs to be sufficient to change the economic incentives driving harvest from the original source.

On the question of acceptance, substitution theory hinges on the concept of utility, but this is by no means a straightforward matter to judge or measure, since there are two inter-related forces at play. First, for a specific end use, is the substitute product physically and/or functionally similar enough to serve the desired purpose? Second, will consumers perceive the substitute to be as satisfying, or at least acceptable enough, to sway their choice? The first of these forces should be objectively verifiable, but the latter is a more complex construct of personal attitudes, values and habits, along with social norms and other external influences. Confounding judgements of both of these forces is the fact that wildlife products in trade often have multiple end uses and for some of those uses, even functionality (such as medicinal efficacy or aesthetic appearance) is very hard to measure.

Even if a substitute is accepted, there remains the question of whether the desirability of the original supply will be sufficiently reduced to relieve the conservation threat it was suffering. The most obvious manifestation of this, assuming rational decision-making by those involved, will be reduced demand for the original goods leading to a reduced price, which in turn reduces the incentive to harvest. How much impact this will have depends on the responsiveness of harvesters to price changes, which economists refer to as the price elasticity of supply. In some cases, a 10% reduction in price might lead harvesters to move on to other more lucrative activities. In other cases, even a 50% reduction in price may still leave continued use of the original supply the most lucrative activity for harvesters, because they lack better alternatives.

The rise of synthetic wildlife substitutes

Laboratory production of biological products that serve to substitute for or enhance goods derived from wild animals and plants is not a new concept. Laboratory-produced orchid hybrids have long served as an alternative to naturally-occurring “species” orchids for collectors (Arditti and Krikorian, 1996). Production of chemically synthesized ursodeoxycholic acid (UDCA)—the active ingredient in bear bile used for medicine in Asia—began in the 1950s and had strong acceptance in medicinal use by the 1990s (Boatright *et al.*, 2009). Plant stem cell culture similarly became an important development in the manufacture of cosmetics in the 1990s, with strong connections to the use of wild plants in many of the same products (Barbulova *et al.*, 2014).



MARTIN HARVEY / WWF

Salt-water Crocodiles *Crocodylus porosus* being skinned for their leather and meat at a crocodile farm, Darwin, Northern Territory, Australia.

Over the past 10–15 years, rapid developments in the field of synthetic biology have raised the possibility of a new form of wildlife product substitution: laboratory production of complex biological systems that replicate or even enhance the form and function of the natural substance. Advances in the sequencing (reading) and fabrication (writing) of DNA, and reductions in cost as technologies improve are making the manufacture of synthetic wildlife product substitutes increasingly feasible. And this possibility is now attracting significant private sector interest; with a handful of innovative companies now entering this field and looking to prove the concept that synthetic wildlife products could replace those derived from endangered wildlife species and thereby help reduce the pressure of poaching and illegal trade.

The opportunities and risks of trading synthetic rhinoceros horn – a case example

RHINOCEROS CONSERVATION AND TRADE

Products from Asian and African rhinoceros species, particularly horns, have long been valued in trade and this demand has played a critical role in driving rhinoceros poaching over the past 50 years. This has caused significant declines or even extinctions for some rhinoceros species or subspecies and constrained population growth for other rhinoceros species that were recovering from critically low levels caused by unregulated 19th and early 20th century sport hunting and trade. Today the vast majority of wild rhinoceroses inhabit just a few countries, in Africa: South Africa, Namibia, Zimbabwe and Kenya; and in Asia: India and Nepal (Milliken, 2014).

During the 1970s and 1980s there were two principle markets driving the rhinoceros horn trade: the production of traditional Asian medicine (TAM) in China, Japan, South Korea and Taiwan on the one hand; and dagger handle carving in Yemen on the other. The policy response through CITES and national laws was prohibition of international trade and increasing pressure on individual countries similarly to ban domestic trade in their national markets. By the mid-1990s all key markets had been suppressed through regulatory action, encouragement of use of substitutes for medicines and carving, and strategic interventions with TAM practitioners to gain their support in avoiding use of rhinoceros horn in medicines. As a result, illegal trade and poaching levels in Africa declined drastically and there was a protracted period of recovery of rhinoceros populations that lasted into the mid-2000s (Milliken, 2014).

This period of relative calm in the global rhinoceros horn trade (though poaching levels in South-east Asia sadly continued unabated), was shattered from 2008 onwards when a largely new illegal market for rhinoceros horn emerged in Viet Nam and began to play a central role in driving increased poaching, particularly in South Africa (Milliken, 2014). The international response through CITES policy, anti-poaching, anti-trafficking and demand reduction measures has been stepped up, but as of 2015, poaching in Africa shows no substantial sign of abating.

UNDERSTANDING THE RHINOCEROS HORN MARKET TODAY

Although there has been a long history of rhinoceros horn use in Viet Nam in traditional medicine, TRAFFIC research indicates that the recent increase in demand arises from aggressive marketing of a range of novel uses: as a medicinal cancer treatment apparently triggered by urban myth about

► **Rhinoceros horn cut into smaller pieces to be sold by weight for use by a traditional medicine practitioner, Hanoi, Viet Nam.**



ROBERT PATTERSON / WWF

▼ **Rhinoceros horn dagger handle, Yemen.**



HARTMUT JUNGIUS / WWF

miracle cures; as an expensive detoxicant, including as a hangover cure, associated with overt display of wealth; and as a gift used to curry favour among the elite (Milliken and Shaw, 2012). Other novel uses appear to have been promoted as illegal traders seek new channels for sales. There are indications that these largely non-traditional forms of use are penetrating other markets too, with particular concerns being raised about status-driven consumption of durable collectable goods in China (Milliken, 2014).

A notable and important characteristic of the current rhinoceros horn market in Viet Nam is the presence of a significant proportion of fake goods, commonly derived from buffalo horns. There is therefore already a strong sensitivity to proving authenticity in this trade (Milliken and Shaw, 2012).

Owing to the underground and criminalized nature of today's rhinoceros horn trade, it is difficult to gain up-to-date insights into key market variables, such as trends in the amount of horn being traded into specific end uses or the changes over time in prices paid at key points along the supply chain. Nevertheless, it is known that prices paid at source and in end markets are extraordinarily high. Poachers may earn what would in other occupations locally be many years' salary from involvement in a single operation. Retail prices in Asia have been reported at multiple times the price of gold (Biggs *et al.*, 2013).

At the supply end, such high prices are apparently sufficient to sustain extreme efforts by poachers to overcome the strong protection and enforcement measures introduced by private and public institutions. How much those prices would need to decrease for these motivations to reduce to a level at which pressure on rhinoceros populations is significantly reduced remains unknown.

For the demand side, there is an added concern that the preponderance of luxury end uses may be placing rhinoceros horn as what has been termed a "Veblen Good", for which demand increases as price increases, in apparent contradiction of the normal law of demand, which would predict decreasing demand as price increases. For such goods, high price and its symbolism of exclusivity and social status becomes the overriding element of their utility (Leibenstein, 1950).

Approach	Success factors	Advantages	Disadvantages
1) Overt alternative	<p>i) Consumers must perceive the synthetic substitute products are at least as effective/desirable as those from natural horn (and perhaps that they have additional advantages, such as clean laboratory production)</p> <p>ii) The price of synthetic products must be significantly lower than the price of those from natural horn (and consumers would have to prove to be most motivated by qualities of the product other than how expensive it is)</p> <p>iii) There would need to be a range of synthetic products to supply all of the most important market segments</p>	<p>+ The current market in Viet Nam appears to be “fashion” driven, so new products backed by a convincing marketing pitch might catch on</p> <p>+ The products would be identified as synthetic, so would not fall foul of wildlife trade legislation</p> <p>+ Sale of differentiated substitutes does not contradict current policy on demand contraction for natural horn</p> <p>+ Current product manufacturers or consumers using natural horn might be persuaded to adopt the synthetic substitute on cost grounds</p>	<p>- Product segmentation is complicated and changing, so there is a risk of simply creating a parallel market</p> <p>- Costs of production and marketing of multiple products may challenge the need to keep the price of the substitute products low</p> <p>- Messaging about product benefits may serve to reinforce acceptability of natural horn</p> <p>- Introduction of additional novel products may perversely attract more consumers looking for the “real thing”</p>
2) Covert imitation	<p>i) Traders must be unable to distinguish synthetic whole horns from natural horns</p> <p>ii) After infiltration of synthetic horn into the trade chain, consumers must become convinced that they are likely to be buying an inferior alternative, such that the prices they are willing to pay for any horn reduce significantly</p> <p>iii) Traders must fail to come up with a system to guarantee provenance/quality of natural horns</p>	<p>+ Only one synthetic product is needed – an unprocessed horn</p> <p>+ There is no need to gain in depth understanding of end market segmentation as this approach is focused on the supply of raw material</p> <p>+ Costs of “marketing” the news about the inferior alternative will be much lower than those for marketing multiple end products</p>	<p>- Traders may quickly work out how to differentiate natural horn from synthetic imitations in the trade chain, as they do already with fake horn, and protect the high price of the “real thing”</p> <p>- Legal issues may arise at the point of insertion into the trade chain</p> <p>- This approach would initially contradict current policy aimed at demand contraction for natural horn</p> <p>- Economic theory is untested in this context – it is not clear how much more inferior the alternative should be perceived to be for the price of natural horn to be significantly undermined</p> <p>- Enforcement and judicial action may be undermined by uncertainty about the identity (synthetic vs natural) of horns in trade; any use of chemical or genetic “markers” to aid enforcers could also be accessed by traders through laboratory testing</p>

Table 1. Comparison of theories of change for introducing synthetic rhinoceros horn to the market.

WHAT IS THE SYNTHETIC RHINOCEROS HORN OPTION?

A number of private sector initiatives have come to light over the past year or so that propose the production of synthetic rhinoceros horn as a substitute for that sourced from the wild (“natural horn”) in order to help relieve pressure on rhinoceros populations caused by trade demand. Although there are differences between approaches being developed by the different companies involved, they have in common the aim to produce through synthetic biology a powder that shares key biological and chemical characteristics with natural horn (Corbyn, 2015). Some companies have made additional claims that they aim to use 3D printing technology to produce solid synthetic “horns” that are physically indistinguishable from natural horns.

None of the companies involved has made public any precise plan for introducing synthetic horn to the market, but media reports and direct correspondence between TRAFFIC and company representatives, indicates that a variety of options are under consideration. These range from covertly injecting synthetic horn into the supply line in source countries as part of a plan to undermine the market price for natural horn, through to demand-side release of products that either purport falsely to contain natural horn or are marketed as containing synthetic horn with claims that it is somehow “better than the real thing”. Companies have engaged consumer research support in Viet Nam and advice on supply-side issues from academics. However, to date there does not seem to have been any commercial release of synthetic horn into the trade chain.

LEE SIOW LING / TRAFFIC



Vials of bear bile products in Malaysia, sold in packaged boxes originating from Jilin, China.

ANALYSIS OF VIABILITY

Without clear-cut proposals about how synthetic horn might be introduced to the trade chain, what impact is envisaged and what the theory of change might be for achievement of such impact, it is difficult to provide a definitive assessment of opportunities and risks. Therefore, at this stage a set of relevant issues are examined from a theoretical standpoint.

Amidst the various reports of the intentions of different companies expressing interest in this business, there appear to be two basic theories of change for introduction of synthetic horn into the market:

- 1) ***To supply an alternative “rhinoceros horn” raw material and/or consumer products identified overtly as being of synthetic origin but promoted as being of at least equal and maybe better utility as natural horn.*** It is hypothesized that if the synthetic substitute is sold at a cheaper price than natural horn, the price paid for natural horn will also decrease and that incentives for illegal supply will decline as a result. Proponents apparently believe that rhinoceros horn goods are subject to the normal rule of demand and that consumers are not attracted primarily by exclusivity and high price.
- 2) ***To supply synthetic imitations of “real” horns covertly into the trade chain of natural horn, with the objective of letting it be known after some time that an inferior substitute has infiltrated the market in order to undermine market confidence that it can discern the real thing.*** It is hypothesized that a consequent reduction in price will occur as traders and consumers are only willing to accept a value based on the worst case that they are obtaining synthetic, not natural horn. Proponents refer to a theory known as “Gresham’s Law”, often stated as “bad money drives out good”, which applies when the “true” value of something is markedly different from the value people accept because they are unable to discern good from bad quality in the marketplace (Phlips, 1983).

Clearly there is a tension between these two approaches since the former requires consumer confidence that the substitute is at least as good as natural horn, while the latter requires consumers to view the infiltration of a synthetic alternative to be significantly less good than natural horn.

Table 1 summarizes the likely success factors for each approach and notes key advantages/disadvantages of each. Of the two approaches examined, the “covert imitation”

option appears to pose the biggest risk of failure. Aside from the challenges of gaining market entry to a business highly sensitized to fakes and imitations, this approach hinges on application of economic theory that is not tested in this field and could seriously undermine, rather than complement, current regulatory efforts.

By contrast the “overt alternative” approach hinges on much simpler and well-tested economic and marketing theories. However, its success would require a market entry approach that targets multiple product segments and succeeds in convincing consumers that it really is at least as “good as the real thing”. There is a risk that consumer acceptance could be nil or much lower than expected. Although market research in Viet Nam reportedly indicates that some potential consumers claimed a willingness to choose synthetic over natural horn products (Corbyn, 2015), this might not prove to be an accurate prediction of actual consumer behaviour. Experience from other wildlife trade chains in Asia, such as those for bear bile and ginseng medicines, has revealed strong consumer preference for wild-sourced over farmed ingredients (Dutton *et al.*, 2011; Hankins, 2009). A similar preference for natural over synthetic horn could prevail.

Even if the synthetic product gains a significant degree of consumer acceptance, there is a risk that it will be viewed as a distinct alternative commodity, rather than as a substitute. If there were such a high degree of imperfection in the relationship between products of synthetic and natural horn, the lower price of the former may have no impact on demand for the latter and there would be no reason to believe illegal trade and poaching levels would reduce. Arguably, an increasingly visible trade in the synthetic product, if not accepted as a high quality substitute, could even encourage even more consumers to “seek the best” and lead to increasing demand for natural horn.

A variation on the overt alternative approach would be to take a different view of demand dynamics and test the possibility that consumers are actually valuing rhinoceros horn as a Veblen Good. An overt synthetic alternative could be pitched as even better than the real thing for an even higher price. If it were true that a primary motivation for consumers was exclusivity and high price, rather than any distinct utility of natural horn, this could lead to a reduction in demand for natural horn. However, pitching an alternative as superior would be a tough marketing challenge and even if successful the reduction in price for natural horn might not be sufficient to reduce incentives for poaching—layers of segmented products are not uncommon in other luxury markets, such as those for high-end watches or vehicles.

SOME TENTATIVE CONCLUSIONS

The potential approaches for use of synthetic rhinoceros horn outlined here do not provide simple, predictable means to strengthen efforts to undermine demand for natural horn that is driving current high poaching levels in Africa. Nevertheless, with current efforts to reduce poaching, trafficking and consumer demand struggling to have a significant impact, it would be rash to rule out the possibility that trade in synthetic rhinoceros horn could play a role in future conservation strategies.

This initial analysis points to some important questions that need to be addressed in judging the likely viability and impact of any approach to the use of synthetic rhinoceros horn as a strategic intervention to undermine trade in natural rhinoceros horn:

Viability:

- Are production costs of synthetic horn low enough and production volumes high enough for deployment in such market interventions?
- Are there any legal obstacles to the release of synthetic horn into the supply chain?
- Will the synthetic product be accepted by traders and/or consumers at the point of insertion into the trade chain (whether as an imitation or an alternative)?
- Will any financial benefits from the trade in synthetic horn be used to increase incentives for in situ rhinoceros conservation?
- Will the criminals who currently control illegal trade develop ways to undermine the acceptance of synthetic horn?

Impact:

- Will the market react as predicted by the economic theory behind any intervention taken?
- Will the price of natural horn be depressed to a point where incentives for poaching and illegal trade are significantly decreased?

Although it does not appear that any synthetic horn has yet been released commercially into the trade chain, it is quite likely that this will happen before long, since a number of companies are competing to get ahead of the pack with this initiative. Unlike most other conservation interventions aimed to address the rhinoceros horn trade challenge, there is no government or inter-governmental institution with a clear mandate to decide whether synthetic horn should be released. An overt alternative product sold in Viet Nam may have to satisfy local regulation of medicine, cosmetic or food market business, but this is likely to address only human health risks. A covert infiltration of horn at the supply side would by its very nature likely be carried out without government approval. As such, the decision to release synthetic horn lies largely with the individual companies involved. Yet the impact on wider efforts to address this challenge could be profound.

The future of synthetic substitutes in wildlife trade

There is little doubt that the rapidly evolving field of synthetic biology is going to make production of substitute wildlife products an increasingly affordable and accessible option for conservation planning and business development in the future. As in the case of the not-unrelated subject of GMO use in agriculture, there are important opportunities for benefit, but also significant risks. Decision making about synthetic wildlife product release into the market at this point lies with individual companies and there is a high probability that such decisions will be taken on the basis of inadequate understanding of the dynamics of wildlife trade chains and the nature of existing interventions being taken to address unsustainable and illegal trade. Looking ahead, there needs to be strong consideration of how well-informed decisions might best be made about such releases in future that increase the likelihood of positive impact. Future work should include:

- Research on specific wildlife trade chains aimed to improve understanding of supply and demand dynamics, in particular on the likely impact of price changes on incentives for illegal activity and on the factors influencing consumer choice;
- Cross-referencing with research and experience on substitution and synthetics in other commodity trade, for example the significant body on economic impacts of synthetic diamond production and trade;

- Development of collaborative approaches by governments and businesses on assessment of opportunities and risk, and on policy mechanisms that might shape decisions about strategic release of synthetic wildlife products;
- Assessment of market and conservation impacts of any strategic synthetic product releases.

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