AN ABSTRACT OF THE THESIS OF

Michael R. Naffziger for the degree of Master of Science in Chemistry presented on July 7, 2010.

Title: Aryl Acetylene Substituent Effects: The Synthesis and Application of Biaryls

Abstract Approved:

________________________________________________________________________

Rich G. Carter

The work described herein details the synthesis and application of biphenyls that probe the effects of hydrogen, Cl / Br, and methyl substituents on the aryl ring of the terminal acetylenic carbon. From this work, we successfully developed the rapid synthesis of phenyl acetylenes in 3-4 steps from inexpensive commercially available materials. Using these mild conditions, a wide host of functionalized acetylenes has been easily achieved, avoiding complex and or difficult synthetic transformations.

With the functionalized acetylenes in hand, we demonstrated that the subtle change from hydrogen to either methyl or halogen imparts diverse results when subjected to [4+2] or [3+2] cycloadditions. This knowledge has helped to explain other unexplained observations from previous work within this project. These biphenyls were then further investigated by performing various synthetically useful functional group transformations and comparing
the differences the substituents have on the corresponding reaction. Noteworthy is the total synthesis of siamenol, a carbazole isolated from the bark of *Murriaya siamensis*, where the key carbazole forming step is effected by the substituents about the molecule in the synthesis of siamenol derivatives.
Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

by
Michael R. Naffziger

A THESIS

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________________________________________________________________________

Major Professor, representing Chemistry

________________________________________________________________________

Chair of the Department of Chemistry

________________________________________________________________________

Dean of the Graduate School

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Michael R. Naffziger, Author
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LIST OF ABBREVIATIONS

Bn.................................................benzyl
brsm .............................................based on recovered starting material
Bu.................................................butyl
COSY ...........................................correlation spectroscopy
Cy.................................................cyclohexyl
DABCO ........................................diazabicyclo[2.2.2]octane
DIBAL-H .......................................diisobutylaluminium hydride
DMF .............................................dimethylformamide
DMPU...........................................N, N’-dimethylpropyleneurea
E...................................................entgegen
KHMDS ........................................potassium hexamethyldisilazide
LDA ..............................................lithium diisopropylamide
LiHMDS.........................................lithium hexamethyldisilazide
Me ................................................methyl
MeCN...........................................acetonitrile
mg ..............................................milligram
Min .............................................minute
MWI..............................................microwave irradiation
n-................................................normal
NaHMDS........................................sodium hexamethyldisilazide
NMP ............................................N-methylpyrrolidinone
NMR.............................................nuclear magnetic resonance
o-................................................ortho
Ph..............................................phenyl
PhMe...........................................toluene
psi.................................................pounds square inch

$p$-TSA...........................................para-toluenesulfonic acid

r.t...............................................room temperature

$t$-...................................................tertiary

TBAF ............................................tetrabutylammonium fluoride

TBS ..............................................tert-butyldimethylsilyl

tert-...............................................tertiary

THF ..............................................tetrahydrofuran

Tf..................................................triflate

TMEDA...........................................$N$, $N$, $N'$, $N'$-tetramethylethylenediamine

TMS............................................trimethylsilyl

TMSCl ...........................................trimethylsilyl chloride

W..................................................watt

Z...................................................zusammen
Chapter 1

Introduction
1.1 Importance of Biaryls

The construction of biaryls is an important transformation in pharmaceuticals,\textsuperscript{1} asymmetric catalysis,\textsuperscript{2} and organic materials.\textsuperscript{3} Strategies to construct such motifs focus around the coupling of suitable precursors via transition metal catalysis.\textsuperscript{4} Though these methods offer a variety of mild conditions and potentially high yielding reactions, there are limitations in the choice of requisite coupling partners, such as functional group compatibility,\textsuperscript{5} high cost and/or availability,\textsuperscript{6} and steric requirements.\textsuperscript{7} To bypass these shortcomings, we developed and utilized a cycloaddition-focused route to achieve densely functionalized biaryls.\textsuperscript{8} This method features simple access to highly substituted biaryls via aryl acetylenes, which originate from inexpensive and widely available starting materials.\textsuperscript{9} Ultimately, these biaryls can be used as a template for further synthetic transformations, Scheme 1.1

![Scheme 1.1 Highly Substituted Biaryls via [4+2] Cycloadditions](image)

1.2 Diels-Alder Approach to Biaryls

Our initial investigations focused on the utility of these biphenyls as synthetic templates. These templates could then be differentially functionalized to furnish highly complex motifs that would be difficult to achieve
via other modern synthetic methods.\textsuperscript{5} From these studies, a relationship between the substituent about the aryl ring and on the acetylene was noticed. A series of acetylenes were synthesized to serve as useful substrates to probe the reactivity in cycloadditions. With an extensive exploration with [4+2] cycloadditions, these acetylenes will also be utilized in [3+2] cycloadditions to compare their reactivity’s to the [4+2] cycloaddition reactions as well as regioisomer product ratios, Scheme 1.2.

![Scheme 1.2 Proposed Investigation of [3+2] and [4+2] Cycloadditions with Differently Substituted Phenyl Acetylenes](image)

### 1.3 Substituent Effects

Previous work from the Carter group has mostly been focused about the substituent on the terminal acetylene carbon.\textsuperscript{8} The substituents (\textit{i.e.} phosphonates, esters, amides, stananes, and tertiary alcohols) were chosen for their synthetic utility instead of their importance to cycloaddition reactivity. Though the previous studies are important to the understanding of these systems, little information was garnered as to the reactivity difference between these groups. To construct a direct comparison between the substituents about our phenyl acetylenes, my study focused on the effects hydrogen, methyl and halogens played on the acetylene, as well as the difference
between an electron withdrawing halogen, versus electron rich methyl group about the aromatic ring, Scheme 1.3.

\[
\begin{align*}
\text{Scheme 1.3 Scope of [3+2] and [4+2] Phenyl Acetylene Cycloadditions}
\end{align*}
\]

1.4 Summary

The work described within will highlight the differences between the substituents about the aryl ring and on the terminal acetylenic carbon within [4+2] and [3+2] cycloaddition reaction. With the cycloadducts in hand, further investigation concerning the different substituents effect on subsequent functionalization will also be investigated. Though the effects of the different substituents will be compared, detailed mechanistic / kinetic analysis falls outside the scope of this thesis. Hence, the conducted studies only serve to explain the reactivity difference of the selected substituents.
1.5 References


2. (a) McCarthy, M.; Guiry, P. J. Tetrahedron, 2001, 57, 3809-44. (b)...


Chapter 2

Synthesis of Aryl Acetylenes
2.1 Synthesis of o-nitrobenzaldehydes

From previous studies with functionalized acetylenes, our group has investigated the synthesis and synthetic utility of acetylenic phosphine oxides, esters, amides, tertiary propargylic alcohols, and stananes, compared to the terminal, unsubstituted, phenyl acetylene (Figure 2.1) where the majority of the acetylenes possess an electron-withdrawing group. It was believed that the electron-withdrawing acetylenic substituents would polarize the acetylene and become a better dienophile. In keeping with this trend, the investigation of acetylenic halides would also demonstrate similar electron-withdrawing properties to previous examples, as well as lower the steric hindrance about the reaction center. Conversely, with the majority of the work centered about electron withdrawing substituents on the acetylenic carbon, the use of methyl acetylenes was also desired. Though work has been published on cycloaddition reactions with propargylic tertiary alcohols, there was still little known about the utilization of a slight electron donating substituent, with minimal steric hindrance, within these cycloaddition reactions.

![Figure 2.1 Representative Acetylenes in the Diels-Alder Approach to Biaryls](image-url)
The synthesis of the aryl acetylenes start from commercially available chlorinated o-nitrotoluenes. Conversion of the toluenes **2.9** and **2.10** to the corresponding benzaldehyde (Scheme 2.1) was accomplished via a homologation / oxidative route developed by Pfizer. Commercially available benzoic acid **2.15** could also be converted to benzaldehyde **2.13** via a two-step methyl esterification / reduction sequence.

![Scheme 2.1 Synthesis of o-nitrobenzaldehydes](image)

### 2.2 Synthesis of Terminal Acetylenes

With the desired benzaldehydes in hand, we investigated several methods to generate phenyl acetylenes in a rapid and reproducible fashion. Of the methods tried, Corey-Fuchs, Colvin, and Ohira-Bestmann, the utilization of diazophosphonate reagent, **2.16**, provided the best compatibility towards our desired product.

**2.2.1 Ohira-Bestmann Protocol**

Based on the pioneering work from Gilbert and Seyferth, Ohira greatly enhanced the synthetic ability of a phosphonium anion addition to an aldehyde to generate acetylenes. Treating the chlorinated o-nitrobenzaldehydes **2.12** – **2.14** with diazophosphonate **2.16** (Scheme 2.2) the terminal acetylenes **2.17** – **2.19** were furnished in excellent yields. This reaction could be scaled up to
5-gram reactions when quenched with pH 7 buffer, instead of NaHCO$_3$ (aq.), and concentrated in vacuo.

\[
\begin{align*}
\text{Scheme 2.2 Ohira-Bestmann Synthesis of o-nitrophenylacetylenes}
\end{align*}
\]

2.2.2 Corey-Fuchs Protocol

As an alternative to the Ohira-Bestman protocol, we explored several conditions to furnish the phenyl acetylene without the need for the diazo phosphonate. Initially, traditional Corey-Fuchs protocols generated in excellent yields gem-dibromides 2.22 and 2.23 (Scheme 2.3), however, upon elimination to the acetylene with alkyl lithium bases only decomposition products were observed. This could be explained by comparing the propensity of an alkyl lithium’s ability to undergo facile lithium / halogen exchange, or nucleophilic aryl substitution / elimination with electron deficient aryl starting material. When employing Colvin conditions to the o-nitrobenzaldehydes, the addition of lithiated TMS-diazomethane unfortunately provided only unidentifiable decomposition products.
2.3 Synthesis of Chloro and Bromo Acetylenes

Though utilization of the *gem*-dibromide, from the Corey-Fuchs method, was not suitable to furnish terminal acetylenes, it was found to be a desirable route to yield halogenated acetylenes. The benzaldehydes 2.12 or 2.24 (Scheme 2.4) were treated at room temperature with either CBr$_4$ or CCl$_4$, and PPh$_3$ to give the corresponding *gem*-dihalides in excellent yields. To convert the olefin to the desired alkyne, several bases and co-solvents were investigated. When lithium bases (*e.g.* n-BuLi, t-BuLi, LiHMDS) were used with and without an anti-chelation co-solvent (*e.g.* DMF, NMP, DMPU, TMEDA) large amounts of decomposition were observed. Potassium bases (KHMDS) gave an inseparable mixture of terminal and halo-acetylenes. Interestingly, the usage of NaHMDS proved vital in this transformation with one equivalent of NaHMDS. The desired halo-acetylenes 2.28 – 2.30 were easily isolated in excellent yield.
Scheme 2.4 Synthesis of Haloacetylenes via $\text{gem}$-dihalide

2.4 Synthesis of Methyl Acetylenes

Initial attempts in the synthesis of methyl acetylenes followed in house conditions for the synthesis of acetylenic phosphine oxides, esters, amides, tertiary alcohols, and stannanes 2.2 – 2.6 (Scheme 2.5). These conditions employed formation of the lithium acetylide, followed by electrophilic quenching with MeI. Unfortunately these conditions resulted in irreproducible yields and required lengthy purification schemes. Interestingly, the desired methyl acetylenes can be derived from the homobenzaldehydes 2.32 and 2.33 isolated from the Pfizer oxidation (Scheme 2.5). After initial attack of the phosphonium anion, and elimination of nitrogen, the resulting homophenylacetylene can undergo a base catalyzed rearrangement, resulting in clean formation of methylacetylenes 2.31 and 2.34. These mild conditions represent a new novel route to synthesize o-nitrophenylpropynes that contain sensitive electrophilic functional groups that are not easily generated from standard nucleophilic alkylation conditions.
2.5 Acetylene Synthesis via Enol Triflate Elimination

In an effort to furnish large amounts of acetylene 2.17, a more scalable alternative to the diazophosonate chemistry was required. The Ohira-Bestmann route also did not reflect the elegant simplicity desired since the terminal acetylene carbon, initially installed via enamine formation, was oxidatively cleaved and reinstalled via Ohira’s diazophosphonate. These concerns were addressed through an elimination strategy centered about the enamine (Scheme 2.6). After hydrolysis of the enamine, phenyl acetaldehyde 2.32 was converted into enol triflate 2.35 with a near stoichiometric ratio of NaHMDS and PhNTf$_2$. With the enol triflate in hand, subsequent elimination with *in situ* generated t-BuONa / t-BuOH gave desired terminal acetylene 2.17 in good yields on 100-gram scale. Though the step count from toluene to acetylene did not improve, the overall step count is lowered since the time intensive synthesis of diazophosphonate 2.18 is avoided.
Scheme 2.6 Synthesis of Acetylene 2.17 via Enol Triflate Elimination

2.6 Summary

Having established reliable and reproducible routes to a set of acetylenes that bear a halo and o-nitro functionality, further investigations concerning [4+2] and [3+2] cycloadditions were carried out. Each of these routes demonstrate simple synthetic transformations, from inexpensive commercially available starting materials, to yield highly functionalized materials not easily obtained from typical synthetic transformations.
2.7 References


Aryl Acetylene Substituent Effects:  
The Synthesis and Application of Biaryls

Chapter 3

Utilization of [4+2] Cycloaddition to Construct Biaryls
3.1 Synthesis of Dienes

With terminal acetylenes in hand, focus was turned to the synthesis of simple, electron rich dienes that could undergo [4+2] cycloaddition readily. Initially, we employed acyclic dienes due to their commercial availability, e.g. the TBS variant of Danishefsky’s diene, or after two synthetic steps, as with Brassard’s diene\(^1\) 3.3 (Scheme 3.1). Over time, our focus shifted towards the utilization of cyclic 1,3-dienes\(^2\) due to their ease of preparation, synthetic utility, and possible mechanistic interest.\(^3\) Diene 3.6 could be obtained after simple acid catalyzed enone formation, 3.5, followed by treatment with LDA and TMSCl to give the desired 1,3-diene. With the spurious commercial availability of diene 3.9, Birch reduction\(^4\) of anisole 3.7, and rhodium catalyzed isomerization gave a 1:3 ratio of dienes 3.8 and 3.9 respectfully. Though this diene was used as a mixture, only diene 3.9 reacted to give the desired products.\(^5\) Interestingly, morpholino diene 3.11\(^6\) is furnished after refluxing in PhMe to give only the thermodynamic product in 87%.
3.2 Application of Acyclic Dienes

Initially, the acetylenes were not considered as potent dienophiles since the nitro group is not in complete conjugation with the aryl ring.\(^5\)\(^,\)\(^7\) Treating terminal acetylenes 2.19 – 2.21 with acyclic Brassard’s diene\(^1\) 3.3 (Scheme 3.2) gave the desired biphenyl after a 2-step-1-pot [4+2] cycloaddition / elimination pathway in decent yields. Originally, the aromatization of the southern ring commenced with the addition of TBAF, however, low yields (ca. 40%) hindered these conditions as a viable route to these biphenyls. After subsequent trails with different bases, DABCO was observed to be the best choice. Though the exact elimination / aromatization role DABCO performs is not completely known, it is plausible that it facilitates cleavage of the siloxy, TMS-O, bond on the ketal. Upon cleavage, a dieneone is generated after ipso-elimination of methoxide. After proton transfer on the dieneone, the ortho-phenol is furnished, 3.12 – 3.14.
**Scheme 3.2 Scope of Acyclic Brassard’s Diene**

The TBS-analog of Danishefsky’s diene 3.3, also worked well to generate biphenyls 3.12 – 3.14 with a para-hydroxy substituent to the biphenyl bond (Scheme 3.3). As opposed to the DABCO sponsored elimination / aromatization with cycloadducts from Brassard’s diene, the Danishefsky cycloadducts observed good transformations when TBAF was utilized. Also, in contrast to Brassard’s diene, the TBS-analog of Danishefsky’s diene demonstrated greater thermal stability resulting in increased reaction temperatures, and higher overall yields.

**Scheme 3.3 Scope of Acyclic TBS-Danishefsky’s Diene**

3.3 Application of Cyclic Dienes
Though utilization of acyclic dienes initially provided access to biphenyls, they proved difficult to purify the biphenyl due to the excess diene hydrolyzing and decomposing during the reaction or work-up. This setback was sidestepped by the utilization of cyclic dienes. Undergoing a proposed Alder-Rickert pathway, Table 1, after the [4+2] cycloaddition, the [2.2.2] bicycle collapsed via retro [4+2] cycloreversion to extrude ethylene. These cycloadditions proved to be easier to purify as well as provide increased yields of the desired biphenyl.

Table 3.1 [4+2] Cycloaddition / Retro [4+2] Cycloaddition Synthesis of Biphenyls

<table>
<thead>
<tr>
<th>Acetylene</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>R</th>
<th>R'</th>
<th>Yield* (Biphenyl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.19</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>Allyl</td>
<td>90% (3.19)</td>
</tr>
<tr>
<td>2.20</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>Allyl</td>
<td>82% (3.20)</td>
</tr>
<tr>
<td>2.21</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>Allyl</td>
<td>78% (3.21)</td>
</tr>
<tr>
<td>2.19</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>OMe</td>
<td>Benzyl</td>
<td>63% (3.22)</td>
</tr>
<tr>
<td>2.20</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>OMe</td>
<td>Benzyl</td>
<td>71% (3.23)</td>
</tr>
<tr>
<td>2.21</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>OMe</td>
<td>Benzyl</td>
<td>67% (3.24)</td>
</tr>
</tbody>
</table>

*Yields reported over two steps

Having investigated the scope of terminal acetylenes with various electron rich dienes, focus was turned to the reactivities of the methyl acetylenes. Subjecting methyl acetylene 2.31 to the same reaction conditions in Table 3.1, gave only trace amounts of desired biphenyl. Only under extended reaction times, or increased temperatures did these alkyl acetylenes provide isolable amounts of the desired biphenyl. Along with the low yield, the [4+2]
cycloadditions with acetylene 2.31 proved difficult to purify, due to the cyclic diene’s decomposition products in the form of redox products. Submitting the starting acetylene, MeO-diene, and desired biphenyl separately to the same reaction conditions proved this speculation. After 12 h at 140°C, the starting methyl acetylene and desired biphenyl show negligible amounts of decomposition, however, the diene (being a ca. 2:1 mix of the 1,3- and 1,4-methoxycyclohexadiene) showed significant amounts of anisole and cyclic-aliphatic signals in the crude NMR of the reaction mix. Monitoring the reaction via NMR, confirmed the propensity of diene redox products versus [4+2] cycloaddition. Even though the NMR tube was incapable of stirring the sample, the reaction’s ¹H-NMR, and COSY spectra were much cleaner than when the reaction was preformed on the bench top. This suggested that this reaction is light sensitive since the NMR’s sample coils are in the dark. The reaction was repeated on the bench top, with the exclusion of light. Comparing the crude NMR spectra of the reactions preformed with ambient light versus in the dark, light was confirmed to encourage a decomposition pathway. The light could affect the reactivity by either promoting the diene’s instability at high temperatures, or causing the reaction to undergo another pathway such as diradical formation,⁹ initial [2+2] / rearrangement,¹⁰ or stepwise ionic addition,¹¹ or a combination of the pathways.

As shown in Table 3.2, the reactivities of the protonated versus methylated acetylenes are apparent. The reactivities do not appear to be due to the chlorine substituent on the aryl ring, since the methyl substituted aryl ring, entry 3, has a similar isolated yield as entry 1.

Table 3.2 Difference in Reactivity between Terminal and Methyl Acetylenes
3.3.1 Cycloadditions with Methyl Acetylenes

Since the methyl acetylenes proved less reactive, requiring longer reaction times, in the absence of light, alternative methods were sought. The utilization of microwave irradiation in chemical synthesis is reaching an age of applicability. Since a microwave reactor heats the reaction from the inside out, as opposed to conventional convectional heating, the reaction can be heated in a matter of seconds to 300°C, depending on the solvent. This rapid heating allows for reactants to quickly receive the required thermal energy and react minimizing decomposition products. In the case of methyl acetylene cycloadditions, the microwave chamber also excludes UV-vis radiation. With these properties in mind, methyl acetylenes were exposed to microwave irradiation (Table 3.3). Initial attempts, employing conditions similar to conventional heating (eg. 140°C 1 h) neither desired or decomposition products were observed. These experiments also showed, in entries 1 – 3, Table 3.3, that diluting in a solvent drastically decreases the amount of product observed. When the reaction was conducted neat, entry 4 Table 3.3, only a trace amount of product was observed after 10 min. Only after increasing the reaction temperature to 200°C, for 20 min, entry 5 Table 3.3, was a similar product yield recorded, compared to entry 2 in Table 3.2.
Due to the scale of the reaction at hand (ca. 20 mg of acetylene), we also explored the ability to compare MWI procedures to conventional heating. The reaction was submitted to analogous set of conditions via conventional heating (high grade silicone oil, 200°C, 20 min, exclude ambient light). This series of reactions in Scheme 3.4 (conducted neat, in the absence of light) reacted comparably to the microwave irradiated reactions, indicating that on small scale (ca 20 mg) the utilization of a small sealable pressure vessel, is similar to microwave irradiation.
Scheme 3.4 Scope of Methyl Acetylene 2.31. [4+2] Cycloadditions via Conventional Heating Microwave Mimic (Drop-and-Dip)

3.3.2 Cycloadditions with Chloro Acetylenes

With the initial results from the methyl acetylenes in hand, focus was turned to the scope of chloro acetylenes, in hopes of furnishing subsequent orthogonal functionalization of the biphenyl, e.g. a 2,2'-dihalo biphenyl, as well as probing what effect the halogen has on acetylenic carbon. Acetylene 2.30 was chosen since it is the opposite of acetylene 2.31, with respect to the chloro and methyl substituents. As shown in Scheme 3.5, subjecting the chloro or bromo acetylenes (not listed) to a combination of conventional or microwave heating techniques, in the presence or absence of light, and in solution or neat, mostly garnered unidentifiable decomposition products. Interestingly, when diene 3.9 is added to acetylene 2.30, a small amount of the desired biphenyl is isolated (26%) after only 5 min of heating. Considering the [4+2] cycloaddition results, the alkyl, hydrogen, and halogen substituted acetylenes appear to have very diverse reactivities.
Scheme 3.5 Scope of Chloro Acetylene 2.30. [4+2] Cycloaddition via “Drop-and-Dip” Conditions

3.4 Summary

Having investigated and compared the reactivities of the terminal, methyl, and halo acetylenes within a [4+2] cycloaddition, it appears that the substituent on the terminal acetylene carbon plays an active role. Utilization of an alkyl group on the acetylene retards the overall reactivity, whereas having an electron withdrawing halo group sponsors mostly decomposition products.
3.5 References

1 Savard, J.; Brassard, P. Tetrahedron, 1984, 40, 3455-64.


Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

Chapter 4

Utilization of [3+2] Cycloadditions to Construct Biaryls
4.1 Current [3+2] Cycloaddition Methods

The ubiquitous nature of aromatic five-membered moieties in pharmacy makes their synthesis important.\(^1\) Since the seminal report of azide dipoles by Sharpless, this reaction has become a standard in terms of cycloadditions.\(^2\) Typically, click chemistry utilizes a terminal acetylene and a copper (I) catalyst.\(^3\) These conditions repeatedly yield only 1,4-substituted triazoles instead of the 1,5-substitution. This is explained through the formation of a copper-acetylide which polarizes the C-C triple bond, and directs the azide regioselectivity. Also, typical conditions of “click chemistry” occur at room temp, only with the copper catalyst. Work has been focused in the area of click chemistry catalysis where copper is not used. In many of these cases, the regioselectivity can be switched from the 1,4-triazole, to the 1,5-triazole with rhodium catalysts.\(^4\)

The utility of reactions can also be observed in cascading sequences of reactions such as a Sonogashira coupling, followed by [3+2] addition of organic azides.\(^5\) This utility is also observed in the synthesis of synthetically useful Triazole heterocycles. Recent examples include the synthesis of triazole boronic acids\(^6\) and triazole complex heterocycles.\(^7\) The utility of these reactions is also observed in the ability to generate pharmacologically desired molecules easily.\(^8\)

4.2 Synthesis of Triazoles

Utilizing the electron deficient parent o-nitrophenyl acetylenes with benzyl azide, Table 4.1, the desired cycloadduct was furnished in good yields with only one regioisomer observed, entry 1. Interestingly, when the methyl acetylenes were subjected to the reaction conditions, good yields were also furnished; however, a mixture of regioisomers was observed, entry 2. Characterization of the regioisomeric products was preformed via 2D-NMR pulse sequences, or from x-ray structures when the regioisomers were
possible to separate. Converse to the [4+2] reactions, the chloro- and bromoacetylenes, entries 5-7, gave excellent yields with benzyl azide, and also gave essentially one regioisomer (11:1, crude NMR). Interestingly, the reactivity of the terminal acetylene without a halogen, entry 3, did provide the desired triazole as one regioisomer, however, the yield is not as high as the other entries. Employing typical conditions (Cu$_2$SO$_4$, ascorbic acid, t-BuOH / H$_2$O, rt) in entry 4, resulted in quantitative yields of the same regioisomer obtained from the thermal, uncatalyzed conditions.

**Table 4.1** Synthesis of Azide Dipolar Addition to Acetylenes

![Diagram of reaction]

<table>
<thead>
<tr>
<th>Acetylene</th>
<th>R$_1$</th>
<th>R$_2$</th>
<th>Yield*</th>
<th>Triazole (A:B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.19</td>
<td>Cl</td>
<td>H</td>
<td>74%</td>
<td>4.1 (1:0)</td>
</tr>
<tr>
<td>2.31</td>
<td>Cl</td>
<td>Me</td>
<td>73%$^a$</td>
<td>4.2 (2:1)</td>
</tr>
<tr>
<td>2.22</td>
<td>Me</td>
<td>H</td>
<td>46%</td>
<td>4.3 (1:0)</td>
</tr>
<tr>
<td>2.22</td>
<td>Me</td>
<td>H</td>
<td>98%$^b$</td>
<td>4.3 (1:0)</td>
</tr>
<tr>
<td>2.30</td>
<td>Me</td>
<td>Cl</td>
<td>59%</td>
<td>4.4 (6:1)</td>
</tr>
<tr>
<td>2.34</td>
<td>Me</td>
<td>Me</td>
<td>43%</td>
<td>4.5 (1:1)</td>
</tr>
<tr>
<td>2.29</td>
<td>Cl</td>
<td>Cl</td>
<td>68%$^c$</td>
<td>4.6 (11:1)</td>
</tr>
<tr>
<td>2.28</td>
<td>Cl</td>
<td>Br</td>
<td>86%</td>
<td>4.7 (11:1)</td>
</tr>
<tr>
<td>8.18</td>
<td>Cl</td>
<td>Ph</td>
<td>67%</td>
<td>4.8 (3:1)</td>
</tr>
</tbody>
</table>

(a) reaction heated to 120°C, (b) reaction conditions: Cu$_2$SO$_4$, ascorbic acid, t-BuOH:H$_2$O (1:1), rt, (c) conducted for 48 h
4.3 Synthesis of Isoxazoles

Comparing the results from the azide addition, production of isoxazoles were pursued from the treatment with nitrile oxides. Initially these reactions were conducted with p-methoxyphenylnitrile oxide and the terminal acetylene. These reactions were very facile (~30 min) and provided pure desired product after filtration from the mother liquor. When either the chloro- or methylacetylenes were used, only nitrile oxide dimerization products could be observed. Utilization of the bulky mesitylene nitrile oxide also provided dimerization products with substituted acetylenes. Due to the reactivity of the nitrile oxide paired with the lower reactivity of the substituted acetylenes, the hydroximyl chloride was added via syringe pump. This procedure gave only one regioisomer into a heated solution of the acetylene and NEt$_3$ in PhMe, furnished only one regioisomer desired isoxazoles, entries 1-6, in good yields, Table 4.2. Characterization of the isoxazoles was preformed via 2D-NMR pulse sequences, or from x-ray structures when able.
**Table 4.2** Isoxazole Synthesis via Nitrile Oxide Addition to Substituted Acetylenes

![Reaction Scheme]

<table>
<thead>
<tr>
<th>Entry</th>
<th>R₁</th>
<th>R₂</th>
<th>Isoxazole</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cl</td>
<td>H</td>
<td>4.9</td>
<td>79%</td>
</tr>
<tr>
<td>2</td>
<td>Cl</td>
<td>Me</td>
<td>4.10</td>
<td>72%</td>
</tr>
<tr>
<td>3</td>
<td>Me</td>
<td>H</td>
<td>4.11</td>
<td>73%</td>
</tr>
<tr>
<td>4</td>
<td>Me</td>
<td>Cl</td>
<td>4.12</td>
<td>65%</td>
</tr>
<tr>
<td>5</td>
<td>Cl</td>
<td>Cl</td>
<td>4.13</td>
<td>70%</td>
</tr>
<tr>
<td>6</td>
<td>Cl</td>
<td>Br</td>
<td>4.14</td>
<td>68%</td>
</tr>
<tr>
<td>7</td>
<td>Me</td>
<td>Me</td>
<td>4.15</td>
<td>74%</td>
</tr>
</tbody>
</table>

![Crystal Structure]

**Figure 4.2** X-ray Crystal Structure of Isoxazole Entry 2, Table 4.2 as an ORTEP Representation, Ellipsoids Shown at the 30% Probability Level.
4.4 Summary

In contrast to the [4+2] reactions, the reactivities of the terminal, alkyl, and halo acetylenes all provide access to a set of substituted triazole products that are not as easily available by other methods. Comparing the reactivities between azide and nitrile oxide addition to the substituted acetylenes, the isolation of both regioisomers, for the azide addition, suggests that the intermediates are able to adopt two possible transition state structures. By
increasing the temperature of the reaction, the energy barriers between the two transition states is easier to overcome, resulting in an increasing amount of the thermodynamic product. Conversely, due to the reactivity of the nitrile oxide only a kinetic product is isolated. This warrants further investigation as to the distribution of molecular orbitals of the acetylene and nitrile oxide, to establish a free energy diagram.
4.5 References


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Chapter 5

Functionalization of Biphenyls
5.1 Introduction

One advantage to the cycloaddition approach to biaryl / heterocycle synthesis is the fact that the reactivity is often orthogonal to traditional cross-coupling experiments. Consequently, we felt it was important to demonstrate this utility of resulting functional groups in the product biaryls / heterocycles for use in cross-coupling experiments. Additionally, functional group manipulation of the resulting products needed to be demonstrated to illustrate the practicality of this chemistry for the scientific community.

5.2 Palladium Mediated Cross-Coupling

With a viable route to the biphenyls, we sought to explore Suzuki coupling to demonstrate how these biphenyls serve as a template towards diversely substituted biphenyls. Utilizing Fu’s conditions\(^1\) \((\text{Pd}_2(\text{dba})_3/P(\text{C}_6\text{H}_{11})_3)\) for the majority of the biphenyls, coupling of phenyl boronic acid to the 4-, 5-, and 6-chlorobiphenyls proceeded smoothly, Table 5.1.
Table 5.1 Suzuki Coupling of PhB(OH)$_2$ About Aryl Ring

<table>
<thead>
<tr>
<th>Entry</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Product</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>5.1</td>
<td>98% (48 h)</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>5.2</td>
<td>84%</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>5.3</td>
<td>88%</td>
</tr>
</tbody>
</table>

Demonstrating diversity with the Pd$_2$(dba)$_3$/P(c-C$_6$H$_{11}$)$_3$ catalytic system, was explored with the sterically hindered 6-chlorobiphenyl, Table 5.2. Electron rich boronic acids, entries 1-4, reacted cleanly to provide the triaryls in high yield. When employing electron deficient boronic acids, entry 5, *e.g.* p-cyanophenylboronic acid, only low yields were observed. In this case, the more active [t-Bu$_3$P]$_2$Pd, was required to produce good yields of the electron deficient boronic acids, entries 5-7, 9, and. There was a limit to the usage of electron deficient boronic acids. When using penta-fluorophenyl-, entry 7 or o- or p-trifluoromethylphenylboronic acid, entry 8 and 10, either no reaction occurred (as with C$_6$F$_5$-B(OH)$_2$) or proto-dehalogenation (as with o/p-CF$_3$-C$_6$H$_4$-B(OH)$_2$), even when using the more active palladium source. Though there is a limitation with highly electron deficient boronic acids, this method does illustrate the ability to use these highly substituted biphenyls as templates for further synthetic manipulation.
Table 5.2 Suzuki Coupling of Various Boronic Acids to Sterically Hindered Aryl Chloride 3.12.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Ar</th>
<th>Conditions</th>
<th>Product</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4-MeO-C₆H₄⁻</td>
<td>A</td>
<td>5.4</td>
<td>90%</td>
</tr>
<tr>
<td>2</td>
<td>3-MeO-C₆H₄⁻</td>
<td>A</td>
<td>5.5</td>
<td>91%</td>
</tr>
<tr>
<td>3</td>
<td>2-MeO-C₆H₄⁻</td>
<td>A</td>
<td>5.6</td>
<td>80%</td>
</tr>
<tr>
<td>4</td>
<td>2-Me-C₆H₄⁻</td>
<td>A</td>
<td>5.7</td>
<td>89%</td>
</tr>
<tr>
<td>5</td>
<td>4-CN-C₆H₄⁻</td>
<td>A</td>
<td>5.8</td>
<td>43%</td>
</tr>
<tr>
<td>6</td>
<td>4-CN-C₆H₄⁻</td>
<td>B</td>
<td>5.8</td>
<td>80%</td>
</tr>
<tr>
<td>7</td>
<td>C₆F₅⁻</td>
<td>B</td>
<td>5.9</td>
<td>0%</td>
</tr>
<tr>
<td>8</td>
<td>4-CF₃-C₆H₄⁻</td>
<td>Bᵇ</td>
<td>5.10</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>3-CF₃-C₆H₄⁻</td>
<td>Bᵇ</td>
<td>5.11</td>
<td>77%</td>
</tr>
<tr>
<td>10</td>
<td>2-CF₃-C₆H₄⁻</td>
<td>Bᵇ</td>
<td>5.12</td>
<td>N/A</td>
</tr>
</tbody>
</table>

ᵃConditions: A. Pd₂(dba)₃ (2.5 mol %), PCy (10 mol %), dioxane, Cs₂CO₃, 80°C, 24 h; B. (t-Bu₃P)₂Pd (5 mol %), KF, NMP, 80°C, 24 h. ᵇ Extended reaction time (48 h) was employed for this coupling.

5.3 Functional Group Transformation

Selective manipulation of the nitro moiety and/or the benzylic phenol is possible, Scheme 5.1. On the basis of our previous work, Zn/HOAc can be used to cleanly reduce the nitro group to the corresponding amine without deprotection of the benzyl phenol. A tandem reduction process to reveal both the phenol and aniline moieties is also possible via hydrogenation with Pd/C. Finally, selective removal of the benzyl moiety can be accomplished with BCl₃.
Scheme 5.1 Selective Functional Group Transformation.

5.4 Summary

Construction of biphenyls via a Diels-Alder pathway can provide molecules that are structurally diverse and attractive for use in the total synthesis of natural products. The position of the halogen about the aryl ring does not prove to have a dramatic effect on the reactivities with subsequent Suzuki couplings, as seen in the previous cycloaddition reactions.
5.5 References

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Chapter 6

Synthesis of Siamenol
6.1 Isolation

Siamenol is an alkaloid isolated from the small tree, *Murraya siamensis*, in southeast Asia, Figure 6.1.\(^1\) Notably, siamenol is a 2-hydroxycarbazole with a prenyl side chain in the C\(_3\) position. This species of trees are known to demonstrate antibiotic, cytotoxic, and antiviral properties, however, after performing assays on the extraction from this particular species of *Murraya*, activity against HIV was observed. After careful chromatographic separation of the extract, siamenol proved to be solely responsible for anti-HIV activity via XTT-tetrazolium anti-HIV assay.\(^2\)

![Figure 6.1 Carbazoles Isolated from Murraya siamensis](image)

6.2 Previous Syntheses

The Knölker group has previously synthesized Siamenol.\(^3\) Their synthesis features Buchwald – Hartwig coupling of analine 6.4 and bromide 6.5 to furnish diarylanaline 6.6. The carbazole skeleton, 6.7, was then achieved nicely, via palladium mediated oxidative cyclization, to give only one regioisomer. After bromination of the aryl ring and deprotection of methyl ether 6.8, siamenol was afforded via nickel catalyzed alkylation with prenyl bromide. Though synthesis affords a facile route to the siamenol core, unfortunately, it is limited by the poor nickel coupling of the prenyl group.
Scheme 6.1 Knölker's Synthesis of Siamenol

6.3 Diels-Alder Approach Towards Siamenol

With a working knowledge of palladium couplings and biphenyls, we focused on the reductive cyclization of the nitro group to make carbazoles. This transformation is well known, and was studied during the late 1960’s by Cadogan and coworkers. This reaction invokes two possible mechanisms, each using a phosphine to reduce the nitro group in 6.10 to a nitroso moiety, 6.11 (Scheme 6.2). Once another phosphine attacks the nitroso oxygen, another equivalent of phosphine oxide is eliminated, leaving an electron deficient nitrene 6.12. Once the nitrene has formed, the lower aromatic ring attacks, followed by proton transfer, to make the carbazole skeleton 6.14.
Scheme 6.2 Cadogan Reductive Cyclization via Nitrene

This reaction could also proceed via an electrophilic aromatic addition type mechanism, Scheme 6.3. After reduction of the nitro to nitroso, the incoming phosphine generates dipolar intermediate 6.15 in situ, which undergoes nucleophilic attack from the lower phenyl ring, to eliminate the phosphine oxide, followed by H-transfer, 6.16, resulting in the desired carbazole 6.14.

Scheme 6.3 Cadogan Reductive Cyclization via Aromatic Electrophilic Addition

With our investigations, we did not perform mechanistic probes. The two mechanistic explanations above are among the most common when discussing this reaction. The mechanistic information is included not to explain the investigation the presence of a nitrene intermediate, but to illustrate that within the course of the reaction, significant energy is required to break the aromaticity of the lower aryl ring to create the carbazole skeleton.
Considering this energetic barrier, several other products can be deemed plausible, such as azetidines and aziridines, among others, hence lowering the synthetic utility of this reaction. Hence, the investigation at hand elaborates on synthetic transformations leading up to and designed around the Cadogan reductive cyclization to maximize the desired carbazole products.\(^7\)

Preliminary exploration of the Cadogan cyclization focused on transforming the cycloadducts from the TBS-analogue of Danishefsky’s diene. Since the lower aromatic ring only has a para-substituent, regioselectivity would not pose an issue. After heating the \(\o\)-nitrobinaphthyls 6.17 – 6.19 with \(\text{Ph}_3\text{P}\), carbazoles 6.20 – 6.21 were cleanly furnished in good yields (Scheme 6.4).

![Scheme 6.4 Cadogan Reductive Cyclization Synthesis of Carbazoles](image)

6.17 \(X = \text{Cl}, Y = Z = H\) \hspace{1cm} 6.20 \(X = \text{Cl}, Y = Z = H, 75\%\)

6.18 \(Y = \text{Cl}, X = Z = H\) \hspace{1cm} 6.21 \(Y = \text{Cl}, X = Z = H, 87\%\)

6.19 \(Z = \text{Cl}, X = Y = H\) \hspace{1cm} 6.22 \(Z = \text{Cl}, X = Y = H, 84\%\)

Siamenol’s synthesis started with Diels-Alder cycloaddition with acetylene 2.20 and TMS enol ether of cyclohexenone, 3.19. After a quick silica plug, the crude cycloadduct was subjected to Suzuki coupling conditions to install the methyl group, followed by alkylation of the phenol 6.23. Lewis acid mediated Claisen rearrangement\(^8\) of the allyl ether gave the required handle for future cross metathesis with Grubbs’ 2\(^{\text{nd}}\) generation catalysis (Scheme 6.5).\(^9\)
Scheme 6.5 Diels-Alder Mediated Synthesis of Allyl Biphenyl

Initial attempts to furnish the carbazole system were hindered by the unprotected phenol, giving a near 1:1:1 separable mix of the regioisomeric carboxoles 6.25 and 6.26, with the corresponding aniline 6.27. Attempts to inhibit aniline formation with the free phenol via Cadogan reductive cyclization were unsuccessful, and demonstrated that the phenol must be protected (Scheme 6.6).

Scheme 6.6 Carbazole Synthesis via Cadogan Reductive Cyclization

Conversely, after the cross metathesis, the nitro group could be converted to the azide 6.29 under Sandmeyer conditions (Scheme 6.7). Having formed the phenyldiazonium salt in situ, addition of sodium azide furnished the desired phenyl azide in good yields without subsequent chromatography. When phenyl azide 6.29 was converted to the nitrene in situ with BCl$_3$, a
near 1:1:1 ratio of products 6.31, 6.1, and the corresponding aniline was still observed.\textsuperscript{12} When ca. 0.95 equivalents of MeLi were added, the azide decomposition with BCl\textsubscript{3} resulted solely in a near 1:1 ratio of carbazoles 6.31 and 6.1.

![Scheme 6.7 Synthesis of Carbazoles via Azide Decomposition](image)

** Scheme 6.7 Synthesis of Carbazoles via Azide Decomposition **

### 6.4 Synthesis of Siamenol Derivatives

Having successfully developed a template approach to the biphenyl moiety, several branch points for a structure activity study were recognized. In comparison to Knölker’s work,\textsuperscript{3} which depends on the availability of substituted anilines and aryl bromides, this method offers greater access to structurally diverse siamenol derivatives. Depending on which commercially available starting material is chosen, the Diels-Alder product contains all of the desired branch points after one step. That is, either a mild palladium coupling can occur, or the free phenol can be furnished into a handle with the proper protecting group, or the nitro group can easily be converted into a myriad of useful functional group handles in one pot. This is particularly beneficial since many of the carbazole functionalization reactions occur via electrophilic
substitution. This makes the C_2 and C_7 positions electronically inert. Fortunately, our Diels-Alder route supersedes this electronic drawback via the phosphine mediated Cadogan reductive cyclization. The usefulness of this strategy was demonstrated in the synthesis of siamenol derivatives that could be submitted for a structure-affinity relationship (SAR) study, Scheme 6.8.

Scheme 6.8 Synthetic Forecast of Desired Carbazoles

Starting from the requisite phenyl acetylene, Scheme 6.9, the Diels-Alder cycloaddition with diene 3.15 gave good yields of biphenyls. To ease purification, the crude cycloadduct is eluted past a silica plug, diluted, and allylated. To give biphenyls 6.32 – 6.34 in good yields, isolation of pure biphenyl did not preformed until after the Claisen rearrangement step.
Scheme 6.9 Synthesis of TBS-phenol Carbazole Precursor

Unfortunately, when the subsequent Suzuki coupling was carried out, the 4- and 6-chlorobiphenyls, 6.32 and 6.34, were not methylated under Pd$_2$(dba)$_3$ conditions. This suggests that biphenyl 6.33 undergoes more of a nucleophilic substitution mechanism than the other chloro derivatives due to the orientation of the nitro group. This set back was alleviated after the cycloadducts were allylated and subsequently subjected to the Claisen rearrangement conditions protecting the subsequent free phenol as a TBS-ether. After exploring Suzuki coupling conditions, PEPPSI$^{13c}$ was observed as the best catalysis to couple the methyl group, and not isomerize the allyl group to a methyl styrene.

With the methylated biphenyls in hand, Cadogan reductive cyclization conditions were employed to avoid the use and generation of potentially explosive azides. The reductive cyclization can be carried out at a lower temp, 100°C, with the use of the more nucleophilic tri-$n$-butylphosphine, Table 6.1. Upon purification, the unreacted phosphine proved to be a problematic impurity in the desired carbazoles due to air oxidation. Though an oxidative
aqueous workup did not completely remove the phosphine, semi-prep HPLC did provide a reasonable means to purify the carbazole to medicinal trial levels (>98%). Since HPLC was required, the yields of purified carbazoles obtained are low, due to repeated runs on small amounts of phosphine oxide contaminated carbazole.

Table 6.1 Cadogan Reductive Cyclization of Allyl Siamenol Derivatives

<table>
<thead>
<tr>
<th>Entry</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Yield</th>
<th>Carbazole</th>
<th>A:B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>72%</td>
<td>6.38</td>
<td>1.2:1</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>Cl</td>
<td>H</td>
<td>68%</td>
<td>6.39</td>
<td>1.1:1</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>73%</td>
<td>6.40</td>
<td>1:1</td>
</tr>
<tr>
<td>4</td>
<td>Me</td>
<td>H</td>
<td>H</td>
<td>64%</td>
<td>6.41</td>
<td>1:1</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>Me</td>
<td>H</td>
<td>67%</td>
<td>6.42</td>
<td>1.1:1</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>H</td>
<td>Me</td>
<td>60%</td>
<td>6.43</td>
<td>1.2:1</td>
</tr>
</tbody>
</table>

With the allyl siamenol derivatives in hand, focus was shifted to the prenyl derivatives, Scheme 6.10. As in our first synthesis of siamenol, the prenyl group can be installed via olefin cross-metathesis with 2-methyl-2-butene and Grubbs' 2nd generation catalyst. This transformation was easier to monitor through the TBS ether before installation of the methyl group.
Scheme 6.10 Cross Metathesis and PEPPSI® Coupling of Siamenol Derivatives

With the prenyl benzenes in hand, Cadogan reductive cyclization could be carried out with subsequent silyl ether deprotection to give both 1- and 3-prenyl siamenol derivatives, Table 6.2. Purification of the prenyl derivatives posed similar problems with phosphine and phosphine oxide impurities. Utilization of semi-prep HPLC provided analytical samples suitable for medicinal testing.

Table 6.2 Cadogan Reductive Cyclization of Prenyl Siamenol Derivatives

<table>
<thead>
<tr>
<th>Entry</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Yield</th>
<th>Carbazole</th>
<th>A:B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cl</td>
<td>H</td>
<td>H</td>
<td>75%</td>
<td>6.47</td>
<td>1:1</td>
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<td>Cl</td>
<td>H</td>
<td>68%</td>
<td>6.48</td>
<td>1.1:1</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>H</td>
<td>Cl</td>
<td>73%</td>
<td>6.49</td>
<td>1.2:1</td>
</tr>
<tr>
<td>4</td>
<td>Me</td>
<td>H</td>
<td>H</td>
<td>65%</td>
<td>6.50</td>
<td>1.1:1</td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>Me</td>
<td>H</td>
<td>64%</td>
<td>6.1</td>
<td>1.1:1</td>
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<tr>
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<td>H</td>
<td>H</td>
<td>Me</td>
<td>61%</td>
<td>6.51</td>
<td>1:1</td>
</tr>
</tbody>
</table>
6.5 Summary

There was a direct trend between the methyl and chloro derivatives during the Cadogan reductive cyclization. Regardless of the location of the chlorine, the reactivity was greater than the methyl derivatives, possibly due the electron withdrawing nature. As the phosphine removes the nitro group's oxygen's, the chlorine can destabilize the resulting nitrene. Then chlorine-destabilized nitrene is then more electrophilic and undergoes subsequent nucleophilic attack from the lower aromatic ring, to generate the carbazole skeleton. Also, in all of the reductive cyclizations, the 1-allyl / prenyl carbazoles are observed in a slight excess over the 3-allyl / prenyl carbazoles. Presuming that the aromatic rings are orthogonal to each other, there is an equal probability of the nitrene intermediate to be attacked by either side. The slight preference of the 1-allyl / prenyl could be explained by a week pre-complexation of the nitrene to the alkene.
6.6 References


Chapter 7

Conclusion
7.1 Future Work

This work comprises the synthesis and exploration of terminal, methyl, chloro, and bromo o-nitrophenyl acetylenes within [4+2] and [3+2] reactions, Scheme 7.1. From these studies significant information has been gained that relates the reactivity difference between different substituents on the acetylene versus the aryl ring. However, a detailed explanation as to these reactivity differences has not yet been investigated.

Scheme 7.1 Scope of Terminal, Methyl, Chloro, and Bromo Acetylenes within [4+2] and [3+2] Cycloadditions

To address mechanistic details, in the case of the methyl acetylene reactivities, the corresponding phenyl allene 7.4 should be synthesized and investigated, Scheme 7.2. With allene 7.4 in hand, it would be possible to explore which isomer is more reactive under [4+2] cycloaddition conditions. When the reaction of acetylene 2.31 and the methoxy diene (X = OMe, Y = H, Scheme 7.2) are mixed at 140°C in an NMR tube, allenic proton signals are not observed in the ¹H-NMR spectrum. However, this does not prove that an allene intermediate is not present since the NMR time scale, on which the spectrometer operates with, might be longer than the lifetime of a fleeting intermediate.
Considering the synthesis of acetylene **2.31**, with Ohira’s diazophosphonate and homobenzaldehyde **2.32**, Scheme 7.3, it is quite possible that allene **7.4** is generated in situ from base mediated rearrangement of homophenyl acetylene **7.5**. This would indicate that the methyl acetylene is the preferred product under basic conditions. Along with the NMR spectra for the progressing reaction, and possible mechanistic analysis for the synthesis of acetylene **2.31**, more information about the presence of allene **7.4** is needed to understand the possible cycloaddition intermediates associated with alkyl substituted acetylenes.

**Scheme 7.3 Proposed Base Mediated Rearrangement of Acetylene 7.5**

Other mechanistic probes for the cycloaddition reactions would be the synthesis of aryl cyclopropyl derivaties such as **7.6**, Scheme 7.4. Molander has demonstrated nice synthetic utility with stable potassium tetrafluoroborates in a myriad of palladium mediated cross couplings. By
having a cyclopropane ring coupled to the aryl ring, it should be possible to probe the presence of diradical formation. If a diradical is not generated on the acetylene, then a biphenyl 7.8 should be isolated, otherwise products will be isolated where the cyclopropane has opened like a radical clock. However, it is possible that if a diradical is generated in situ, it might not be in resonance with the aryl ring. In this case the cyclopropane should be coupled to the acetylene, via the bromo or chloro acetylene, and the [4+2] reaction should be repeated.

![Scheme 7.4 Radical Clock [4+2] Mechanism Probe](image)

**Scheme 7.4** Radical Clock [4+2] Mechanism Probe

### 7.2 Conclusion

Considering the differences between the reactions investigated, this work does illustrate a general correlation between the substituents on the acetylene and about the aryl ring to the reactivity of the molecule. The methyl acetylenes are slightly deactivated towards the reported cycloadditions, whereas the halo acetylenes are activated, following the trend observed in previous reports. The reactivity differences of halogen vs. alkyl groups about the aryl ring are reflected in the siamenol derivative synthesis, i.e. Cadogan carbazole formation, where the methylated biphenyls have a lower reactivity than the chlorobiphenyls. Together, this investigation has garnered valuable insight to the nature of the methyl and chloro acetylenes when compared to
the corresponding terminal acetylenes and has contributed a substantial amount of information concerning the synthesis of highly substituted biphenyls to the synthetic community.
7.3 References


Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

Chapter 8

Experimental Section
8.1 General Procedures

Infrared spectra were recorded neat unless otherwise indicated and are reported in cm\(^{-1}\). \(^1\)H-NMR and \(^{13}\)C-NMR spectra were recorded in deuterated solvents and are reported in ppm relative to tetramethyl silane and referenced internally to the residually protonated solvents. Optical rotations were recorded using a sodium lamp at 589 nm in CHCl\(_3\). Routine monitoring of reactions was performed using EM Science DC-Alufolien silica gel, aluminum-backed TLC plates. Flash chromatography was performed with the indicated eluents on EM Science Gedurian 230-400 mesh silica gel. Air and / or moisture sensitive reactions were performed under usual inert atmosphere conditions. Reactions requiring anhydrous conditions were performed under a blanket of argon, in glassware dried in an oven at 120°C or by a Bunsen flame, then cooled under argon. Solvents and commercial reagents were purified via Glass Contour\textsuperscript{®} Solvent Purification Systems (SPS), in accord with Perrin and Armarego\textsuperscript{1} or used without further purification.

8.2 Experimental Procedures


To a stirred solution of 2.19 (18.53 g, 108.0 mmol) in dry DMF (240 mL) was added \(N,N\)-dimethylformamide dimethyl acetal (DMF••DMA) (39.5 g, 44.0 mL, 331 mmol). After heating at 140°C for 16 h, the dark red solution was cooled to 0°C and added slowly, over 1 h via cannula, to a rapidly stirred solution of NaIO\(_4\) (83.0 g, 388.0 mmol) in H\(_2\)O (291 mL) and DMF (77 mL) at 0°C. The reaction flask was washed with DMF (20 mL) at 0°C and added to NaIO\(_4\) mixture. The reaction was stirred at 0°C for 2 h then allowed to warm to rt. After an additional 6 h,
the orange solution was filtered and rinsed with PhMe/EtOAc (1:1, 200 mL). The filtrate was then washed with H_2O (3 x 150 mL) and sat. aq. NaCl (3 x 150 mL). The dried (MgSO_4) extract was concentrated in vacuo to a dark red oil, and hexanes (40 mL) were added. Solids were isolated and recrystallized in PhMe to give the known aldehyde 2.13^2 (17.23 g, 92.88 mmol, 86%). ^1H NMR (400 MHz, CDCl_3) δ 10.42 (s, 1H), 8.01 (dd, J = 1.0, 8.2 Hz, 1H), 7.79 (dd, J = 1.0, 8.1 Hz, 1H), 7.65 (t, J = 8.1 Hz, 1H); ^13C NMR (100 MHz, CDCl_3) δ 188.6, 148.4, 138.6, 132.9, 132.4, 123.4, 121.9.

MRN-I-20, MRN-I-27, MRN-I-47, MRN-I-74, MRN-IV-65, Aldehyde B: To a stirred solution of 2.10 (5.248 g, 30.59 mmol) in dry DMF (172 mL) was added N,N-dimethylformamide dimethyl acetal (DMF••DMA) (13.7 g, 12.0 mL, 88.5 mmol). After heating at 140°C for 16 h, the dark red solution was cooled to 0°C and added slowly, over 20 min via cannula, to a rapidly stirred solution of NaIO_4 (18.7 g, 87.4 mmol) in H_2O (69 mL) and DMF (23 mL) at 0°C. The reaction flask was washed with DMF (20 mL) at 0°C and added to NaIO_4 mixture. The reaction was stirred at 0°C for 30 min then allowed to warm to rt. After an additional 4 h, the orange solution was filtered and rinsed with PhMe (200 mL). The filtrate was then washed with H_2O (2 x 200 mL) and sat. aq. NaCl (2 x 100 mL). The dried (MgSO_4) extract was filtered, concentrated in vacuo to a dark red oil, and purified by flash chromatography over silica gel, eluting with 20-50% EtOAc / Hexanes to give known aldehyde 2.14^4 (4.737 g, 25.53 mmol, 84%). ^1H NMR (400 MHz, CDCl_3) δ 10.41 (s, 1H), 8.13 (d, J = 2.0 Hz, 1H), 7.97 (dd, J = 8.3, 2.0 Hz, 1H), 7.78 (dd, J = 8.3, 2.0 Hz, 1H); ^13C NMR (100 MHz, CDCl_3) δ 186.9, 150.1, 140.2, 134.2, 130.9, 129.3, 124.8.
MRN-VII-91, MRN-VIII-10, MRN-XI-32, Aldehyde 2.16: To a stirred solution of 2.11 (4.56 g, 4.00 mL, 30.17 mmol) in dry DMF (75 mL) was added N,N-dimethylformamide dimethyl acetal (DMF••DMA) (10.8 g, 12.0 mL, 90.3 mmol). After heating at 140°C for 72 h, the dark red solution was cooled to rt and added quickly to a rapidly stirred solution of NaIO₄ (21.04 g, 98.37 mmol) in H₂O (74 mL) and DMF (24 mL) at 0°C. The reaction flask was washed with DMF (5 mL) at 0°C and added to NaIO₄ mixture. The reaction was stirred at 0°C for 2 h, before warmed to rt. The orange solution was filtered and rinsed with Et₂O (200 mL). The filtrate was then washed with H₂O (3 x 25 mL) and sat. aq. NaCl (3 x 25 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to a dark red oil and purified via flash chromatography over silica gel, eluting with 10-30% Et₂O / hexanes gave aldehyde 2.16 (4.390 g, 26.58 mmol, 89%) as an orange solid. ¹H NMR (300 MHz, CDCl₃) δ 10.32 (s, 1H), 7.99 (dd, J = 7.5, 1.5 Hz, 1H), 7.65-7.50 (m, 2H), 2.45 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 190.4, 148.7, 139.2, 137.0, 131.9, 131.3, 121.9, 19.4.

MRN-VII-46, MRN-VII-71, Enamine 8.1: To a stirred solution of 2.9 (3.855 g, 22.46 mmol) in dry DMF (50 mL) was added N,N-dimethylformamide dimethyl acetal (DMF••DMA) (8.07 g, 9.00 mL, 67.75 mmol). After heating at 140°C for 16 h, the dark red solution was cooled to rt and diluted with Et₂O (200 mL) and washed with HCl (2 x 50 mL, 10% v/v), sat aq. NaHCO₃ (2 x 50 mL), and sat aq. NaCl (2 x 5 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give 8.1 (4.940 g, 111.0 mmol, 97%) as a red oil. IR (thin film, cm⁻¹) 3081, 2847, 2808, 1634, 1585, 1524, 1378, 1101, 952, 866, 835, 774, 752, 723; ¹H NMR (300 MHz, CDCl₃) δ 7.49 - 7.32 (m, 2H), 6.97 (t,
$J = 7.8$ Hz, 1H), 6.70 (d, $J = 13.8$ Hz, 1H), 5.10 (d, $J = 13.8$ Hz, 1H), 2.86 (s, 6H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ 150.0, 145.5, 133.0, 132.1, 131.9, 123.1, 122.1, 86.9, 39.3. HRMS (EI+) calcd. for C$_{10}$H$_{11}$N$_2$O$_2$Cl 226.0509, found 226.0508.

MRN-VII-74, MRN-VII-93, MRN-VIII-22, MRN-IX-41, MRN-IX-48, MRN-IX-61, Enamine 8.1: (E)-2-(2-chloro-6-nitrophenyl)-N,N-dimethylethenamine: A 2-L, single necked, round-bottomed flask, equipped with a powder funnel and magnetic stirring bar, was charged with DMF (1-L)$^5$ and 2-chloro-6-nitrotoluene$^6$ 2.9, (69.74 g, 406.5 mmol, 1 equiv.). $N,N$-Dimethylformamide dimethylacetal$^7$ (162 mL, 1.22 mol, 3 equiv.) was added via syringe to the yellow solution. The powder funnel was replaced by a Fredrichs condenser and the mixture was brought to 135°C in a silicon oil bath over 2 hours. The reaction was covered with aluminum foil to aid heating. After 18 hours, the reaction evolved to a brick red solution and showed complete conversion via TLC.$^8,^9$ The mixture was cooled to room temperature over 2 hours, and then carefully poured over 2 min into a rapidly, mechanically stirred, ice-cooled solution of sat. aq. NaHCO$_3$ (500 mL) and Et$_2$O (500 mL) in a 2-L Erlenmeyer flask. After 15 min, the solution was transferred to a separatory funnel and let settle for 15 min. A 1-L portion of the mixture was collected in an Erlenmeyer flask, and the remaining solution in the separatory funnel was washed with 5% NaHCO$_3$ (aq.)$^{10}$ (4 x 300 mL). The ethereal partition was collected and set aside. The previously collected 1-L portion was transferred to a separatory funnel and extracted with ether (3 x 400 mL) via separatory funnel. The ethereal partitions were combined and concentrated via rotary evaporation (38°C, 28 mmHg) to give enamine 8.1 as a dark red liquid.$^{11}$

Aldehyde 2.32: 2-(2-chloro-6-nitrophenyl)acetaldehyde: A 2-L, three necked, round-bottomed flask, equipped with a mechanical stirrer, yellow poly-
cap and powder funnel, was immersed in a ice-cold water bath, and charged with the red enamine 8.1 oil and diluted with Et₂O (300 mL). To the solution was added 1 M HCl (300 mL), and the powder funnel was replaced by a 90° gas inlet adapter open to the air. The mixture was allowed to warm to rt over 2.5 hours with vigorous stirring. The biphasic solution was transferred to a 2-L separatory funnel and the ethereal partition was collected. The aqueous partition was acidified to pH = 1 with 3M HCl and was extracted with MTBE (2 x 200 mL). The ethereal partitions were combined and washed with 10% NaHCO₃ (2 x 50 mL), H₂O (100 mL), and brine (2 x 50 mL), dried over Na₂SO₄, filtered and concentrated via rotary evaporation (38°C, 28 mmHg) and then under high vacuum (50°C, 0.50 mmHg) to provide aldehyde 2.32 as a red oil (69.34 g 347.4 mmol, 85%). IR (thin film, cm⁻¹) 3432, 2844, 2733, 1731, 158, 1351, 1109, 1019, 876, 802, 730, 667; 1H NMR (300 MHz, CDCl₃) δ 9.74 (s, 1H), 7.97 (dd, J = 8.4, 1.2 Hz, 1H), 7.74 (dd, J = 8.4, 1.2 Hz, 1H), 7.46 (t, J = 8.4, 1H), 4.31 (s, 2H); 13C NMR (75 MHz, CDCl₃) δ 195.5, 150.8, 137.1, 134.3, 129.0, 126.8, 123.5, 44.5; HRMS (EI+) calcd. for C₈H₇NO₃Cl (M+H) 200.0114, found 200.0117.

MRN-IX-70, Aldehyde 2.33: To a stirred solution containing 2.11 (5.26 g, 6.00 mL, 34.8 mmol) and dry DMF (80 mL), was added N,N-dimethylformamide dimethylacetal (14.0 mL, 12.6 g, 105.7 mmol) was added via syringe to the yellow solution and heated to 140°C. After 24 hours, the reaction evolved to a brick red solution and cooled to room temperature, and quenched with aq. NaHCO₃ (200 mL, 5% w/v) and extracted with Et₂O (3 x 150 mL). The ethereal partition were combined and concentrated in vacuo to give enamine 8.2 as a dark red liquid (ca. 200 mL).
To a mechanically stirred solution of the dark red enamine 8.2 and Et₂O (250 mL), was added aq HCl (250 mL, 10% v/v). After 2.5 hours of vigorous stirring, the biphasic solution was extracted with Et₂O (3 x 100 mL). The ethereal partitions were combined and washed with aq. NaHCO₃ (2 x 100 mL, 10% w/v), and sat aq. NaCl (2 x 100 mL). The dried (Na₂SO₄) extract was in vacuo to provide crude 2.33 as a red oil. Purification via flash chromatography over silica gel, eluting with PhMe gave pure B (5.121 g, 28.58 mmol, 82%) as dark orange oil. IR (thin film, cm⁻¹) 3430, 2842, 2732, 1724, 1610, 1524, 1348, 935, 803, 731, 672; ¹H NMR (300 MHz, CDCl₃) δ 9.86 (t, J = 0.9 Hz, 1H), 7.85 (d, J = 8.2 Hz, 1H), 7.51 (d, J = 7.4 Hz, 1H), 7.37 (t, J = 7.9 Hz, 1H), 4.02 (s, 2H), 2.38 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 196.8, 150.5, 140.3, 135.1, 128.0, 126.5, 122.7, 43.9, 20.4; HRMS (Cl⁺) calcd. for C₈H₅NO₂Cl (M+H) 180.0661, found 180.0666.

MRN-I-53, MRN-I-75, MRN-II-45, MRN-III-60, MRN-IV-45, Methyl ester 8.3: To a stirred solution of 2.17 (9.393 g, 46.60 mmol) in dry DMF (155 mL) at 0°C was added K₂CO₃ (13.23 g, 95.72 mmol) and MeI (19.38 g, 8.5 mL, 136.5 mmol) and warmed to 40°C. After 1 h, the solution was cooled to rt and diluted with EtOAc (115 mL). The solution was washed with H₂O (3 x 100 mL), and sat. aq. NaCl (3 x 100 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica gel, eluting with 40-60% EtOAc / Hexanes, to give the known methyl ester 8.3 (9.244 g, 42.87 mmol, 92%) as a pale yellow solid. ¹H NMR (400 MHz, CDCl₃) δ 7.95 (d, J = 8.7 Hz, 1H), 7.73 (d, J = 2.3 Hz, 1H), 7.63 (dd, J = 8.7, 2.3 Hz, 1H), 3.98 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 164.7, 146.1, 139.7, 131.6, 129.8, 129.4, 125.5, 53.6.
MRN-I-54, MRN-I-76, MRN-II-46, MRN-III-61, MRN-IV-47, Aldehyde 2.14:
To a stirred solution of 8.3 (8.20 g, 38.0 mmol) and dry CH$_2$Cl$_2$ (205 mL) was added DIBAL-H (48.0 mL, 48.0 mmol, 1.0 M in CH$_2$Cl$_2$) at -78°C. After 45 min, MeOH (20 mL) was added and the solution was allowed to warm to rt. Next, aq. sodium tartrate (200 mL, 10% w/v) was added and the suspension was left to stir vigorously until a bilayer was distinct. The solution was diluted with CH$_2$Cl$_2$ (100 mL) and washed with H$_2$O (2 x 100 mL), sat. aq. NaCl (2 x 100 mL). The dried (Na$_2$SO$_4$) extract was purified via flash chromatography over silica gel, eluting with 20-50% EtOAc / Hexanes to give the known aldehyde 2.14$^{16}$ (6.80 g, 36.7 mmol, 97%). $^1$H NMR (400 MHz, CDCl$_3$) δ 10.46 (s, 1H), 8.15 (d, $J = 8.7$ Hz, 1H), 7.94 (d, $J = 2.3$ Hz, 1H), 7.74 (dd, $J = 2.4$, 8.7 Hz, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 187.0, 147.5, 141.0, 133.5, 132.7, 129.4, 126.2.

MRN-VII-98, MRN-XI-33, gem-Dichloride 2.27: To a stirred solution of 2.16 (5.828 g, 33.29 mmol) and CH$_2$Cl$_2$ (350 mL), was added CCl$_4$ (8.29 g, 5.20 mL, 52.93 mmol), and PPh$_3$ (27.77 g, 105.9 mmol) at rt. After 30 h, the black solution was concentrated in vacuo until ca. 100 mL of mixture remained. The residue was then purified via flash chromatography over silica gel, eluting with 0-10% EtOAc / Hexanes to give impure 2.27 (6.038 g) as a yellow oil.

MRN-VII-100 Chloroacetylene 2.30: To a stirred solution of impure 2.27 (3.316 g, 14.29 mmol) and THF (36.0 mL) at -78°C was added NaHMDS (15.0 mL, 15.0 mmol, 1M in THF) over 10 min turning from an orange to darks
brown solution. After 1 h, the reaction was warmed to 0°C and quenched with sat. aq. NH₄Cl (50 mL). After 5 min, the orange-brown solution was extracted with Et₂O (3 x 50 mL), and washed with sat. aq. NaCl (2 x 20 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 35% hexanes / PhMe to give 2.30 (2.372 g, 12.13 mmol, 85%) as a yellow solid. MP 93-94°C; IR (thin film) 2213, 1526, 1456, 1381, 802, 740, 693; ¹H NMR (400 MHz, CDCl₃) δ 7.85 (d, J = 8.2, 1H), 7.51 (d, J = 7.6 Hz, 1H), 7.37 (t, J = 8.0, 1H), 2.55 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 151.2, 144.2, 133.9, 128.2, 122.0, 116.9, 80.3, 63.4, 21.2; HRMS (Cl+) calcd. for C₉H₇NO₂Cl (M+H) 196.0165, found 196.0154.

MRN-VI-96, MRN-VI-97, MRN-VI-98, MRN-VII-20, MRN-VII-43, MRN-XI-61, gem-Dichloride 2.26: To a stirred solution of 2.13 (3.118 g, 16.80 mmol) and CH₂Cl₂ (170 mL), was added CCl₄ (3.98 g, 2.50 mL, 25.9 mmol), and PPh₃ (13.36 g, 50.93 mmol) at rt. After 30 h, the black solution was concentrated in vacuo until ca. 50 mL of mixture remained. The residue was then purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give 2.26 (3.567 g) as an impure yellow oil.

MRN-VII-14, MRN-VII-15, MRN-VII-16, MRN-VII-55, MRN-XI-34, Chloroacetylene 2.29: To a stirred solution of impure 2.26 (3.567 g, 14.12 mmol) and THF (35.0 mL) was added NaHMDS (14.30 mL, 14.30 mmol, 1 M in THF) at -78°C. After 1 h, the dark brown solution was quenched with sat. aq. NH₃Cl (20 mL), extracted with EtOAc (3 x 50 mL), and washed with sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 20-50 % EtOAc / Hexanes to give 2.29 (2.954 g, 13.67 mmol, 97%) as a bright yellow crystalline solid. MP 93-94°C; IR (thin film) 2217, 1526, 1338, 1118, 797, 750, 737 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 7.96 (dd, J = 8.1, 1.2 Hz, 1H), 7.72
(dd, J = 8.1, 1.2 Hz, 1H), 7.43 (t, J = 8.2 Hz, 1H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ 151.7, 139.5, 13.7, 128.9, 122.7, 117.3, 82.3, 61.8; HRMS (EI+) calcd. for C$_8$H$_3$NO$_2$Cl$_2$ 214.9541, found 214.9539.

MRN-IV-58, MRN-VI-31, MRN-VII-31, gem-Dibromide 2.25: To a stirred solution of 2.13 (2.628 g, 14.16 mmol), CH$_2$Cl$_2$ (94 mL), and CBr$_4$ (7.104 g, 21.42 mmol) at 0°C, was added PPh$_3$ (11.23 g, 42.81 mmol, 0.4 M in CH$_2$Cl$_2$) via cannula over 5 min. After 15 h, the black solution was concentrated to ca. 60 mL and transferred to a flash column. Purification of the residue via flash chromatography over silica gel, eluting with 0-20% EtOAc / hexanes gave crude 2.25 (4.117 g) as an orange solid.

MRN-VI-32, MRN-VI-33, MRN-VI-34, MRN-VI-55, MRN-VII-34, MRN-IX-82, Bromoacetylene 2.28: To a stirred solution of impure 2.25 (3.051 g, 8.937 mmol) and THF (22 mL) at -78°C, was added NaHMDS (9.00 mL, 9.00 mmol, 1 M in THF) via syringe over 5 min and allowed to slowly warm to 0°C. After 2 h, the dark brown mixture was quenched with sat. aq. NH$_4$Cl (20 mL) and extracted with EtOAc (3 x 20 mL). The combined organic parts were washed with H$_2$O (2 x 10 mL) and sat. aq. NaCl (2 x 10 mL). The dried (MgSO$_4$) extract was concentrated in vacuo to a brown solid and purified via flash chromatography over silica gel, eluting with PhMe to give 2.28 (1.971 g, 7.567 mmol, 85%) as a yellow solid. MP 86-88°C; IR (thin film) 2220, 1527, 1340, cm$^{-1}$; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.85 (dd, J = 8.1, 1.2 Hz, 1H), 7.51 (dd, J = 8.1, 1.2, 1H), 7.37 (t, J = 8.2 Hz, 1H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ151.7, 139.6, 133.7, 128.9, 122.8, 117.7, 72.2, 65.3; HRMS (EI+) calcd. for C$_8$H$_3$NO$_2$ClBr 258.9036, found 258.9035.
MRN-XI-46, Acetylene 2.19: To a stirred solution of 2.13 (16.64 g, 89.67 mmol), K$_2$CO$_3$ (25.14 g, 181.9 mmol), and MeOH (1.34 L) was added diazophosphonate 2.18 $^{17}$ (24.33 g, 208.7 mmol) at rt. After 4 h, the solution was quenched with sat. aq. NaHCO$_3$ (500 mL) and concentrated \textit{in vacuo} to remove the MeOH. The solution was diluted with EtOAc (700 mL) and washed with H$_2$O (3 x 200 mL), and sat. aq. NaCl (2 x 150 mL). The dried (MgSO$_4$) extract was concentrated \textit{in vacuo} and purified by flash chromatography over silica gel, eluting with 1% EtOAc / Hexanes, to give 2.19 (13.84 g, 76.22 mmol, 85%) as a pale yellow solid. MP 94-95°C; IR (thin film) 3286, 1521, 1351, 808, 756, 736, 681; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.92 (dd, $J = 8.2, 1.1$ Hz, 1H), 7.74 (dd, $J = 8.2, 1.1$ Hz, 1H), 7.47 (t, $J = 8.2, 1$H), 3.86 (s, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 139.8, 134.0, 129.6, 123.1, 117.6, 109.9, 91.7, 75.3; HRMS (CI$^+$) calcd. for C$_8$H$_5$NO$_2$Cl (M+H) 182.0009, found 182.0005.

Acetylene 2.21: To a stirred solution of 2.15 (3.667 g, 19.76 mmol), K$_2$CO$_3$ (5.510 g, 39.87 mmol), and MeOH (330 mL) was added diazophosphonate 2.18 (5.168 g, 26.90 mmol) at rt. After 4 h, the solution was quenched with sat. aq. NaHCO$_3$ (200 mL) and concentrated \textit{in vacuo} to remove the MeOH. The solution was diluted with EtOAc (200 mL) and washed with H$_2$O (3 x 50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (MgSO$_4$) extract was concentrated \textit{in vacuo} and purified by flash chromatography over silica gel, eluting with 1% EtOAc / Hexanes, to give 2.21 (2.870 g, 15.81 mmol, 81%) as a pale yellow solid. MP 68-70°C; IR (thin film) 3285, 1555, 1528, 1345, 891, 840, 791, 761; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.09 (d, $J = 2.0$ Hz, 1H), 7.67 (dd,
J = 8.4 Hz, 1H), 7.60 (dd, J = 8.4, 2.0, 1H), 3.59 (s, 1H); $^{13}\text{C}$ NMR (75 MHz, CDCl$_3$) δ 150.5, 136.4, 135.3, 133.1, 124.9, 115.9, 86.3, 77.6; HRMS (Cl+) calcd. for C$_8$H$_5$NO$_2^{37}$Cl (M+H) 183.9979, found 183.9980.

**Acetylene 2.20:** To a stirred solution of 2.14 (3.694 g, 19.90 mmol), K$_2$CO$_3$ (5.528 g, 40.00 mmol), and dry MeOH (350 mL) was added diazophosphonate 2.18 (5.088 g, 26.48 mmol) at rt. After 4 h, the solution was quenched with sat. aq. NaHCO$_3$ (200 mL) and concentrated in vacuo to remove the MeOH. The solution was diluted with EtOAc (300 mL) and washed with H$_2$O (3 x 100 mL), and sat. aq. NaCl (2 x 100 mL). The dried (MgSO$_4$) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 1% EtOAc / Hexanes, to give 2.20 (2.891 g, 15.92 mmol, 80%) as a pale yellow solid. MP 70-73°C; IR (thin film) 3286, 2112, 1599, 1559, 1516, 883, 834, 753; $^1$H NMR (300 MHz, CDCl$_3$) δ 8.04 (d, J = 8.7 Hz, 1H), 7.68 (d, J = 2.3 Hz, 1H), 7.49 (dd, J = 8.7, 2.3 Hz, 1H), 3.60 (s, 1H); $^{13}\text{C}$ NMR (75 MHz, CDCl$_3$) δ 148.5, 139.5, 135.2, 129.6, 126.0, 119.2, 86.6, 77.5; HRMS (Cl+) calcd. for C$_8$H$_5$NO$_2^{37}$Cl (M+H) 183.9979, found 183.9977.

**Phenol 8.5:** To a pressure vessel containing 2.19 (1.739 g, 9.578 mmol) and PhMe (20 mL) was added diene 3.3$^{18}$ (8.423 g, 41.63 mmol) at rt. The mixture was heated at 80°C. After 24 h, the reaction was cooled to 0°C and DABCO (4.414 g, 39.35 mmol) was added and gradually warned to 40°C over 30 min. After 1h at 40°C, the brown mixture was cooled to rt and quenched with aq. HCl (1 M) until pH = 2, diluted with EtOAc (100 mL), washed with H$_2$O
(50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.5 (1.795 g, 6.417 mmol, 67%) as a yellow solid. MP 134-135°C; IR (thin film) 3423, 1620, 1529, 1444, 1356; ¹H NMR (300 MHz, CDCl₃) δ 7.78 (dd, J = 8.1, 1.0 Hz, 1H), 7.73 (dd, J = 8.1, 1.0, Hz, 1H), 7.46 (t, J = 8.1, 1H), 7.00 (d, 8.5 Hz, 1H), 6.58 (dd, J = 8.5, 2.4 Hz, 1H), 6.49 (d, J = 2.4 Hz, 1H), 5.05 (s, 1H), 3.82 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.8, 154.2, 152.2, 137.6, 134.0, 131.3, 131.2, 129.6, 122.6, 114.2, 107.1, 102.5, 55.8; HRMS (CI+) calcd. for C₁₃H₁₀NO₄Cl (M+) 279.0298, found 279.0304.

![Chemical structure of 8.5 and 3.12](image)

**Chloride 3.12:** To a stirred solution of 8.5 (1.245 g, 4.500 mmol) and dry DMF (22.0 mL) was added NaH (397.2 mg, 9.93 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (7.76 g, 5.40 mL, 45.4 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (100 mL), diluted with EtOAc (150 mL), washed with H₂O (50 mL), and sat. aq. NaCl (2 x 100 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.12 (1.582 g, 4.277 mmol, 95%) as a bright yellow crystalline solid. MP 99-100°C; IR (thin film) 2936, 1612, 1583, 1529, 1441; ¹H NMR (400 MHz, CDCl₃) δ 7.82 (dd, J = 8.1, 1.2 Hz, 1H), 7.73 (dd, J = 8.1, 1.2 Hz, 1H), 7.443 (t, J = 8.1 Hz, 1H), 7.36-7.23 (m, 5H), 7.13 (d, J = 8.3 Hz, 1H), 6.63 (dd, J = 8.3, 2.3 Hz, 1H), 6.60 (d, J = 2.3 Hz, 1H), 5.05 (s, 2H), 3.85 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.4, 156.6, 151.4, 136.8, 136.7, 133.4, 132.0, 130.7, 128.6, 128.4, 127.7, 126.8, 122.2, 116.2, 105.1, 100.3, 70.3, 55.3; HRMS (FAB+) calcd. for C₂₀H₁₆NO₄Cl (M+) 369.0768, found 369.0759.
**Phenol 8.6:** To a pressure vessel containing 2.20 (189.3 mg, 1.043 mmol) and PhMe (2.0 mL) was added diene 3.3 (872.8 mg, 4.313 mmol) at rt. The mixture was heated at 80°C. After 24 h, the reaction was cooled to 0°C and DABCO (670.8 mg, 5.980 mmol) was added and gradually warmed to 40°C over 30 min. After 30 min at 40°C, the brown mixture was cooled to rt and quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (25 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 20 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.6 (178.9 mg, 646.6 mmol, 62%) as a yellow oil. IR (thin film) 3389, 2933, 1622, 1600, 1561, 1518, 865, 830, 727; ¹H NMR (400 MHz, CDCl₃) δ 7.92 (d, J = 8.5 Hz, 1H), 7.46 (dd, J = 8.5, 2.3, Hz, 1H), 7.43 (d, J = 2.3, 1H), 7.17 (d, 8.5 Hz, 1H), 6.63 (dd, J = 8.5, 2.4 Hz, 1H), 6.41 (d, J = 2.4 Hz, 1H), 4.94 (s, 1H), 3.84 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.4, 153.4, 147.9, 138.8, 134.4, 132.6, 130.5, 127.9, 125.6, 116.6, 106.9, 102.0, 55.4; HRMS (EI+) calcd. for C₁₃H₁₀NO₄Cl (M+) 279.0298, found 279.0290.

**Chloride 3.13:** To a stirred solution of 8.6 (100 mg, 361.4 mmol) and dry DMF (1.8 mL) was added NaH (30.8 mg, 0.77 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (7.19 mg, 500 mL, 4.20 mmol). After 10 min, the yellow solution was quenched with sat. aq.
NH₄Cl (15 mL), diluted with EtOAc (20 mL), washed with H₂O (15 mL), and sat. aq. NaCl (2 x 25 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.13 (124.3 mg, 336.2 mmol, 93%) as a bright yellow crystalline solid. MP 121-124°C; IR (thin film) 2925, 2851, 1617, 1595, 1531, 1268, 1049, ; ¹H NMR (400 MHz, CDCl₃) δ 7.91 (dd, J = 0.3, 8.6 Hz, 1H), 7.45-7.39 (m, 2H), 7.37-7.33 (m, 3H), 7.27-7.22 (m, 3H), 6.65 (dd, J = 8.4, 2.4 Hz, 1H), 6.55 (d, J = 2.4 Hz, 1H), 5.00 (s, 2H), 3.85 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.5, 156.2, 147.9, 138.6, 136.3, 135.1, 132.6, 130.2, 128.5, 127.9, 127.6, 127.2, 125.5, 119.2, 105.6, 100.3, 70.7, 55.4; HRMS (EI⁺) calcd. for C₂₀H₁₆NO₄Cl (M⁺) 369.0768, found 369.0776.

Phenol 8.7: To a pressure vessel containing 2.21 (185.2 mg, 1.020 mmol) and PhMe (2.0 mL) was added diene 3.3 (834.1 mg, 4.102 mmol) at rt. The mixture was heated at 80°C. After 24 h, the reaction was cooled to 0°C and DABCO (493.6 mg, 4.401 mmol) was added and gradually warmed to 40°C over 30 min. After 1h, the brown mixture was cooled to rt and quenched with sat. aq. NH₄Cl (15 mL), diluted with EtOAc (20 mL), washed with H₂O (20 mL), and sat. aq. NaCl (2 x 15 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give impure 8.7 (363.0 mg) as a yellow oil and used without further purification.

Chloride 3.14: To a stirred solution of 8.7 (363.0 mg) and dry DMF (3.6 mL) was added NaH (93.2 mg, 2.33 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (1.22 g, 0.85 mL, 7.15 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (10 mL),
diluted with EtOAc (30 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.14 (233.9 mg, 0.632 mmol, 62% over 2 steps) as a bright yellow crystalline solid. MP 126-128°C; IR (thin film) 3032, 2925, 1608, 1527, 1260, 1050; ¹H NMR (400 MHz, CDCl₃) δ 7.93 (d, J = 2.2 Hz, 1H), 7.58 (dd, J = 8.3, 2.2 Hz, 1H), 7.44-7.20 (m, 7H), 6.63 (dd, J = 8.4, 2.4 Hz, 1H), 6.54 (d, J = 2.4 Hz, 1H), 5.00 (s, 2H), 3.84 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.4, 156.1, 149.7, 136.3, 133.8, 133.3, 132.6, 131.7, 130.2, 128.5, 127.9, 127.1, 124.2, 119.2, 105.6, 100.3, 70.6, 55.4; HRMS (EI+) calcd. for C₂₀H₁₆NO₄Cl (M+) 369.0768, found 369.0766.

Phenol 8.9: To a pressure vessel containing 2.19 (147.1 mg, 810.2 mmol) and PhMe (1.3 mL) was added diene 8.8 (630 mg, 700 mL, 2.94 mmol) at rt. The mixture was heated at 120°C. After 24 h, the reaction was cooled to 0°C and TBAF (3.0 mL, 3.0 mmol, 1.0 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (20 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.9 (161.0 mg, 644.9 mmol, 80%) as a yellow solid. MP 83-84°C; IR (thin film) 3423, 1614, 1529, 1361, 1201; ¹H NMR (400 MHz, CDCl₃) δ 7.72 (d, J = 8.0, 2H), 7.45 (t, J = 8.0 Hz, 1H), 7.18 (d, J = 8.5, 2H), 6.94 (d, 8.5 Hz, 2H), 5.00 (s, 1H); ¹³C NMR (75 MHz, CDCl₃) δ 156.3, 151.9, 136.5, 134.7, 133.5, 130.7, 129.1, 126.5, 122.2, 115.9; HRMS (Cl+) calcd. for C₁₂H₉NO₃Cl (M+) 250.0271, found 250.0277.
**Chloride 3.16:** To a stirred solution of 8.9 (111.4 mg, 446.2 mmol) and dry DMF (2.0 mL) was added NaN (48.1 mg, 1.20 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (790.9 mg, 550 mL, 4.624 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (20 mL), diluted with EtOAc (20 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.16 (137.2 mg, 403.8 mmol, 90%) as a bright yellow crystalline solid. MP 85-89°C; IR (thin film) 3088, 2873, 1610, 1531, 1244, 1027; ¹H NMR (400 MHz, CDCl₃) δ 7.73 (d, J = 8.1 Hz, 2H), 7.55-7.35 (m, 6H), 7.20 (d, J = 8.7 Hz, 2H), 7.10 (d, J = 8.7 Hz, 2H), 5.14 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 159.2, 151.6, 136.7, 136.1, 134.4, 133.2, 130.2, 128.7, 128.7, 128.1, 127.7, 126.2, 121.9, 114.8, 70.1; HRMS (FAB+) calcd. for C₁₉H₁₄NO₃Cl 339.0662, found 339.0669.

**Phenol 8.10:** To a pressure vessel containing 2.20 (116.8 mg, 643.3 mmol) and PhMe (1 mL) was added diene 8.8 (495 mg, 550 mL, 2.32 mmol) at rt. The mixture was heated at 120°C. After 24 h, the reaction was cooled to 0°C and THF (3.6 mL, 3.6 mmol, 1.0 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (30 mL), washed with H₂O (15 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give
impure 8.10 (171.3 mg) as a yellow oil, and was used without further purification.

**Chloride 3.17:** To a stirred solution of 8.10 (171.3 mg) and dry DMF (3.2 mL) was added NaH (101.5 mg, 2.538 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (1.44 g, 1.00 mL, 8.41 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (15 mL), diluted with EtOAc (30 mL), washed with H₂O (15 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated *in vacuo* and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.17 (170.6 mg, 502.0 mmol, 78% over 2 steps) as a bright yellow crystalline solid. MP 144-147°C; IR (thin film) 3087, 2888, 1609, 1653, 1249, 1028; ¹H NMR (400 MHz, CDCl₃) δ 7.85 (d, J = 2.2 Hz, 1H), 7.60 (dd, J = 8.3, 2.2 Hz, 1H), 7.53-7.36 (m, 6H), 7.27 (d, J = 8.8 Hz, 2H), 7.08 (d, J = 8.8 Hz, 2H), 5.14 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 159.2, 149.5, 136.7, 134.3, 133.5, 133.0, 132.3, 129.2, 128.7, 128.6, 128.2, 127.6, 124.2, 115.3, 70.1; HRMS (EI+) calcd. for C₁₉H₁₄NO₃Cl (M+) 339.0662, found 339.0660.

![Chemical structure of Chloride 3.17](image)

**Phenol 8.11:** To a pressure vessel containing 2.21 (123.7 mg, 681.3 µmol) and PhMe (1 mL) was added diene 8.8 (495 mg, 550 µL, 2.203 mmol) at rt. The mixture was heated at 120°C. After 24 h, the reaction was cooled to 0°C and TBAF (3.7 mL, 3.7 mmol, 1.0 M in THF) was added. After 10 min, the brown mixture was quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (30 mL), washed with H₂O (15 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated *in vacuo* and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.11.
(169.4 mg) as a yellow oil, with minor impurities, and used without further purification.

**Chloride 3.18:** To a stirred solution of 8.11 (169.4 mg) and dry DMF (3.0 mL) was added NaH (155.6 mg, 3.89 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (1.44 g, 1.0 mL, 8.41 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH$_4$Cl (15 mL), diluted with EtOAc (20 mL), washed with H$_2$O (15 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO$_4$) extract was concentrated *in vacuo* and purified by flash chromatography over silica gel, eluting with 0-10% Et$_2$O / Hexanes to give 3.18 (175.9 mg, 517.6 mmol, 76% over 2 steps) as a bright yellow crystalline solid. MP 147-148°C; IR (thin film) 3067, 1609, 1531, 1249, 1028; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.85 (d, $J = 2.0$ Hz, 1H), 7.60 (dd, $J = 8.3$, 2.0 Hz, 1H), 7.55-7.35 (m, 6H), 7.27 (d, $J = 8.6$ Hz, 2H), 7.08 (d, $J = 8.6$ Hz, 2H), 5.14 (s, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 159.2, 149.5, 136.7, 134.3, 133.5, 133.0, 132.3, 129.2, 128.7, 128.6, 128.2, 127.6, 124.2, 115.3, 70.1; HRMS (EI+) calcd. for C$_{19}$H$_{14}$NO$_3$Cl (M+) 339.0662, found 339.0652.

![Diagram](attachment:chemical_diagram.png)

**Phenol 8.13:** To a pressure vessel containing 2.19 (52.6 mg, 289.7 mmol) was added diene 8.12 (269.9 mg, 1.361 mmol) at rt. The mixture was heated at 140°C. After 24 h, the reaction was cooled to 0°C and TBAF (1.4 mL, 1.4 mmol, 1M in THF) was added. After 10 min, the brown mixture was quenched with sat. aq. NH$_4$Cl (20 mL), diluted with EtOAc (30 mL), washed with H$_2$O (20 mL), and sat. aq. NaCl (2 x 20 mL). The dried (Na$_2$SO$_4$) extract was concentrated *in vacuo* and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.13 (53.6 mg, 191.6 mmol, 66%) as a bright yellow solid. MP 136-138°C; IR (thin film) 3432, 3080, 2929, 1613, 1587, 1531, 1355, 1303; $^1$H NMR (300 MHz, CDCl$_3$) δ 7.84 (dd, $J = 8.1$, 1.2 Hz, 1H), 7.27 (d, $J = 8.6$ Hz, 2H), 7.08 (d, $J = 8.6$ Hz, 2H), 5.14 (s, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 158.5, 149.6, 136.7, 134.4, 133.5, 133.0, 132.3, 129.2, 128.7, 128.6, 128.2, 127.6, 124.2, 115.3, 70.1; HRMS (EI+) calcd. for C$_{19}$H$_{14}$NO$_3$Cl (M+) 339.0662, found 339.0652.
Hz, 1H), 7.73 (dd, J = 8.1, 1.2 Hz, 1H), 7.44 (t, J = 8.1, 1H), 7.05 (d, 8.8 Hz, 1H), 6.56-6.50 (m, 2H), 3.74 (s, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$ 157.6, 157.8, 151.5, 136.7, 133.5, 131.8, 130.9, 128.5, 122.1, 115.3, 107.4, 99.4, 55.6; HRMS (EI+) calcd. for C$_{13}$H$_{10}$NO$_4$Cl (M+H) 279.0298, found 279.0293.

**Chloride 3.22:** To a stirred solution of 8.13 (26.4 mg, 94.4 mmol) and dry DMF (50 mL) was added NaH (8.2 mg, 205 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (187 mg, 130 mL, 1.07 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH$_4$Cl (10 mL), diluted with EtOAc (20 mL), washed with H$_2$O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO$_4$) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et$_2$O / Hexanes to give 3.22 (18.1 mg, 48.9 mmol, 96%) as a bright yellow crystalline solid. MP 104-106°C; IR (thin film) 2959, 1614, 1583, 1530, 1245, 1037; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 7.80 (dd, J = 8.1, 1.3 Hz, 1H), 7.72 (dd, J = 8.1, 1.3 Hz, 1H), 7.53-7.34 (m, 6H), 7.12 (d, J = 8.3 Hz, 1H), 6.69 (dd, J = 8.3, 2.3 Hz, 1H), 6.65 (d, J = 2.3 Hz, 1H), 5.11 (s, 2H), 3.73 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$160.9, 157.5, 151.5, 136.7, 136.7, 133.5, 131.8, 130.8, 128.7, 128.5, 128.2, 127.8, 122.2, 115.9, 105.4, 99.6, 70.3, 55.6; HRMS (EI+) calcd. for C$_{20}$H$_{16}$NO$_4$Cl (M+) 369.0768, found 369.0760.

**Phenol 8.14:** To a pressure vessel containing 2.20 (106.8 mg, 588.2 mmol) was added diene 8.12 (364.7 mg, 1.839 mmol) at rt. The mixture was heated
at 140°C. After 24 h, the reaction was cooled to 0°C and TBAF (1.8 mL, 1.8 mmol, 1M in THF) was added. After 10 min, the brown mixture was quenched with sat. aq. NH₄Cl (20 mL), diluted with EtOAc (30 mL), washed with H₂O (20 mL), and sat. aq. NaCl (2 x 20 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give **8.14** (124.6 mg, 445.5 mmol, 76%) as a bright yellow solid. MP 178-181°C; IR (thin film) 3458, 1613, 1596, 1523, 1350, 1037; ¹H NMR (400 MHz, DMSO-d₆) δ 9.83 (s, 1H), 7.95 (dd, J = 8.4, Hz, 1H), 7.61 (dd, J = 8.4, 2.4, 1H), 7.51 (d, 2.4 Hz, 1H), 7.19 (d, J = 8.4 Hz, 1H), 6.50 (dd, J = 8.4, 2.4 Hz, 1H), 6.45 (d, J = 2.0, 1H), 3.58 (s, 3H); ¹³C NMR (100 MHz, DMSO-d₆) δ 160.2, 157.1, 148.3, 137.8, 134.8, 132.3, 130.9, 128.1, 126.2, 116.1, 108.4, 99.5, 55.4; HRMS (El+) calcd. for C₁₃H₁₀NO₄Cl (M+) 279.0298, found 279.0303.

**Chloride 3.23:** To a stirred solution of **8.14** (28.9 mg, 103.3 mmol) and dry DMF (50 mL) was added NaH (12.0 mg, 300 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (186.9 mg, 130 mL, 1.07 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (30 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give **3.23** (36.1 mg, 97.6 mmol, 94%) as a bright yellow crystalline solid. MP 98-99°C; IR (thin film) 3062, 2941, 1612, 1582, 1526, 1273, 1040; ¹H NMR (400 MHz, CDCl₃) δ 7.89 (d, J = 8.4 Hz, 1H), 7.58-7.34 (m, 7H), 7.25 (d, J = 8.4 Hz, 1H), 6.72 (dd, J = 8.4, 2.3 Hz, 1H), 6.60 (d, J = 2.3 Hz, 1H), 5.14 (s, 2H), 3.70 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 160.93, 157.1, 148.3, 137.8, 134.8, 132.3, 130.9, 128.1, 126.2, 116.1, 108.4, 99.5, 55.4; HRMS (El+) calcd. for C₁₃H₁₀NO₄Cl (M+) 279.0298, found 279.0303.
106.0, 99.5, 70.3, 55.2; HRMS (EI+) calcd. for C_{20}H_{16}NO_{4}Cl (M+) 369.0768, found 369.0762.

**Phenol 8.15:** To a pressure vessel containing 2.21 (103.0 mg, 567.3 mmol) was added diene 8.12 (353.4 mg, 1.782 mmol) at rt. The mixture was heated at 140°C. After 24 h, the reaction was cooled to 0°C and TBAF (1.8 mL, 1.8 mmol, 1M in THF) was added. After 10 min, the brown mixture was quenched with sat. aq. NH_{4}Cl (20 mL), diluted with EtOAc (30 mL), washed with H_{2}O (20 mL), and sat. aq. NaCl (2 x 20 mL). The dried (Na_{2}SO_{4}) extract was concentrated *in vacuo* and purified via flash chromatography over silica, eluting with 0-20% EtOAc / Hexanes to give 8.15 (115.8 mg, 414.0 mmol, 73%) as a bright yellow solid. MP 90-92°C; IR (thin film) 3385, 1617, 1531, 1359, 1265, 1037; ^{1}H NMR (400 MHz, DMSO-\textit{d}_{6}) \delta 9.81 (s, 1H), 8.04 (d, J = 2.0 Hz, 1H), 7.81 (dd, J = 8.4, 2.0, 1H), 7.47 (d, 8.4 Hz, 1H), 7.14 (d, J = 8.4 Hz, 1H), 6.51 (dd, J = 8.4, 2.4 Hz, 1H), 6.45 (d, J = 2.4 Hz, 1H), 3.58 (s, 3H); ^{13}C NMR (100 MHz, DMSO-\textit{d}_{6}) \delta 160.1, 157.0, 150.1, 134.4, 133.2, 132.2, 131.5, 130.8, 124.1, 116.2, 108.4, 99.5, 55.3; HRMS (EI+) calcd. for C_{13}H_{10}NO_{4}Cl (M) 279.0298, found 279.0293.

**Chloride 3.24:** To a stirred solution of 8.15 (26.4 mg, 94.4 µmol) and dry DMF (50 mL) was added NaH (15.0 mg, 375 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added BnBr (187 mg, 130 mL, 1.07
mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (10 mL), diluted with EtOAc (30 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (MgSO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-10% Et₂O / Hexanes to give 3.24 (32.2 mg, 87.1 mmol, 92%) as a bright yellow crystalline solid. MP 94-97°C; IR (thin film) 2933, 1613, 1532, 1357, 1261, 1036; ¹H NMR (400 MHz, CDCl₃) δ 7.94 (d, J = 2.2 Hz, 1H), 7.61 (dd, J = 8.3, 2.2 Hz, 1H), 7.52-7.32 (m, 6H), 7.23 (d, J = 8.4 Hz, 1H), 6.72 (dd, J = 8.4, 2.3 Hz, 1H), 6.60 (d, J = 2.3 Hz, 1H), 5.14 (s, 2H), 3.70 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 160.8, 156.9, 149.8, 136.6, 133.6, 133.3, 132.6, 131.3, 130.2, 128.7, 128.2, 127.7, 124.2, 118.8, 106.0, 99.5, 70.31, 55.2; HRMS (Cl⁺) calcd. for C₂0H₁₆NO₄Cl (M⁺) 369.0768, found 369.0756.

**Enone 3.5:** To a stirred solution of 3.4 (1.07 g, 9.53 mmol) and PhMe (48.0 mL) was added BnOH (1.96 mL, 2.06 g, 19.1 mmol), and p-TSA (45.4 mg, 0.238 mmol). The reaction flask was equipped with a Dean Stark trap and heated at 140°C. After 12 h, the reaction was cooled to rt, concentrated in vacuo and purified by chromatography over silica gel, eluting with 20 – 50% EtOAc / Hexanes to give known enone 3.5¹⁹ (1.65 g, 8.16 mmol, 86%) as a yellow crystalline solid. ¹H NMR (300 MHz, CDCl₃) δ 7.44-7.28 (m, 5H), 5.50 (s, 1H), 4.91 (s, 2H), 2.50 (t, J = 6.3 Hz, 2H), 2.39 (t, J = 6.3 Hz, 2H), 2.03 (q, J = 6.3 Hz, 2H); ¹³C NMR (75 MHz, CDCl₃) δ 199.7, 177.5, 135.2, 128.7, 128.6, 127.9, 103.4, 70.5, 36.8, 29.1, 21.2.
**Diene 3.6:** To a flask containing LDA\textsuperscript{20} (15.7 mL, 13.4 mmol, 0.86 M in THF / hexanes) was added a solution of 3.5 (2.56 g, 12.8 mmol) in THF (6.7 mL) at -78°C. After 10 min, TMSCl (1.67 g, 1.95 mL, 15.3 mmol) was added. After 1 h, the reaction was warmed to rt, poured into a cold solution of aq. NaHCO\textsubscript{3} (50 mL, 5% w/v), extracted with Et\textsubscript{2}O (100 mL), and washed with H\textsubscript{2}O (75 mL) and sat. aq. NaCl (75 mL). The dried extract (MgSO\textsubscript{4}) was concentrated \textit{in vacuo} to give 3.6 (3.51 g, 12.8 mmol, 99%) as a pale yellow oil. IR (neat) 2943, 1605, 1361, 1H NMR (300 MHz, CDCl\textsubscript{3}) \(\delta\) 7.42-7.31 (m, 5H), 4.88 (s, 1H), 4.81 (s, 2H), 4.61-4.59 (m, 1H), 2.31-2.25 (m, 4H), 0.23 (s, 9H); \(^{13}\)C NMR (100 MHz, CDCl\textsubscript{3}) \(\delta\) 160.1, 149.0, 136.6, 128.5, 128.0, 127.7, 96.0, 94.7, 69.4, 27.4, 21.8, 0.21; HRMS (Cl+) calcd. for C\textsubscript{16}H\textsubscript{22}O\textsubscript{2}Si (M+H) 275.1467, found, 275.1477.

**Triaryl 5.1:** To a pressure vessel was added 3.12 (1.162 g, 3.141 mmol), PhB(OH)\textsubscript{2} (1.350 g, 11.07 mmol), Cs\textsubscript{2}CO\textsubscript{3} (1.767 g, 5.245 mmol), Pd\textsubscript{2}(dba)\textsubscript{3} (73.3 mg, 80.0 mmol), PCy\textsubscript{3} (76.6 mg, 273 mmol), and dry dioxane (5.80 mL). The solution was sealed under Ar and heated to 80°C. After 48 h, the mixture was filtered over a pad of Celite-\textregistered, eluting with Et\textsubscript{2}O (200 mL) and concentrated \textit{in vacuo}. The residue was purified by flash chromatography over silica gel, eluting with 10 % Et\textsubscript{2}O/hexanes, to give 5.1 (1.267 g, 3.078 mmol, 98%) as a bright yellow crystalline solid. MP 124-126°C; IR (thin film) 3031, 2934, 1612, 1582, 1529, 1511, 1359, 1048; \(^1\)H NMR (400 MHz, CDCl\textsubscript{3}) \(\delta\) 7.87 (dd, \(J = 8.0, 1.2\) Hz, 1H), 7.63 (dd, \(J = 7.6, 1.6\) Hz, 1H), 7.53 (t, \(J = 7.6, 1H\)), 7.37-7.25 (m, 3H), 7.25-7.17 (m, 5H), 7.10-7.02 (m, 2H), 6.83 (d, \(J = 8.4\) Hz, 1H), 6.40 (d, \(J = 2.4\) Hz, 1H), 6.39 (dd, \(J = 8.4, 2.4\) Hz, 1H), 4.99 (d, \(J = 12.4, 1H\)), 4.87 (d, \(J = 12.4, 1H\)), 3.74 (s, 3H); \(^{13}\)C NMR (100 MHz, CDCl\textsubscript{3}) \(\delta\) 160.7, 156.8, 151.2, 144.6, 140.1, 137.0, 133.9, 131.5, 131.1, 129.2, 128.4,
127.8, 127.7, 127.6, 127.0, 126.7, 122.5, 117.5, 104.8, 99.9, 70.0, 55.2; HRMS (FAB+) calcd. for C_{26}H_{21}NO_{4} (M+) 441.1471, found 411.1462.

**Triaryl 5.2:** To a pressure vessel was added **3.13** (36.7 mg, 99.2 mmol), PhB(OH)$_2$ (53.0 mg, 435 mmol), Cs$_2$CO$_3$ (82.9 mg, 254 mmol), Pd$_2$(dba)$_3$ (3.4 mg, 3.8 mmol), PCy$_3$ (8.1 mg, 29 mmol), and dry dioxane (300 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite®, eluting with Et$_2$O (60 mL) and concentrated *in vacuo*. The residue was purified by flash chromatography over silica gel, eluting with 10 % Et$_2$O/hexanes, to give **5.2** (37.3 mg, 96.1 mmol, 84%) as a bright yellow crystalline solid. MP 127-131°C; IR (thin film) 3067, 2932, 1611, 1586, 1519, 1348, 1050; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.06 (d, $J$ = 8.4 Hz, 1H), 7.75-7.57 (m, 4H), 7.57-7.4 (m, 3H), 7.4-7.2 (m, 6H), 6.67 (dd, $J$ = 8.3, 2.0 Hz, 1H), 6.60 (d, $J$ = 2.0, 1H), 5.05 (s, 2H), 3.86 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 161.2, 156.3, 148.4, 145.6, 139.0, 136.5, 133.8, 131.4, 130.3, 129.1, 128.6, 128.5, 127.8, 127.4, 127.1, 126.1, 124.8, 120.6, 105.5, 100.4, 70.7, 55.4; HRMS (EI+) calcd. for C$_{26}$H$_{21}$NO$_4$ (M+) 411.1471, found 411.1475.

**Triaryl 5.3:** To a pressure vessel was added **3.14** (13.2 mg, 35.7 mmol), PhB(OH)$_2$ (17.6 mg, 144 mmol), Cs$_2$CO$_3$ (24.8 mg, 76.1 mmol), Pd$_2$(dba)$_3$
(0.1 mg, 1.2 mmol), PCy$_3$ (1.1 mg, 3.9 mmol), and dry dioxane (60 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite-®, eluting with Et$_2$O (40 mL) and concentrated in vacuo. The residue was purified by flash chromatography over silica gel, eluting with 0-10 % Et$_2$O/hexanes, to give 5.3 (12.2 mg, 31.5 mmol, 88%) as a bright yellow crystalline solid. MP 130-2°C; IR (thin film) 3054, 2925, 1610, 1520, 1356, 1091, 1024; $^1$H NMR (400 MHz, CDCl$_3$) δ 8.18 (d, $J = 1.9$ Hz, 1H), 7.86 (dd, $J = 8.0$, 1.9 Hz, 1H), 7.74-7.63 (m, 2H), 7.58-7.42 (m, 4H), 7.38-7.23 (m, 6H), 6.67 (dd, $J = 8.4$, 2.3 Hz, 1H), 6.58 (d, $J = 2.3$ Hz, 1H), 5.04 (s, 2H), 3.85, (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 161.1, 156.3, 149.9, 140.9, 138.6, 136.5, 133.2, 131.8, 130.8, 130.3, 129.1, 128.5, 128.3, 127.8, 127.1, 127.0, 122.5, 120.1, 105.5, 100.4, 70.7, 55.4; HRMS (EI+) calcd. for C$_{26}$H$_{21}$NO$_4$ (M+) 411.1471, found 411.1455.

Triaryl 5.4: To a pressure vessel was added 3.12 (43.8 mg, 118 mmol), p-MeO-C$_6$H$_4$-B(OH)$_2$ (68.9 mg, 453 mmol), Cs$_2$CO$_3$ (69.6 mg, 214 mmol), Pd$_2$(dba)$_3$ (2.3 mg, 2.5 mmol), PCy$_3$ (4.3 mg, 15 mmol), and dry dioxane (250 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite-®, eluting with Et$_2$O (60 mL) and concentrated in vacuo. The residue was purified by flash chromatography over silica gel, eluting with 10 % Et$_2$O/hexanes, to give 5.4 (47.0 mg, 107 mmol, 90%) as a bright yellow crystalline solid. MP 131-133°C; IR (thin film) 2957, 2923, 2853, 1610, 1581, 1527, 1514, 1356, 1246; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.83 (dd, $J = 8.0$, 1.4 Hz, 1H), 7.61 (dd, $J = 7.7$, 1.4 Hz, 1H), 7.51 (t, $J = 8.0$ Hz, 1H), 7.40-7.24 (m, 3H), 7.18 (d, $J = 6.3$ Hz, 2H), 6.98 (d, $J = 8.9$ Hz, 2H), 6.84 (d, $J = 8.3$ Hz, 1H), 6.73 (d, $J = 8.9$ Hz, 2H), 6.41 (d, $J = 2.3$ Hz, 1H), 6.39 (dd, $J = 8.3$, 2.4 Hz, 1H), 4.98 (d, $J = 12.6$ Hz, 1H), 4.88 (d, $J = 12.5$ Hz, 1H).
Hz, 1H), 3.80 (s, 3H), 3.76 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 160.6, 158.6, 156.8, 151.3, 144.3, 137.0, 133.9, 132.5, 131.5, 130.9, 130.4, 128.4, 127.7, 127.6, 126.7, 122.2, 117.7, 113.3, 104.9, 99.9, 70.0, 55.2, 55.2; HRMS (Cl+) calcd. for C$_{27}$H$_{24}$NO$_5$ (M+H) 442.1654, found 442.1668.

![Chemical structure](image)

**Triaryl 5.5:** To a pressure vessel was added 3.12 (47.3 mg, 128 mmol), m-MeO-C$_6$H$_4$-B(OH)$_2$ (65.5 mg, 431 mmol), Cs$_2$CO$_3$ (92.0 mg, 282 mmol), Pd$_2$(dba)$_3$ (2.9 mg, 3.2 mmol), PCy$_3$ (1.8 mg, 6.4 mmol), and dry dioxane (300 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite-®, eluting with Et$_2$O (60 mL) and concentrated *in vacuo*. The residue was purified by flash chromatography over silica gel, eluting with 10% Et$_2$O/hexanes, to give 5.5 (51.4 mg, 116 mmol, 91%) as a crystalline yellow, 1:1 mixture of atropisomers. MP 127-129°C; IR (thin film) 2929, 1612, 1583, 1528, 1512, 1360, 1227, 1042, 753; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.91-7.85 (m, 1H), 7.69-7.63 (m, 1H), 7.57-7.50 (m, 1H), 7.39-7.19 (m, 5H), 7.13 (t, J = 7.6 Hz, 1H), 6.89-6.84 (m, 1H), 6.80-6.76 (m, 1H), 7.64-6.68 (m, 1H), 6.63-6.58 (m, 1H), 6.47-6.38 (m, 2H), 4.99 (d, J = 12.4 Hz, 1H), 4.87 (d, J = 12.4 Hz, 1H), 3.75 (s, 3H), 3.60 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 160.8, 158.9, 156.8, 151.2, 144.4, 141.4, 137.0, 133.8, 131.4, 131.0, 128.8, 128.4, 127.8, 127.6, 126.7, 122.6, 121.8, 117.6, 114.4, 113.4, 104.9, 99.9, 70.1, 55.3, 55.0; HRMS (Cl+) calcd. for C$_{27}$H$_{23}$NO$_5$ 441.1576, found 441.1577.
Triaryl 5.6: To a pressure vessel was added 3.12 (42.3 mg, 114 mmol), o-MeO-C₆H₄-B(OH)₂ (64.4 mg, 432 mmol), Cs₂CO₃ (74.3 mg, 228 mmol), Pd₂(dba)₃ (2.5 mg, 2.7 mmol), PCy₃ (3.3 mg, 12 mmol), and dry dioxane (230 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite-®, eluting with Et₂O (60 mL) and concentrated in vacuo. The residue was purified by flash chromatography over silica gel, eluting with 10% Et₂O/hexanes, to give 5.6 (40.4 mg, 91.5 mmol, 80%) as a bright yellow crystalline solid. MP 123-124°C; IR (thin film) 3003, 2954, 1613, 1582, 1527, 1512, 1358, 1274, 1242, 1039, 1026, 755; ¹H NMR (400 MHz, CDCl₃) δ 7.90 (dd, J = 8.0, 1.3 Hz, 1H), 7.63-7.55 (br, 1H), 7.50, (t, J = 8.0 Hz, 1H), 7.39-7.16 (m, 6H), 7.04-6.59 (br, 4H), 6.48-6.21 (br, 2H), 4.98, (d, J = 12.4 Hz, 1H), 4.92 (d, J = 12.4 Hz, 1H), 3.719 (s, 3H), 3.5-3.2 (br, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 160.4, 156.5, 156.1, 150.7, 141.7, 137.0, 134.8, 132.3, 131.0, 130.9, 128.9, 128.4, 127.8, 127.6, 127.3, 126.7, 122.7, 120.0, 118.1, 110.3, 104.2, 99.5, 70.0, 55.2, 55.0; HRMS (FAB+) calcd. for C₂₇H₂₃NO₅ 441.1576, found 441.1595.

Triaryl 5.7: To a pressure vessel was added 3.12 (39.0 mg, 105 mmol), o-Me-C₆H₄-B(OH)₂ (69.5 mg, 511 mmol), Cs₂CO₃ (112.3 mg, 344.7 mmol), Pd₂(dba)₃ (2.4 mg, 2.6 mmol) and dry dioxane (300 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite-®, eluting with Et₂O (60 mL) and concentrated in vacuo. The
residue was purified by flash chromatography over silica gel, eluting with 10 % Et₂O/hexanes, to give 5.7 (40.0 mg, 93.9 mmol, 89%) as a crystalline yellow, 1:1 mixture of atropisomers. MP 72-75°C; IR (thin film) 3062, 2924, 1613, 1578,1528, 1512, 1269, 1049, 757; ¹H NMR (400 MHz, CDCl₃) δ 7.95-7.87 (m, 1H), 7.57-7.45 (m, 2H), 7.39-7.10 (m, 8H), 7.06-6.89 (m, 1H), 6.83-6.72 (m, 1H), 6.37 (dd, J = 10.0, 2.4 Hz, 1H), 6.28 (dt, J = 8.5, 2.3 Hz, 1H), 5.05-4.85 (m, 2H), 3.71 (s, 3H), 2.19 (s, 1.3 H), 1.80 (s, 1.7 H); ¹³C NMR (100 MHz, CDCl₃) δ 160.5, 160.4, 156.6, 156.3, 151.2, 151.1, 144.4, 144.4, 139.5, 139.4, 137.0, 136.8, 136.1, 135.1, 134.5, 134.3, 132.2, 131.8, 131.5, 130.4, 130.1, 129.7, 129.6, 128.5, 128.4, 127.7, 127.6, 127.4, 127.3, 126.8, 126.7, 125.1, 125.0, 122.7, 122.6, 117.8, 117.0, 104.6, 104.4, 99.5, 70.1, 70.0, 55.1, 20.4, 19.3; HRMS (EI+) calcd. for C₂₇H₂₃NO₄ 425.1627, found 425.1612.

**Triaryl 5.8:** To a pressure vessel was added 3.12 (41.0 mg, 111 mmol), p-CN-C₆H₄-B(OH)₂ (64.2 mg, 437 mmol), KF (58.4 mg, 1.00 mmol), Pd[BU₃P]₂ (4.0 mg, 7.8 mmol) and NMP (300 mL). The solution was sealed under Ar and heated to 80°C. After 24 h, the mixture was filtered over a pad of Celite®, eluting with Et₂O (60 mL) and concentrated in vacuo. The residue was purified by flash chromatography over silica gel, eluting with 10 % Et₂O/hexanes, to give 5.8 (40.0 mg, 91.5 mmol, 80%) as a bright yellow crystalline solid. MP 142-144°C; IR (thin film) 2950, 2918, 2228, 1610, 1582, 1531, 1513, 1272, 1242, 1048, 737; ¹H NMR (400 MHz, CDCl₃) δ 7.93 (t, J = 4.8 Hz, 1H), 7.85-7.78 (m, 1H), 7.75-7.70 (m, 1H), 7.60-7.54 (m, 2H), 7.50-7.45 (m, 2H), 7.37-7.28 (m, 1H), 7.19-7.10 (m, 4H), 6.80 (d, J = 8.4 Hz, 1H), 6.42 (d, J = 2.3 Hz, 1H), 6.39 (dd, J = 8.4, 2.3 Hz, 1H), 4.96 (d, J = 12.4 Hz, 1H), 4.84 (d, J = 12.4 Hz, 1H), 3.77 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 161.1, 156.6, 151.2, 144.9, 142.7, 136.6, 133.3, 132.9, 131.6, 131.3, 130.0,
128.5, 128.2, 127.8, 126.8, 123.5, 118.7, 116.6, 110.9, 105.1, 100.0, 70.1, 55.3; HRMS (Cl+) calcd. for \( \text{C}_{27}\text{H}_{20}\text{N}_{2}\text{O}_{4} \) 436.2423, found 436.1426.

**Triaryl 5.11:** To a pressure vessel was added **3.12** (110.3 mg, 298.2 mmol), \( m\text{-CF}_3\text{-C}_6\text{H}_4\text{-B(OH)}_2 \) (235.8 mg, 1.241 mmol), KF (155.5 mg, 2.676 mmol), \( \text{Pd}[^{[\text{Bu}_3\text{P}]}_2 \) (9.0 mg, 18 mmol) and NMP (600 mL). The solution was sealed under Ar and heated to 80°C. After 48 h, the mixture was filtered over a pad of Celite®, eluting with Et\(_2\)O (60 mL) and concentrated *in vacuo*. The residue was purified by flash chromatography over silica gel, eluting with 50-75% PhMe/hexanes, to give **5.11** (100.2 mg, 229.6 mmol, 77%) as a bright yellow crystalline solid. MP 121-124°C; IR (thin film) 3067, 2938, 1613, 1582, 1531, 1513, 1359, 1335, 1271, 1061, 756; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.93, (dd, \( J = 8.0, 1.4 \) Hz, 1H), 7.63 (dd, \( J = 8.0, 1.4 \) Hz, 1H), 7.57 (t, \( J = 7.8, 1 \)H), 7.49 (d, \( J = 7.7 \) Hz, 1H), 7.36-7.20 (m, 8H), 6.83 (d, \( J = 8.3 \) Hz, 1H), 6.42 (d, \( J = 2.2 \) Hz, 1H), 6.39 (dd, \( J = 8.3, 2.2 \) Hz, 1H), 4.97 (d, \( J = 12.4 \) Hz, 1H), 4.86 (d, \( J = 12.4 \) Hz, 1H), 3.74 (s, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 161.1, 156.7, 151.2, 143.1, 140.7, 136.7, 133.5, 132.5, 131.4, 131.3, 130.0 (q, \( J_{(C-F)} = 32 \) Hz), 128.4, 128.2, 128.1,127.7, 126.7, 126.1 (q, \( J_{(C-F)} = 4 \) Hz), 123.9 (q, \( J_{(C-F)} = 273 \) Hz), 123.9 (q, \( J_{(C-F)} = 4 \) Hz), 123.2, 122.6, 119.9, 116.9, 105.1, 99.9, 70.1, 55.3; HRMS (El+) calcd. for \( \text{C}_{27}\text{H}_{26}\text{F}_3\text{NO}_4 \) 479.1344, found 479.1334.
**Phenol 5.14:** To a stirred solution of 5.1 (45.3 mg, 110 mmol) in CH$_2$Cl$_2$ (98 mL) was added BCl$_3$ (600 mL, 600 mmol, 1.0 M in heptane) at 0°C. After 4 h, the reaction was quenched with MeOH (2.0 mL), concentrated *in vacuo,* and purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / hexanes to give 5.14 (32.9 mg, 102 mmol, 92%) as a bright yellow oil. IR (neat) 3522, 1620, 1592, 1526, 1360, 1264, 1040, 877, 764; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.85 (dd, $J = 8.0, 1.4$ Hz, 1H), 7.68 (dd, $J = 8.0,1.4$ Hz, 1H), 7.60 (t, $J = 8.0$ Hz, 1H), 7.28-7.21 (m, 3H), 7.19-7.12 (m, 2H), 6.77(d, $J = 8.0$ Hz, 1H), 6.41-6.32 (m, 2H), 4.95 (br, 1H), 3.65 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 160.8, 154.0, 151.7, 145.2, 139.5, 134.1, 131.5, 129.7, 129.1, 128.5, 128.0, 127.4, 122.6, 115.0, 106.7, 101.7, 55.2; HRMS (EI+) calcd. for C$_{19}$H$_{15}$NO$_4$ 321.1001, found 321.0999.

![Chemical structure](image)

**Aniline 5.13:** To a stirred solution of 5.1 (44.6 mg, 101 mmol) in glacial HOAc (410 mL) was added Zn dust (41.0 mg, 627 mmol) at rt. After 20 h, the mixture was quenched with sat. aq. NaHCO$_3$ (15 mL), diluted with EtOAc (20 mL) and washed with H$_2$O (20 mL) and sat. aq. NaCl (20 mL). The dried extract (Na$_2$SO$_4$) was concentrated *in vacuo* and purified via flash chromatography over silica gel, eluting with 15-25% EtOAc / Hexanes to give 5.13 (34.2 mg, 90.9 mmol, 90%) as a colorless oil. MP °C; IR (neat) 3471, 3379, 3058, 2835, 1609, 1580, 1266, 1044; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.38-7.13 (m, 11H), 7.01 (d, $J = 9.0$ Hz, 1H), 6.87 (dd, $J = 8.0,1.1$ Hz, 1H), 6.83 (dd, $J = 8.0, 1.1$ H, 1H), 6.54-6.41 (m, 2H), 5.02 (d, $J = 12.8$ Hz, 1H), 4.92 (d, $J = 12.8$ Hz, 1H), 3.76 (s, 3H), 3.52 (br, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 160.2, 157.2, 145.0, 143.2, 142.4, 137.4, 132.9, 129.3, 128.4, 128.1, 127.5, 127.4, 126.6, 126.0, 122.9, 120.2, 119.4, 114.3, 105.4, 100.6, 69.9, 55.3; HRMS (EI+) calcd. for C$_{26}$H$_{23}$NO$_2$ 381.1729, found 381.1721.
**Phenol 5.15**: To a stirred solution of **5.1** (54.7 mg, 1323 mmol) and EtOH (460 mL, absolute) was added Pd/C (62.3 mg, 10% Pd). After stirring under an atmosphere of H₂ for 21 h, the mixture was filtered over a pad of Celite® with EtOAc (50 mL) and concentrated in vacuo. The product was purified via flash chromatography over silica gel, eluting with 15-20% EtOAc / Hexanes to give **5.15** (26.1 mg, 89.6 mmol, 67%) as a colorless oil; IR (neat) 3472, 3382, 3187, 3057, 2959, 1621, 1573, 1265, 1161, 1039; ¹H NMR (400 MHz, CDCl₃) δ 7.30 (t, J = 7.9 Hz, 1H), 7.25-7.10 (m, 5H), 6.95 (dd, J = 7.6, 1.0 Hz, 1H), 6.86 (dd, J = 8.0, 1.0 Hz, 1H), 6.80 (d, J = 8.5 Hz, 1H), 6.54 (d, J = 2.5 Hz, 1H), 6.38 (dd, 8.5, 2.5 Hz, 1H), 3.78 (s, 3H), 4.70-3.40 (br, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 160.7, 154.7, 144.7, 144.0, 141.3, 132.6, 129.1, 129.1, 127.7, 126.5, 121.4, 120.6, 115.9, 114.9, 107.3, 101.6, 55.2; HRMS (EI⁺) calcd. for C₁₉H₁₇NO₂ 291.1259, found 291.1251.

**MRN-VII-68, MRN-VII-95, MRN-VIII-11, MRN-VIII-12, MRN-VIII-13, MRN-VIII-21, MRN-VIII-90, MRN-VIII-91, MRN-IX-42, MRN-IX-44, MRN-IX-49, Enol Triflate 2.35**: To a stirred solution of NaHMDS (118.0 mL, 118.0 mmol, 1.0 M in THF) and THF (225 mL) at 0°C, was added **2.32** (22.47 g, 112.6 mmol) via cannula over 30 min to give a purple solution. After another 20 min, **8.4** (124.0 mL, 124.0 mmol, 1 M in THF) was added via cannula. The mixture was allowed to warm to rt over 2 hours before slowly pured over an ice slurry. The slurry was extracted with Et₂O (3 x 150 mL), and the ethereal parts were
combined, and washed with sat aq. NaCl (2 x 100 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography (4" ID column) over silica gel (200g), eluting with PhMe to give impure 2.35 (23.68 g,) as a dark red-orange solid.

**MRN-VII-69, MRN-VII-81, MRN-VIII-93, MRN-VIII-94, MRN-IX-43, MRN-IX-45, MRN-IX-46, MRN-IX-53, Acetylene 2.19:** To a mechanically stirred suspension of NaH (22.92 g, 573.7 mmol, 60% dispersion in mineral oil) in THF (285 mL) at 0°C, was added t-AmOH (30.5 g, 38.0 mL, 347.0 mmol) via syringe over 5 min to give off slight effervescence. After 15 min, a 0°C solution of 2.35 (95.25 g, 286.9 mmol) in THF (287 mL) was added via cannula, over 30 min, to the vigorously stirred suspension. Upon addition of 2.35, copious effervescence was observed, and the mixture turned from a white suspension to a dark yellow-brown solution. After 30 min, the mixture was warmed to rt and slowly evolved to a burgundy color. After 45 min, the mixture was chilled to 0°C and quenched with abs EtOH (30 mL) and sat aq. NH₄Cl (100 mL, or until pH = 7). The bilayer was extracted with MTBE (3 x 250 mL), and the combined ethereal parts were washed with H₂O (100 mL) and sat aq NaCl (3 x 100 mL). The dried (MgSO₄) extract was concentrated in vacuo to give a brown solid. Purification via flash chromatography over silica gel, eluting with 20-50% EtOAc / hexanes to give 2.19 (9.324 g, 51.34 mmol, 18%) as a yellow solid. MP 94-95°C; IR (thin film) 3286, 1521, 1351, 808, 756, 736, 681; ¹H NMR (400 MHz, CDCl₃) δ 7.92 (dd, J = 8.2, 1.1 Hz, 1H), 7.74 (dd, J = 8.2, 1.1 Hz, 1H), 7.47 (t, J = 8.2, 1H), 3.86 (s, 1H); ¹³C NMR (100 MHz, CDCl₃) δ 139.8, 134.0, 129.6, 123.1, 117.6, 109.9, 91.7, 75.3; HRMS (CI+) calcd. for C₈H₅NO₂Cl (M+H) 182.0009, found 182.0005.

![Reaction Diagram](image-url)

**MRN-VIII-19 Acetylene 2.22:** To a stirred solution of 2.16 (1.655 g, 10.00 mmol), K₂CO₃ (3.620 g, 26.20 mmol), and dry MeOH (140 mL) was added
diazophosphonate 2.18\textsuperscript{21} (2.350 g, 12.23 mmol) slowly, at rt, in ca. 0.2 mL portions over 1 hour. After 3 h, the solution was quenched with pH 7 buffer\textsuperscript{22} (200 mL) and concentrated in vacuo to remove the MeOH and give crude 2.22 as an orange solid (1.387 g). The solid was filtered, and the mother liquor was diluted with EtOAc (150 mL) and washed with sat. aq. NaCl (2 x 50 mL). The dried (MgSO\textsubscript{4}) extract was concentrated in vacuo, and purified by flash chromatography over silica gel, eluting with 1% EtOAc / Hexanes, to give crude 2.22 (138.5 mg). The crude material isolated from recrystallization and column chromatography were combined and recrystallized with hexane to give 2.22 as a pale yellow solid (1.422 g, 8.823 mmol, 88%). MP 58-59°C; IR (thin film, cm\textsuperscript{-1}) 3284, 2108, 1529, 1349, 797, 778, 736, 645; \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \delta 7.81 (d, J = 8.1 Hz, 1H), 7.51 (d, J = 7.6 Hz, 1H), 7.38 (t, J = 8.0 Hz, 1H), 3.75 (s, 1H), 2.56 (s, 3H); \textsuperscript{13}C NMR (75 MHz, CDCl\textsubscript{3}) \delta 151.4, 144.2, 133.8, 128.5, 121.8, 116.7, 89.7, 76.7, 21.2; HRMS (EI+) calcd. for C\textsubscript{9}H\textsubscript{7}NO\textsubscript{2} (M+) 161.0477, found 161.0467.

MRN-X-44, Propyne 2.34: To a stirred solution of 2.33 (4.786 g, 26.71 mmol) and dry MeOH (480 mL) was added K\textsubscript{2}CO\textsubscript{3} (7.322 g, 52.98 mmol), and 2.18 (6.208 g, 32.31 mmol) dropwise via syringe at rt. After 15 h, the dark red mixture was quenched with pH 7 buffer (480 mL), concentrated in vacuo, and filtered. The orange solid was washed with H\textsubscript{2}O (20 mL), dissolved in EtOAc (100 mL) and washed with sat. aq. NaCl (2 x 25 mL). The dried (MgSO\textsubscript{4}) extract was concentrated in vacuo and purified via flash chromatography over silica gel, eluting with 0-15% EtOAc / Hexanes to give 2.34 (2.845 g, 16.34 mmol, 61%) as a orange solid. MP 42-44°C; IR (thin film, cm\textsuperscript{-1}) 2251, 2208, 1607, 1528, 804, 743, 710; \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \delta 7.55 (d, J = 8.1 Hz, 1H), 7.27 (d, J = 7.5 Hz, 1H), 7.12 (t, J = 7.9 Hz, 1H), 2.48 (s, 3H), 2.16 (s,
MRN-VIII-92, MRN-IX-23, MRN-IX-65, MRN-XI-42, Propyne 2.31: To a stirred solution of 2.32 (5.412 g, 27.11 mmol) and dry MeOH (385 mL) was added K₂CO₃ (7.635 g, 55.24 mmol), and 2.18 (6.253 g, 32.55) dropwise via syringe at rt. After 4 h, the dark red mixture was quenched with pH 7 buffer (350 mL), concentrated in vacuo, and filtered. The orange solid was washed with H₂O (20 mL), dissolved in EtOAc (100 mL) and washed with sat. aq. NaCl (2 x 15 mL). The dried (MgSO₄) extract was concentrated in vacuo to give 2.31 (4.467 g, 22.84 mmol, 84%) as a orange solid. MP 100-102°C; IR (thin film, cm⁻¹) 3086, 2249, 2208, 1519, 1346, 881, 809, 742; ¹H NMR (300 MHz, CDCl₃) δ 7.80 (dd, J = 8.1, 1.0 Hz, 1H), 7.64 (dd, J = 8.1, 1.0 Hz, 1H), 7.32 (t, J = 8.2 Hz, 1H), 2.20 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 151.8, 138.6, 133.2, 127.7, 122.4, 118.8, 101.5, 71.8, 5.0; HRMS (El+) calcd. for C₉H₆NO₂Cl (M+) 195.0087, found 195.0088.

MRN-VIII-18, MRN-VIII-45, MRN-VIII-47, MRN-VIII-87, MRN-VIII-88, MRN-X-32, MRN-X-82, MRN-XI-16, MRN-XI-22, MRN-XI-38 Acetylene 8.18: To a pressure vessel was added, DMF (13.0 mL), 2.19 (1.471 g, 8.101 mmol), 8.17 (4.94 g, 2.70 mL, 24.23 mmol), Cul (726.1 mg, 3.812 mmol), PdCl₂(PPh₃)₂ (1.128 g, 1.607 mmol), and NEt₃ (27.0 mL) sequentially. The vessel was
freeze-pumped-thawed (3x), sealed, and wrapped in foil. After 48h, the green solution was eluted through a Celite® pad with Et₂O (40 mL) and purified via flash chromatography over silica gel eluting with 10-25% EtOAc / hexanes to give **8.18** (1.244 g, 4.942 mmol, 61%) as a bright yellow solid. MP 63-65°C; IR (thin film, cm⁻¹) 2219, 2154, 1600, 1534, 923, 879, 803, 755, 735, 689; ¹H NMR (400 MHz, CDCl₃) δ 7.96 (dd, J = 8.3, 1.2 Hz, 1H), 7.73 (dd, J = 8.1, 1.2 Hz, 1H), 7.70-7.60 (m, 2H), 7.50-7.35 (m, 4H); ¹³C NMR (75 MHz, CDCl₃) δ 153.0, 138.5, 133.6, 132.1, 129.7, 128.5, 128.2, 122.8, 122.0, 118.6, 103.4, 81.6; HRMS (EI+) calcd. for C₁₄H₈NO₂Cl (M+) 257.0243, found 257.0250.

**MRN-IX-72, Triazole 4.1**: To a pressure vessel containing **2.19** (45.3 mg, 249 µmol) was added dry PhMe (500 µL) and azide **8.16** (130.7 mg, 978.4 µmol) sequentially and heated to 80°C. After 20 h, the reaction was cooled to rt, and went from a yellow solution to a white solid. The mix was filtered, and washed with Et₂O to give the sole regioisomer **4.1** (57.8 mg, 190.6 µmol, 74%) as pure white crystals. MP 174-175°C; IR (thin film, cm⁻¹) 3077, 2879, 1527, 1362, 1229, 1089, 760, 729; ¹H NMR (300 MHz, CDCl₃) δ 7.80 (dd, J = 8.1, 1.2 Hz, 1H), 7.75 (s, 1H), 7.72 (dd, J = 8.1, 1.2 Hz, 1H), 7.49 (t, J = 8.1 Hz, 1H), 7.45-7.35 (m, 3H), 7.35-7.25 (m, 2H), 5.67 (s, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 151.4, 139.6, 135.1, 134.4, 133.4, 129.9, 129.2, 128.8, 127.8, 124.5, 124.2, 122.6, 54.3; HRMS (EI+) calcd. for C₁₅H₁₁N₄O₂Cl (M+) 314.0570, found 314.0581.
MRN-IX-83, Triazole 4.3: To a pressure vessel containing 2.22 (72.2 mg, 448 µmol) was added dry PhMe (800 µL) and azide 8.16 (222.6 mg, 1.666 mmol) sequentially and heated to 80°C. After 24 h, the reaction was cooled to rt, and went from a yellow solution to a white solid. The mix was filtered, and washed with Et₂O to give the sole regioisomer 4.3 (60.5 mg, 205.6 µmol, 46%) as a pure white solid. MP 152-153°C; IR (thin film, cm⁻¹) 1538, 1352; ¹H NMR (300 MHz, CDCl₃) δ 7.70 (d, J = 7.8 Hz, 1H), 7.59-7.18 (m, 8H), 5.64 (s, 2H), 2.26 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 150.8141.5, 140.7, 134.6, 134.1, 129.2, 129.1, 128.8, 127.7, 124.3, 123.2, 121.4, 54.2, 20.7; HRMS (EI⁺) calcd. for C₁₆H₁₄N₄O₂ (M⁺) 294.1117, found 294.1106.

MRN-IX-86, Triazole 4.3: To a stirred solution of 2.22 (111.6 mg, 692.3 µmol) and H₂O / t-BuOH (3.00 mL, 1:1) was added ascorbic acid (20.1 mg, 114 µmol), Cu₂SO₄•5H₂O (9.0 mg, 36 µmol) and azide 8.16 (293.4 mg, 2.196 mmol) sequentially at rt. Upon addition of azide 8.16 a white ppt formed. After 12 h, the mixture was filtered and washed with hexanes to give the sole regioisomer 4.3 (199.6 mg, 678.3 µmol, 98%) as a pure white solid. MP 152-153°C; IR (thin film, cm⁻¹) 1538, 1352; ¹H NMR (300 MHz, CDCl₃) δ 7.70 (d, J = 7.8 Hz, 1H), 7.59-7.18 (m, 8H), 5.64 (s, 2H), 2.26 (s, 3H); ¹³C NMR (75 MHz, CDCl₃) δ 150.8141.5, 140.7, 134.6, 134.1, 129.2, 129.1, 128.8, 127.7, 124.3, 123.2, 121.4, 54.2, 20.7; HRMS (EI⁺) calcd. for C₁₆H₁₄N₄O₂ (M⁺) 294.1117, found 294.1106.

MRN-IX-73, MRN-IX-77, MRN-X-78, Triazole 4.2a, and Triazole 4.2b: To a pressure vessel containing 2.31 (316.2 mg, 1.909 mmol) was added dry PhMe
(2.00 mL) and azide 8.16 (1.066 mg, 8.006 mmol) sequentially and heated to 120°C. After 24 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 20-40% EtOAc / Hexanes to give a mix of regioisomers 4.2a / 4.2b (405.4 mg, 1.233 mmol, 65%, 2:1) as a yellow oil. IR (neat, cm\(^{-1}\)) 1733, 1533, 1455, 1437, 1359, 1122, 883, 806, 728; \(^1\)H NMR (300 MHz, CDCl\(_3\)) major isomer: δ 7.90 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.76 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.55 (t, \(J = 8.1\) Hz, 1H), 7.48-7.34 (m, 3H), 7.24-7.14 (m, 2H), 5.62 (s, 2H), 2.11 (s, 3H); minor isomer: δ 7.95 (dd, \(J = 8.1, 1.3\) Hz, 1H), 7.69 (dd, \(J = 8.1, 1.3\) Hz, 1H), 7.59 (t, \(J = 8.1\) Hz, 1H), 7.48-7.34 (m, 3H), 7.24-7.14 (m, 1H), 6.69-6.94 (m, 1H), 5.40 (d, \(J = 12.7\) Hz, 1H), 5.32 (d, \(J = 12.7\) Hz, 1H), 2.11 (s, 3H); \(^13\)C NMR (75 MHz, CDCl\(_3\)) major isomer: δ 151.7, 138.7, 134.6, 133.6, 132.8, 130.4, 129.1, 128.3, 126.7, 125.2, 122.7, 52.1, 8.5, minor isomer: 151.7, 138.7, 137.9, 134.2, 133.6, 132.6, 131.5, 128.6, 128.4, 128.3, 128.1, 123.1, 53.5, 10.3; HRMS (EI+) calcd. for C\(_{16}\)H\(_{13}\)N\(_4\)O\(_2\)Cl (M+) 328.0727, found 328.0723.

MRN-IX-78, MRN-IX-87, MRN-X-77, Triazole 4.4a and Triazole 4.4b: To a pressure vessel containing 2.30 (639.2 mg, 3.268 mmol) was added dry PhMe (6.00 mL) and azide 8.16 (1.531 mg, 11.50 mmol) sequentially and heated to 120°C. After 24 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 20-40% EtOAc / Hexanes to give an inseparable mix of regioisomers 4.4a / 4.4b (733.6 mg, 2.232 mmol, 68%, 1:7) as a yellow oil. IR (neat, cm\(^{-1}\)) 1534, 1459, 1369; \(^1\)H NMR (400 MHz, CDCl\(_3\)) major isomer: δ 7.90 (d, \(J = 8.0\) Hz, 1H), 7.58 (d, \(J = 8.0\) Hz, 1H), 7.51 (t, \(J = 8.0\) Hz, 1H), 7.44-7.32 (m, 3H), 7.31-7.25 (m, 2H), 5.65 (s, 2H), minor isomer: 8.03 (d, \(J =
8.1 Hz, 1H), 7.61-7.59 (m, 1H), 7.48 (d, J = 8.1 Hz, 1H), 7.40-7.34 (m, 1H), 7.19 (t, J = 7.2 Hz, 2H), 6.96 (d, J = 7.4 Hz, 2H), 5.89 (d, J = 14.8 Hz, 1H), 5.09 (d, J = 14.8 Hz, 1H), 1.59 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) major isomer: $\delta$ 150.2, 141.5, 139.1, 134.8, 133.8, 130.0, 129.1, 128.9, 128.6, 127.3, 124.6, 122.3, 52.3, 20.1, minor isomer: 149.1, 142.4, 135.4, 133.0, 131.4, 130.0, 129.1, 128.8, 128.5, 122.8, 122.8, 119.0, 54.4, 19.1; HRMS (Cl+) calcd. for C$_{16}$H$_{14}$N$_4$O$_2$Cl (M+H) 329.0805, found 250.0791.

MRN-X-48, MRN-X-51, MRN-X-51, MRN-XI-17, Triazole 4.5a, and Triazole 4.5b: To a pressure vessel containing 2.34 (69.2 mg, 390.5 µmol) was added dry PhMe (800 µL) and azide 8.16 (174.3 mg, 1.309 mmol) sequentially and heated to 120°C. After 72 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 20-40% EtOAc / Hexanes to give an inseparable mix of regioisomers C / D (50.3 mg, 168 µmol, 43%, 1:1) as a yellow oil. IR (neat, cm$^{-1}$) 1529, 1496, 1455, 1353, 1016, 914, 804, 754, 731; $^1$H NMR (400 MHz, CDCl$_3$) isomer mix: $\delta$ 7.88 (d, J = 8.1 Hz, 1H), 7.75 (d, J = 8.0 Hz, 1H), 7.58-7.47 (m, 2H), 7.46-7.39 (m, 2H), 7.38-7.27 (m, 3H), 7.26-7.09 (m, 5H), 6.92 (d, J = 7.3 Hz, 2H), 5.56 (s, 2H), 5.49 (d, J = 14.9 Hz, 1H), 5.05 (d, J = 14.9 Hz, 1H), 2.15 (s, 3H), 2.06 (s, 3H), 2.00 (s, 3H), 1.50 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) isomer mix: $\delta$ 150.9, 149.8, 142.5, 142.1, 141.5, 140.2, 134.8, 134.7, 134.3, 134.0, 132.0, 130.7, 129.4, 129.1, 128.6, 128.6, 128.5, 128.3, 128.3, 126.7, 124.9, 122.2, 121.7, 121.0, 53.2, 52.0, 20.2, 19.1, 10.2, 8.2; HRMS (El+) calcd. for C$_{17}$H$_{16}$N$_4$O$_2$ (M+) 308.1273, found 308.1288.
**MRN-IX-79, MRN-IX-91, MRN-XI-54, Triazole 4.6a and Triazole 4.6b:** To a pressure vessel containing 2.29 (552.9 mg, 2.559 mmol) was added dry PhMe (5.00 mL) and azide 8.16 (1.354 g, 10.17 mmol) sequentially and heated to 120°C. After 48 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 10-25% EtOAc / Hexanes to give an inseparable mix of regioisomers 4.6a / 4.6b (710.9 mg, 2.036 mmol, 80%, 11:1) as a yellow oil. IR (neat, cm\(^{-1}\)) 1608, 1533, 1355, 1226, 991, 883, 808, 759, 727, 704; \(^1\)H NMR (400 MHz, CDCl\(_3\)) major isomer \(\delta\) 7.97 (dd, \(J = 8.2, 1.2\) Hz, 1H), 7.80 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.59 (t, \(J = 8.2\) Hz, 1H), 7.43-7.33 (m, 3H), 7.29-7.25 (m, 2H), 5.65 (s, 2H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 150.9, 137.5, 137.4, 134.2, 133.7, 131.2, 129.1, 128.6, 127.2, 125.5, 123.1, 123.1, 52.3; HRMS (Cl+) calcd. for C\(_{15}\)H\(_{11}\)N\(_4\)O\(_2\)Cl\(_2\) (M+H) 349.0259, found 349.0257.

**MRN-IX-85, MRN-X-73, MRN-X-76, Triazole 4.7a and Triazole 4.7b:** To a pressure vessel containing 2.28 (866.9 mg, 3.328 mmol) was added dry PhMe (7.00 mL) and azide 8.16 (1.195 g, 8.975 mmol) sequentially and heated to 80°C. After 12 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 10-25% EtOAc / Hexanes to give an inseparable mix of regioisomers 4.7a / 4.7b (1.038 g, 2.637 mmol, 79%, 11:1) as a red-orange solid. MP 126-128°C; IR (neat, cm\(^{-1}\)) 1534, 1328; \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 7.97 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.78 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.59 (t, \(J = 8.1\) Hz, 1H).
Hz, 1H), 7.43-7.26 (m, 3H), 7.24-7.20 (m, 2H), 5.67 (s, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 150.9, 137.5, 137.4, 134.2, 133.7, 131.2, 129.1, 128.6, 127.2, 125.5, 123.1, 123.1, 52.3; HRMS (Cl+) calcd. for C$_{15}$H$_{10}$N$_4$O$_2$ClBr (M+) 391.9675, found 391.9658.

MRN-X-87, Triazole 4.8a and Triazole 4.8b: To a pressure vessel containing 8.18 (246.6 mg, 957 µmol) was added dry PhMe (2.00 mL) and azide 8.16 (391.3 mg, 2.939 mmol) sequentially and heated to 120°C. After 48 h, the reaction was cooled to rt, and concentrated in vacuo. The crude cycloadduct was purified via flash chromatography over silica gel, eluting with 20-40% EtOAc / Hexanes to give a separable mix of regioisomers 4.8a / 4.8b (250.1 mg, 641.2 µmol, 67%, 3:1) as a yellow oil. IR (neat, cm$^{-1}$) 1603, 1534, 1355, 1116, 911, 805, 731, 698; $^1$H NMR (400 MHz, CDCl$_3$) major isomer δ 7.86 (d, $J = 8.1$ Hz, 1H), 7.64 (d, $J = 8.1$ Hz, 1H), 7.48 (t, $J = 8.1$ Hz, 1H), 7.42-7.25 (m, 6H), 7.17 (d, $J = 7.2$ Hz, 2H), 7.08 (d, $J = 7.5$ Hz, 2H), 5.58 (s, 2H), minor isomer δ 8.02 (d, $J = 8.1$ Hz, 1H), 7.73 (d, $J = 8.1$ Hz, 1H), 7.64 (t, $J = 8.1$ Hz, 1H), 7.45-7.31 (m, 2H), 7.29-7.18 (m, 6H), 7.06 (d, $J = 7.2$ Hz, 2H), 5.45 (d, $J = 15.0$ Hz, 1H), 5.38 (d, $J = 15.0$ Hz, 1H); $^{13}$C NMR (100 MHz, CDCl$_3$) major isomer δ 151.5, 138.8, 137.4, 137.0, 135.4, 133.8, 130.4, 129.7, 129.1, 128.9, 128.1, 126.9, 126.3, 125.4, 122.8, 52.2, minor isomer δ 149.8, 145.9, 137.9, 135.0, 133.4, 132.2, 130.6, 129.0, 128.7, 128.6, 128.4, 128.3, 128.3, 126.1, 123.8, 53.5; HRMS (EI+) calcd. for C$_{21}$H$_{15}$N$_4$O$_2$Cl (M+) 390.0883, found 390.0887.
MRN-IX-94 Isoxazole 4.9: To a stirred 80°C solution containing 2.19 (63.8 mg, 351 µmol), NEt₃ (500 µL, 363 µg, 3.59 mmol), and PhMe (700 µL), was added a toluene solution of 8.19 (15.4 mL, 3.846 mmol, 250 mM) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 2-8% EtOAc / Hexanes gave pure 4.9 (105.9 mg, 309.0 µmol, 88%) as a yellow oil. IR (thin film, cm⁻¹) 1750, 1613, 1536, 1464, 1439, 1382, 1353, 906, 882, 808, 757, 737; ¹H NMR (300 MHz, CDCl₃) δ 8.02 (dd, J = 8.2, 1.2 Hz, 1H), 7.83 (dd, J = 8.2, 1.2 Hz, 1H), 7.65 (t, J = 8.2 Hz, 1H), 7.00 (s, 2H), 6.49 (s, 1H), 2.36 (s, 3H), 2.25 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 162.3, 162.2, 150.2, 139.1, 137.3, 136.3, 134.4, 131.7, 128.4, 125.5, 123.1, 122.4, 107.6, 21.8, 20.2; HRMS (EI⁺) calcd. for C₁₈H₁₅N₂O₃Cl (M⁺) 342.0771, found 342.0759.

MRN-IX-98, MRN-X-14, Isoxazole 4.11: To a stirred 80°C solution containing 2.22 (47.2 mg, 293 µmol), 8.19 (519.9 mg, 2.630 mmol), and PhMe (1.50 mL), was added a toluene solution of NEt₃ (2.40 mL, 3.60 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 10-25 % EtOAc / Hexanes to give impure 4.11 as a solid. The impure solid was recrystallized from hexanes / methanol to give pure 4.11 (87.1 mg, 269 µmol, 92%) as a pale yellow oil. IR (thin film, cm⁻¹) 1613, 1528,
1457, 1381, 1354, 906, 855, 832, 802, 707; $^1$H NMR (300 MHz, CDCl$_3$) δ 7.92 (dd, $J = 7.7$, 1.0 Hz, 1H), 7.63 (d, $J = 6.5$ Hz, 1H), 7.58 (t, $J = 7.7$ Hz, 1H), 6.99 (s, 2H), 6.29 (s, 1H), 2.40 (s, 3H), 2.36 (s, 3H), 2.24 (s, 6H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ 164.8, 162.3, 149.6, 140.8, 139.0, 137.2, 134.9, 130.8, 128.4, 125.7, 122.3, 122.1, 106.1, 21.2, 20.2, 20.0; HRMS (EI+) calcd. for C$_{19}$H$_{18}$N$_2$O$_3$ (M+) 322.1317, found 322.1304.

**MRN-IX-100, Isoxazole 4.10:** To a stirred 80°C solution containing 2.31 (41.4 mg, 212 µmol), 8.19 (446.3 mg, 2.258 mmol), and PhMe (1.00 mL), was added a toluene solution of NEt$_3$ (1.72 mL, 2.58 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 5-15 % EtOAc / Hexanes to give impure 4.10 as a yellow oil. The impure oil was triturated and recrystallized from hexanes / methanol to give pure 4.10 (65.6 mg, 184 µmol, 87%) as a pale yellow solid. MP 151-153°C; IR (thin film, cm$^{-1}$) 1609, 1535, 1456, 1437, 1348, 901, 852, 808, 759, 735; $^1$H NMR (400 MHz, CDCl$_3$) δ 8.08 (dd, $J = 8.2$, 1.2 Hz, 1H), 7.85 (dd, $J = 8.1$, 1.2 Hz, 1H), 7.68 (t, $J = 8.2$ Hz, 1H), 7.00 (s, 2H), 2.37 (s, 3H), 2.18 (s, 6H), 1.75 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 163.4, 159.0, 150.3, 139.0, 137.5, 137.0, 134.5, 131.8, 128.3, 124.8, 123.3, 122.8, 114.8, 21.2, 19.7, 7.1; HRMS (EI+) calcd. for C$_{19}$H$_{17}$N$_2$O$_3$Cl (M+) 356.0928, found 356.0926.
**MRN-IX-99, MRN-XI-36, Isoxazole 4.12:** To a stirred 80°C solution containing 2.30 (240.9 mg, 1.231 mmol), 8.19 (2.369 g, 11.98 mmol), and PhMe (6.10 mL), was added a toluene solution of NEt$_3$ (10.1 mL, 15.1 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give impure 4.12 as a yellow solid. The impure solid was recrystallized from methanol to give pure 4.12 (346.8 mg, 977.5 µmol, 73%) as a yellow solid. MP 178-180°C; IR (thin film, cm$^{-1}$) 1538, 1455, 1384, 1339, 912, 880, 854, 803, 748, 735; $^1$H NMR (300 MHz, CDCl$_3$) δ 8.11 (dd, $J = 7.4$, 2.0 Hz, 1H), 7.70 (d, $J = 5.7$ Hz, 1H), 7.66 (t, $J = 7.2$ Hz, 1H), 7.02 (s, 2H), 2.39 (s, 3H), 2.38 (s, 3H), 2.23 (s, 6H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ 161.7, 161.4, 149.0, 141.5, 139.8, 135.5, 131.5, 128.4, 122.8, 122.8, 120.4, 110.0, 21.3, 19.7, 19.5; HRMS (EI+) calcd. for C$_{19}$H$_{17}$N$_2$O$_3$Cl(M+) 356.0928, found 356.0913.

![Reaction Scheme](attachment://reaction_scheme.png)

**MRN-X-11, Isoxazole 4.13:** To a stirred 80°C solution containing 2.29 (41.1 mg, 190 µmol), 8.19 (386.8 mg, 1.957 mmol), and PhMe (1.00 mL), was added a toluene solution of NEt$_3$ (1.67 mL, 2.51 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give impure 4.13 as a yellow solid. The impure solid was recrystallized from methanol to give pure 4.13 (50.2 mg, 133 µmol, 70%) as a light brown oil. IR (thin film, cm$^{-1}$) 1528, 1353; $^1$H NMR (400 MHz, CDCl$_3$) δ 8.21 (dd, $J = 8.2$, 1.2 Hz, 1H), 7.90 (dd, $J = 8.2$, 1.2 Hz, 1H), 7.74 (t, $J = 8.2$ Hz, 1H), 7.02 (s, 2H), 2.38 (s, 3H), 2.23 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 161.5, 159.4, 149.7, 139.8, 137., 137.4, 132.6, 128.4, 123.6, 122.6,
MRN-X-10, Isoxazole 4.14: To a stirred 80°C solution containing 2.28 (42.8 mg, 164 µmol), 8.19 (353.8 mg, 1.790 mmol), and PhMe (1.00 mL), was added a toluene solution of NEt$_3$ (1.43 mL, 2.15 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 2-10 % EtOAc / Hexanes to give impure 4.14 as a yellow solid. The impure solid was recrystallized from methanol to give pure 4.14 (46.8 mg, 111 µmol, 68%) as a light brown oil. IR (thin film, cm$^{-1}$) 1527, 1356, 1116; $^1$H NMR (400 MHz, CDCl$_3$) δ 8.21 (d, J = 8.2 Hz, 1H), 7.90 (d, J = 8.2 Hz, 1H), 7.74 (t, $J = 8.2$ Hz, 1H), 7.02 (s, 2H), 2.38 (s, 3H), 2.23 (s, 3H), 2.20 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 162.9, 161.7, 149.6, 139.8, 138.0, 137.3, 135.0, 132.6, 128.4, 128.3, 123.6, 121.4, 97.3, 21.3, 19.7; HRMS (EI+) calcd. for C$_{18}$H$_{14}$N$_2$O$_3$ClBr (M+) 419.9876, found 419.9880.

MRN-X-49, Isoxazole 4.15: To a stirred 80°C solution containing 2.34 (80.9 mg, 462 µmol), 8.19 (845.6 mg, 4.278 mmol), and PhMe (2.30 mL), was added a toluene solution of NEt$_3$ (3.70 mL, 5.55 mmol, 1.50 M) via syringe pump over 5 hours. After 10 h, the reaction was cooled to rt and filtered. The mother liquor was purified via flash chromatography over silica gel, eluting with 2-10 % EtOAc / Hexanes to give impure 4.15 as a yellow solid. The impure
solid was recrystallized from methanol to give pure 4.15 (115.7 mg, 349.3 µmol, 74%) as a light brown solid. MP 133-135°C; IR (thin film, cm\(^{-1}\)) 1643, 1613, 1533, 1457, 1347, 914, 853, 804, 741; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.99 (dd, \(J = 8.4, 1.3\) Hz, 1H), 7.65 (dd, \(J = 7.7, 1.9\) Hz, 1H), 7.60 (t, \(J = 7.9\) Hz, 1H), 7.00 (s, 2H), 2.36 (s, 3H), 2.33 (s, 3H), 2.18 (s, 6H), 1.67 (s, 3H); \(^13\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 163.3, 161.3, 149.6, 141.4, 138.9, 137.3, 135.0, 130.7, 128.2, 125.0, 122.5, 122.3, 113.4, 21.2, 19.7, 19.6, 6.9; HRMS (EI+) calcd. for C\(_{20}\)H\(_{20}\)N\(_2\)O\(_3\) (M+) 336.1470, found 336.1462.

**MRN-X-45, Biphenyl 3.25:** To a pressure vessel containing 2.19 (63.3 mg, 350 mmol), was added a mixture of 3.8 and 3.9 (200.0 mg, 1.815 mmol, 3.8:3.9 = 3:1 via \(^1\)H-NMR) at rt. The vessel was wrapped in foil, and heated to 200°C. After 20 min, the mixture was cooled to rt, and concentrated in vacuo. Purification via flash chromatography over silica gel, eluting with 0-30% CH\(_2\)Cl\(_2\) / hexanes gave 3.25 (31.2 mg, 119 µmol, 34%) as a yellow solid. IR (thin film, cm\(^{-1}\)) 1530, 1498, 1358, 1261, 1030, 755; \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 7.84 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.74 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.48-7.39 (m, 2H), 7.19 (dd, \(J = 8.3, 1.8\) Hz, 1H), 7.07 (td, \(J = 8.3, 1.8\) Hz, 1H), 7.01 (d, \(J = 8.3\) Hz, 1H), 3.76 (s, 3H); \(^13\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 156.3, 151.1, 136.3, 133.6, 132.1, 130.4, 130.1, 128.7, 123.3, 122.2, 120.7, 111.0, 55.6; HRMS (EI+) calcd. for C\(_{13}\)H\(_{10}\)NO\(_3\)Cl (M+) 263.0349, found 263.0351.

**MRN-X-46, Biphenyl 3.27:** To a pressure vessel containing 2.22 (87.9 mg, 545 mmol), was added a mixture of 3.8 and 3.9 (338.5 mg, 3.072 mmol, 3.8:3.9 = 3:1 via \(^1\)H-NMR) at rt. The vessel was wrapped in foil, and heated to
200°C. After 20 min, the mixture was cooled to rt, and concentrated in vacuo. Purification via flash chromatography over silica gel, eluting with 0-30% CH₂Cl₂ / hexanes gave 3.27 (30.8 mg, 125 µmol, 23%) as an orange solid. IR (thin film) 3419, 2115, 2068, 1608, 1296, 1263, 808; ¹H NMR (400 MHz, CDCl₃) δ 7.73 (d, J = 8.0 Hz, 1H), 7.52 (d, J = 8.0 Hz, 1H), 7.48 – 7.35 (m, 2H), 7.13 – 6.95 (m, 3H), 3.76 (s, 3H), 2.19 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 156.4, 150.5, 139.8, 134.1, 132.5, 129.7, 129.7, 127.8, 125.2, 121.3, 120.9, 111.1, 55.5, 20.4; HRMS (EI⁺) calcd. for C₁₄H₁₃NO₃ (M⁺) 243.0895, found 243.0912.

MRN-X-39, Biphenyl 3.26: To a pressure vessel containing 2.31 (1.4787 g, 7.560 mmol) and xylenes (9.0 mL), was added a mixture of 3.8 and 3.9 (3.949 g, 35.84 mmol, 3.8:3.9 = 3:1 via ¹H-NMR) at rt. The vessel was purged with a stream of Ar, wrapped in foil, and heated to 200°C. After 10 h, the mixture was cooled to rt, and concentrated in vacuo. Purification via flash chromatography over silica gel, eluting with 70-100% PhMe / hexanes gave 3.26 (697.5 mg, 1.596 mmol, 35%) as a yellow solid. MP 85-87°C, IR (thin film, cm⁻¹) 1537, 1353, 1110; ¹H NMR (400 MHz, CDCl₃) δ 7.88 (dd, J = 8.2, 1.2, 1H), 7.75 (dd, J = 8.1, 1.2 Hz, 1H), 7.47 (t, J = 8.1 Hz, 1H), 7.32 (t, J = 7.9 Hz, 1H), 6.93 (d, J = 7.6 Hz, 1H), 6.80 (d, J = 8.3 Hz, 1H), 3.69 (s, 3H), 2.05 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 156.2, 150.9, 137.8, 136.5, 133.6, 131.8, 129.6, 128.8, 123.2, 122.4, 122.3, 108.3, 55.8, 19.5; HRMS (EI⁺) calcd. for C₁₄H₁₂NO₃Cl (M⁺) 277.0506, found 277.0503.

MRN-XI-43, Biphenyl 3.26: To a pressure vessel containing 2.31 (956.3 mg, 4.889 mmol), was added a mixture of 3.8 and 3.9 (1.527 g, 13.86 mmol,
3.8:3.9 = 3:1 via $^1$H-NMR) at rt. The vessel was freeze-pump-thawed (3x), and heated to 140°C. After 48 h, the mixture was cooled to rt, and concentrated in vacuo. Purification via flash chromatography over silica gel, eluting with 10-30% CH$_2$Cl$_2$ / hexanes gave 3.26 (212.8 mg, 934.7 µmol, 19%) as a yellow solid. MP 85-87°C, IR (thin film, cm$^{-1}$) 1537, 1353, 1110; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.88 (dd, $J = 8.2$, 1.2, 1H), 7.75 (dd, $J = 8.1$, 1.2 Hz, 1H), 7.47 (t, $J = 8.1$ Hz, 1H), 7.32 (t, $J = 7.9$ Hz, 1H), 6.93 (d, $J = 7.6$ Hz, 1H), 6.80 (d, $J = 8.3$ Hz, 1H), 3.69 (s, 3H), 2.05 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.2, 150.9, 137.8, 136.5, 133.6, 131.8, 129.6, 128.8, 123.2, 122.4, 122.3, 108.3, 55.8, 19.5; HRMS (EI+) calcd. for C$_{14}$H$_{12}$NO$_3$Cl (M+) 277.0506, found 277.0503.

MRN-X-61, Biphenyl 3.26: To a pressure vessel containing 2.31 (1.104 g, 5.644 mmol), was added a mixture of 3.8 and 3.9 (4.083 g, 37.05 mmol, 3.8:3.9 = 3:1 via $^1$H-NMR) at rt. The vessel was purged with a stream of Ar, wrapped with foil, and heated to 200°C. After 16 h, the mixture was cooled to rt, and concentrated in vacuo to give a red oil. Purification via flash chromatography over silica gel, eluting with 20-50% CH$_2$Cl$_2$ / hexanes gave impure 3.26 (620.5 mg) as an orange solid. Recrystallization from MeOH afforded pure 3.26 (453.0 mg, 1.631 mmol, 30%, 42% BRSM) as a yellow solid. MP 85-87°C, IR (thin film, cm$^{-1}$) 1537, 1353, 1110; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.88 (dd, $J = 8.2$, 1.2, 1H), 7.75 (dd, $J = 8.1$, 1.2 Hz, 1H), 7.47 (t, $J = 8.1$ Hz, 1H), 7.32 (t, $J = 7.9$ Hz, 1H), 6.93 (d, $J = 7.6$ Hz, 1H), 6.80 (d, $J = 8.3$ Hz, 1H), 3.69 (s, 3H), 2.05 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 156.2, 150.9, 137.8, 136.5, 133.6, 131.8, 129.6, 128.8, 123.2, 122.4, 122.3, 108.3, 55.8, 19.5; HRMS (EI+) calcd. for C$_{14}$H$_{12}$NO$_3$Cl (M+) 277.0506, found 277.0503.
MRN-IX-36, Biphenyl 3.30: To a pressure vessel containing 2.31 (52.7 mg, 269 mmol), was added 3.11 (300 µL) at rt. The vessel was wrapped in foil, and heated to 200°C. After 10 min, the mixture was cooled to rt, and concentrated in vacuo. Purification via flash chromatography over silica gel, eluting with 0-30% CH₂Cl₂ / hexanes gave 3.30 (48.3 mg, 145 µmol, 53%) as a yellow oil. IR (thin film, cm⁻¹) 1531, 1360, 1113; ¹H NMR (400 MHz, CDCl₃) δ 7.91 (dd, J = 8.1, 1.2, 1H), 7.75 (dd, J = 8.1, 1.2 Hz, 1H), 7.49 (t, J = 8.3 Hz, 1H), 7.35 (t, J = 7.8 Hz, 1H), 7.13 (d, J = 7.6 Hz, 1H), 7.02 (d, J = 7.9 Hz, 1H), 3.57-3.41 (m, 2H), 3.40-3.25 (br, 2H), 2.79-2.68 (br, 2H), 2.67-2.54 (m, 2H), 2.90 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 151.3, 149.7, 138.0, 136.4, 133.3, 131.2, 129.7, 128.5, 126.2, 122.4, 118.2, 67.0, 52.4, 19.9; HRMS (EI+) calcd. for C₁₇H₁₇N₂O₃Cl (M⁺) 332.0928, found 332.0925.

MRN-X-62, Biphenyl 3.28: To a pressure vessel containing 2.34 (1.021 g, 5.828 mmol), was added a mixture of 3.8 and 3.9 (4.013 g, 36.41 mmol, 3.8:3.9 = 3:1 via ¹H-NMR) at rt. The vessel was purged with a stream of Ar, wrapped with foil, and heated to 140°C. After 10 h, the mixture was cooled to rt, and concentrated in vacuo to give a red oil. Purification via flash chromatography over silica gel, eluting with 20-45% CH₂Cl₂ / hexanes gave impure 3.28 (414 mg) as an orange oil. Repeated flash chromatography over silica gel, eluting with 10-30% CH₂Cl₂ / hexanes afforded pure 3.28 (278.1 mg, 1.081 mmol, 18%) as an orange solid. MP 55-56°C; IR (thin film, cm⁻¹) 1583, 1526, 1469, 1439, 1356, 1258, 1083, 915, 809, 779, 743, 703; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, J = 8.2 Hz, 1H), 7.56 (d, J = 7.6 Hz, 1H), 7.42 (t,
$J = 7.9 \text{ Hz}, \, 1\text{H}), \, 7.31 \, (t, \, J = 8.0 \text{ Hz}, \, 1\text{H}), \, 6.95 \, (d, \, J = 7.6 \text{ Hz}, \, 1\text{H}), \, 6.85 \, (d, \, J = 8.3 \text{ Hz}, \, 1\text{H}), \, 3.70 \, (s, \, 3\text{H}), \, 2.07 \, (s, \, 3\text{H}), \, 2.00 \, (s, \, 3\text{H}); \, ^{13}\text{C} \text{ NMR (100 MHz, CDCl}_3) \, \delta \, 156.3, \, 150.2, \, 139.7, \, 137.2, \, 134.1, \, 132.0, \, 128.9, \, 127.7, \, 124.8, \, 122.5, \, 121.5, \, 108.3, \, 55.7, \, 19.9, \, 19.5; \, \text{HRMS (EI+)} \text{ calcd. for C}_{15}H_{15}NO_3 (M+) 25.1052, \text{ found 257.1058.}

MRN-X-68, Biphenyl 3.28: To a pressure vessel containing 3.24 (948.6 g, 5.415 mmol), was added a mixture of 3.8 and 3.9 (2.434 g, 22.09 mmol, 3.8:3.9 = 3:1 via $^1\text{H-NMR}$) at rt. The vessel was purged with a stream of Ar, wrapped with foil, and heated to 140°C. After 24 h, the mixture was cooled to rt, and concentrated in vacuo to give a red oil. Purification via flash chromatography over silica gel, eluting with 10-30% CH$_2$Cl$_2$ / hexanes gave 3.28 (217.9 mg, 847.0 mmol, 16%) as an orange solid. MP 55-56°C; IR (thin film, cm$^{-1}$) 1583, 1526, 1469, 1439, 1356, 1258, 1083, 915, 809, 779, 743, 703; $^1\text{H} \text{ NMR (400 MHz, CDCl}_3) \, \delta \, 7.83 \, (d, \, J = 8.2 \text{ Hz}, \, 1\text{H}), \, 7.56 \, (d, \, J = 7.6 \text{ Hz}, \, 1\text{H}), \, 7.42 \, (t, \, J = 7.9 \text{ Hz}, \, 1\text{H}), \, 7.31 \, (t, \, J = 8.0 \text{ Hz}, \, 1\text{H}), \, 6.95 \, (d, \, J = 7.6 \text{ Hz}, \, 1\text{H}), \, 6.85 \, (d, \, J = 8.3 \text{ Hz}, \, 1\text{H}), \, 3.70 \, (s, \, 3\text{H}), \, 2.07 \, (s, \, 3\text{H}), \, 2.00 \, (s, \, 3\text{H}); \, ^{13}\text{C} \text{ NMR (100 MHz, CDCl}_3) \, \delta \, 156.3, \, 150.2, \, 139.7, \, 137.2, \, 134.1, \, 132.0, \, 128.9, \, 127.7, \, 124.8, \, 122.5, \, 121.5, \, 108.3, \, 55.7, \, 19.9, \, 19.5; \, \text{HRMS (EI+)} \text{ calcd. for C}_{15}H_{15}NO_3 (M+) 25.1052, \text{ found 257.1058.}

MRN-IX-20, MRN-IX-21, MRN-IX-22, MRN-IX-25, MRN-IX-26, Biphenyl 3.26: To a pressure vessel containing 2.31 (150.1 mg, 767.4 µmol), was added a mixture of 3.8 and 3.9 (250.8 mg, 270 µL, 2.28 mmol, 3.8:3.9 = 3:1 via $^1\text{H-NMR}$) at rt. (300 µL). The mixture was heated via microwave$^{24}$ (200°C,
150 psi, 300 W) for 20 min. The mixture was then diluted with PhMe (1.00 mL), and purified via flash chromatography over silica gel, eluting with 70-100% PhMe / hexanes to give 3.26 (110.8 mg, 399 µmol, 52%) as a yellow solid. MP 85-87°C, IR (thin film, cm\(^{-1}\)) 1537, 1353, 1110; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.88 (dd, \(J = 8.2, 1.2\), 1H), 7.75 (dd, \(J = 8.1, 1.2\) Hz, 1H), 7.47 (t, \(J = 8.1\) Hz, 1H), 7.32 (t, \(J = 7.9\) Hz, 1H), 6.93 (d, \(J = 7.6\) Hz, 1H), 6.80 (d, \(J = 8.3\) Hz, 1H), 3.69 (s, 3H), 2.05 (s, 3H); \(^1^3\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 156.2, 150.9, 137.8, 136.5, 133.6, 131.8, 129.6, 128.8, 123.2, 122.4, 122.3, 108.3, 55.8, 19.5; HRMS (EI+) calcd. for C\(_{14}\)H\(_{12}\)NO\(_3\)Cl (M+) 277.0506, found 277.0503.

MRN-III-89, Carbazole 6.20: To a pressure vessel containing 3.16 (38.7 mg, 114 µmol) and o-C\(_6\)H\(_4\)Cl\(_2\) (230 µL) was added PPh\(_3\) (75.5 mg, 289 µmol) at rt. The mixture was heated to 180°C. After 24 h, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give impure 6.20 (40.2 mg) as a brown solid. Recrystallization from CHCl\(_3\) / Pentane afforded 6.20 (26.3 mg, 85.5 µmol, 75 %) as an off-white solid. MP 158-160°C\(^\circ\); IR (thin film) 3387, 1177; \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.48 (d, \(J = 8.7\) Hz, 1H), 8.02 (br s, 1H), 7.52 (d, \(J = 7.2\) Hz, 2H), 7.45 (t, \(J = 7.2\) Hz, 2H), 7.38 (t, \(J = 7.2\) Hz, 1H), 7.33-7.18 (m, 3 H), 7.03 (dd, \(J = 8.7, 2.2\) Hz, 1H), 6.97 (d, \(J = 0.9\) Hz, 1H), 5.19 (s, 2H); \(^1^3\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 158.5, 140.8, 140.6, 137.0, 128.7, 128.0, 127.8, 127.5, 125.0, 123.9, 120.9, 120.3, 116.4, 109.3, 108.6, 95.7, 70.4; HRMS (EI+) calcd. for C\(_{19}\)H\(_{14}\)NOCl (M+) 307.0764, found 307.0775.
MRN-III-51, Carbazole 6.21: To a pressure vessel containing 3.17 (49.9 mg, 147 µmol) and o-C₆H₄Cl₂ (300 µL) was added PPh₃ (119.4 mg, 455 µmol) at rt. The mixture was heated to 180°C. After 24 h, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give impure 6.21 (50.4 mg) as a brown solid. Recrystallization from CHCl₃ / Pentane afforded 6.21 (43.7 mg, 142 µmol, 89%) as an off-white solid. MP 222-224°C; IR (KBr) 3390, 2916, 1624, 1225, 1176, 1027, 816, 728; ¹H NMR (400 MHz, d₆-DMSO) δ 11.30 (s, 1H), 8.11 (s, 1H), 8.04 (d, J = 7.8 Hz, 1H), 7.68-7.19 (m, 7H), 7.08 (s, 1H), 6.89 (d, J = 7.8 Hz, 1H), 5.22 (s, 2H); ¹³C NMR (100 MHz, d₆-DMSO) δ 158.5, 142.2, 138.7, 137.7, 128.9, 128.3, 128.2, 124.5, 124.3, 123.4, 122.0, 119.4, 116.0, 112.5, 109.4, 96.2, 70.0; HRMS (EI+) calcd. for C₁₉H₁₄NOCl (M+) 307.0764, found 307.0764.

MRN-I-69, MRN-III-88, Carbazole 6.22: To a pressure vessel containing 3.18 (18.7 mg, 55.0 mmol) and o-C₆H₄Cl₂ (150 µL) was added PPh₃ (44.1 mg, 168 µmol) at rt. The mixture was heated to 180°C. After 24 h, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-30% EtOAc / Hexanes to give impure 6.22 (17.6 mg) as a brown solid. Recrystallization from CHCl₃ / Pentane afforded 6.22 (14.2 mg, 46.1 µmol, 84 %) as an off-white solid. MP 235-238°C; IR (KBr) 3396, 2923, 1605, 1016, 797; ¹H NMR (400 MHz, d₆-DMSO) 11.29 (s, 1H), 8.02 (d,
$J = 3.3 \text{ Hz, } 1H), 8.00 (d, J = 3.7 \text{ Hz, } 1H), 7.52 (d, J = 7.2 \text{ Hz, } 2H), 7.46 (d, J = 1.8 \text{ Hz, } 1H), 7.43 (t, J = 7.1 \text{ Hz, } 2H), 7.35 (t, J = 7.3 \text{ Hz, } 1H), 7.14 (dd, J = 8.3, 1.9 \text{ Hz, } 1H), 7.09 (d, J = 2.3 \text{ Hz, } 1H), 6.90 (dd, J = 8.6, 2.3 \text{ Hz, } 1H), 5.21 (s, 2H); ^{13}C \text{ NMR (100 MHz, } d_6-\text{DMSO}) \delta 158.3, 141.9, 140.9, 137.7, 129.0, 128.9, 128.3, 128.2, 122.0, 121.6, 121.1, 119.1, 116.2, 110.8, 109.4, 96.4, 70.0; \text{ HRMS (EI+) calcd. for } C_{19}H_{14}NOCl (M^+) 307.0764, \text{ found 307.0772.}$

**MRN-IX-66, Phenol 8.10:** To a pressure vessel containing 2.20 (1.294 g, 7.126 mmol) and xylenes (14.0 mL) was added known diene 8.41$^{25}$ (4.831 g, 28.70 mmol) at rt. The mixture was heated at 140°C. After 10 h, the reaction was cooled to 0°C and TBAF (29.0 mL, 29.0 mmol, 1 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH$_4$Cl (100 mL), diluted with EtOAc (200 mL), washed with H$_2$O (2 x 50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (Na$_2$SO$_4$) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-35% EtOAc / Hexanes to give the phenol 8.10 (1.928 g) as an impure yellow oil.

**MRN-III-75, MRN-III-78, MRN-III-97, MRN-III-84, Toluene 6.23:** To a pressure vessel containing the impure phenol 8.10 (1.928 g), Cs$_2$CO$_3$ (4.637 g, 14.23 mmol), Pd$_2$(dba)$_3$ (35.8 mg, 39.1 mmol), PCy$_3$ (41.1 mg, 146 mmol), methyl boroxine (2.44 g, 2.70 mL, 19.4 mmol) and dioxane (20 mL). The solution was sealed under Ar and heated to 80°C. After 10 h, the vessel was cooled to rt and filtered over a pad of Celite®, eluting with EtOAc (150 mL) and concentrated in vacuo. The residue was purified by flash chromatography over silica gel, eluting with 0-20 % EtOAc / PhMe, to give 6.23 (1.226 g, 5.348 mmol, 76% over two steps) as a bright yellow crystalline solid. MP 94-97°C; IR (thin film) 3407, 1612, 1517, 1350, 1216, 758; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.79 (d, $J = 8.2$ Hz, 1H), 7.29-7.19 (m, 4H), 6.93-6.87 (m, 2H), 4.96 (br s, 1H),
$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 155.8, 146.9, 143.5, 136.2, 132.7, 129.9, 129.3, 128.3, 124.4, 115.7, 21.4; HRMS (EI+) calcd. for C$_{13}$H$_{11}$NO$_3$ (M+) 229.0739, found 229.0732.

MRN-III-67, MRN-III-70, MRN-III-76, MRN-III-77, MRN-III-81, MRN-III-84, MRN-IV-31, MRN-IV-32, MRN-VI-66, Allyl ether 8.24: To a stirred solution of 6.23 (843.0 mg, 3.677 mmol) and dry DMF (18.0 mL) was added NaH (320.9 mg, 8.022 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added allyl iodide (3.12 g, 1.70 mL, 18.59 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH$_4$Cl (20 mL), diluted with EtOAc (100 mL), washed with H$_2$O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na$_2$SO$_4$) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with PhMe to give 8.24 (990 mg, 3.68 mmol, 99%) as a bright yellow oil. IR (neat) 1610, 1516, 1353, 734; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.782 (d, $J$ = 8.9, 1H), 7.31-7.22 (m, 4H), 7.03-6.97 (m, 2H), 6.18-6.05 (m, 1H), 5.48 (dq, $J$ = 17.2, $J$ = 1.5 Hz, 1H), 5.34 (dq, $J$ = 10.5, 1.3 Hz, 1H), 4.60 (dt, $J$ = 5.3, 1.5 Hz, 2H), 2.47 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$158.6, 147.1, 143.3, 136.1, 133.2, 132.6, 130.1, 129.1, 128.3, 124.3, 117.8, 114.9, 68.9, 21.4; HRMS (EI+) calcd. for C$_{16}$H$_{15}$NO$_3$ (M+) 269.1052, found 269.1042.

MRN-III-87, MRN-IV-15, MRN-IV-33, Phenol 6.24: To a stirred solution of 8.24 (990 mg, 3.68 mmol) in CH$_2$Cl$_2$ (37.0 mL) was added BCl$_3$ (11.1 mL, 11.1
mmol, 1.0 M in hexanes) at -78°C. After 2 h, the reaction was quenched with MeOH (2.0 mL) at -78°C and warmed to rt. The solution was diluted with CH₂Cl₂ (45 mL) and washed with H₂O (2 x 20 mL) and sat. aq. NaCl (2 x 20 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica gel, eluting with 10-30% Et₂O / PhMe to give 6.24 (845.7 mg, 3.141 mmol, 85%) as a yellow crystalline solid. MP 82-83°C; IR (thin film) 3486, 1609, 1520, 1351, 1215, 758; ¹H NMR (400 MHz, CDCl₃) δ 7.78 (d, J = 8.1 Hz, 1H), 7.28-7.22 (m, 2H), 7.14-7.08 (m, 2H), 6.88 (d, J = 8.0 Hz, 1H), 6.06 (m, 1H), 5.24 (dq, J = 5.25, 1.5 Hz, 1H), 5.21 (t, J = 1.6 Hz, 2H), 5.20 (br s, 1H), 3.61 (d, J = 6.0 Hz, 2H), 2.54 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ; HRMS (EI+) calcd. for C₁₉H₁₅NO₄ (M⁺) 269.1052, found 269.1053.

Carbazole 6.27: To a pressure vessel containing 6.24 (51.6 mg, 191.6 mmol) and o-C₆H₄Cl₂ (2.00 mL) was added PPh₃ (205 mg, 782 µmol) at rt. The mixture was heated at 180°C. After 12 h at 180°C, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-25% EtOAc / Hexanes to give 6.27: MP °C; IR (neat); ¹H NMR (400 MHz, CDCl₃) δ 7.78 (d, J = 5.2 Hz, 3H), 7.27 (d, J = 8.0 Hz, 1H), 7.18 (dd, J = 8.0, 1.2 Hz, 1H), 6.86 (s, 1H), 6.15 (m, 1H), 5.26 (dq, J = 12, 1.6 Hz, 1H), 5.23 (dt, J = 4.8, 1.6 Hz, 1H), 5.20 (br s, 1H), 3.61 (d, J = 6.0 Hz, 2H), 2.54 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 153.45, 140.1, 137.8, 137.3, 128.7, 125.8, 123.7, 121.4, 119.5, 117.8, 117.4, 116.3, 110.0, 97.4, 35.7, 21.4; HRMS (EI+) calcd. for C₁₆H₁₅NO 237.1154 (M⁺), found 237.1155.

6.25 and 6.26: To a pressure vessel containing 6.24 (26.6 mg, 98.8 mmol) and o-C₆H₄Cl₂ (1.00 mL) was added ⁷⁷Bu₃P (81 mg, 100 µL, 400 µmol) at rt. The mixture was heated at 180°C. After 12 h at 180°C, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-25 % EtOAc / Hexanes to give sequentially 75 (5.6 mg, 24 µmol, 23%), 76 (9.4 mg, 39 µmol, 38%), and 74 (6.5 mg, 27 µmol, 27%) as off-white solids.

6.25: MP 131-133°C; IR (thin film) 3412, 3212, 2920, 2851, 1639, 1615, 1211, 909, 802; ¹H NMR (400 MHz, CDCl₃) δ 7.78 (d, J = 4.9 Hz, 3H), 7.27 (d, J = 8.2 Hz, 1H), 7.18 (dd, J = 8.2, 1.1 Hz, 1H), 6.86 (s, 1H), 6.15 (ddt, J = 16.5, 10.1, 6.3 Hz, 1H), 5.26 (dq, J = 12.2, 1.6 Hz, 1H), 5.23 (dt, J = 4.9, 1.7 Hz, 1H), 5.19 (br s, 1H), 3.61 (d, J = 3.6 Hz, 2H), 2.54 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 153.4, 140.1, 137.8, 137.3, 128.7, 125.8, 123.7, 121.5, 119.5, 117.9, 117.4, 116.4, 110.0, 97.4, 35.7, 21.5; HRMS (EI⁺) calcd. for C₁₆H₁₅NO 237.1154 (M⁺), found 237.1149.

6.26: MP 154-156°C; IR (thin film) 3459, 3356, 2918, 2850, 1614, 1211, 912, 804; ¹H NMR (400 MHz, CDCl₃) δ 7.91 (br s, 1H), 7.80 (d, J = 8.1 Hz, 1H), 7.79 (s, 1H), 7.32 (d, J = 8.2 Hz, 1H), 7.19 (dd, J = 8.2, 1.3 Hz, 1H), 6.76 (d, J = 8.3 Hz, 1H), 6.13 (ddt, J = 16.0, 10.1, 6.0 Hz, 1H), 5.29-5.19 (m, 2H), 4.96 (br s, 1H), 3.72 (dt, J = 5.9, 1.6 Hz, 2H), 2.54 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 152.0, 140.8, 137.9, 135.6, 128.9, 125.9, 124.1, 119.5, 119.0, 117.5, 116.3, 110.2, 108.9, 106.5, 29.4, 21.5; HRMS (EI⁺) calcd. for C₁₆H₁₅NO 237.1154 (M⁺), found 237.1149.

6.27: MP 136-138°C; IR (thin film) 3376, 3311, 1607, 1270; ¹H NMR (400 MHz, CDCl₃) δ 7.29-7.18 (m, 2H), 7.06-6.97 (m, 2H), 6.85 (d, J = 8.0 Hz, 1H),
6.76 (d, \( J = 7.8 \) Hz, 1H), 6.09 (m, 1H), 5.29-5.17 (m, 2H), 3.92 (br s, 1H), 3.49 (d, \( J = 6.4 \) Hz, 2), 2.34 (s, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\) \( \delta \) 153.4, 140.6, 136.4, 131.9, 131.1, 128.7, 128.4, 128.4, 128.1, 126.1, 116.6, 116.1, 116.0, 35.1, 20.5. HRMS (EI+) calcd. for C\(_{16}\)H\(_{17}\)NO (M+) 239.1310, found 239.1321.

**Phenol 6.28:** To a stirred solution of 6.24 (43.2 mg, 160.4 mmol) in CH\(_2\)Cl\(_2\) (500 µL) and 2-methyl-2-buten (596.0 mg, 0.90 mL, 8.49 mmol) was added Grubbs' 2\(^{nd}\) generation catalyst (4.0 mg, 4.7 µmol) at rt. After stirring for 18 h, the mixture was concentrated in vacuo and purified directly via flash chromatography over silica gel, eluting with 0-10% EtOAc / PhMe to give 6.28 (40.1 mg, 135.0 µmol, 73%) as a yellow oil. IR (neat) 3472, 1608, 1582, 1520, 1352, 824, 755; \(^1\)H NMR (400 MHz, CDCl\(_3\) \( \delta \) 7.77 (d, \( J = 8.8 \) Hz, 1H), 7.25 (d, \( J = 7.1 \) Hz, 2H), 7.09 (dd, \( J = 6.0 \), 2.1 Hz, 2H), 6.86 (d, \( J = 8.8 \) Hz, 1H), 5.48-5.31 (m, 2H), 3.41 (d, \( J = 7.1 \) Hz, 2H), 2.48 (s, 3H), 1.81 (s, 6H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\) \( \delta \) 154.5, 147.1, 143.1, 136.3, 135.2, 132.6, 130.0, 129.5, 128.1, 127.2, 127.1, 124.3, 121.4, 116.0, 29.7, 25.8, 21.4, 17.9; HRMS (EI+) calcd. for C\(_{18}\)H\(_{19}\)NO\(_3\) (M+) 297.1365, found 297.1364.

MRN-IV-42, MRN-V-86, MRN-V-87, Siamenol 6.1 and Carbazole 6.31: To a pressure vessel containing 77 (50.4 mg, 169 mmol) and o-C\(_6\)H\(_4\)Cl\(_2\) (400 µL) was added P\(^3\)Bu\(_3\) (138 mg, 170 µL, 681 µmol) at rt. The mixture was heated at
100°C. After 12 h at 100°C, the reaction was cooled to rt and purified via flash chromatography over silica gel, eluting with 10-25 % EtOAc / Hexanes to give sequentially 6.31 (19.2 mg, 72.3 µmol, 43%), 6.29 (10.8 mg, 40.4 µmol, 24%), and 6.1 (12.4 mg, 46.7 µmol, 28%) as white solids.

6.1: MP 140-143°C; IR (thin film) 3406, 3252, 2920, 2852, 1636, 1617, 1465, 1319, 1210, 1014, 802; ^1^H NMR (400 MHz, CDCl$_3$) δ 7.77 (m, 3H), 7.27 (d, J = 8.0 Hz, 1H), 7.17 (d, J=8.0 Hz, 1H), 6.86 (s, 1H), 5.44 (tt, J = 7.2, 1.2 H, 1H), 5.30 (s, 1H), 3.55 (d, J = 7.2 Hz, 2H), 2.54 (s, 3H), 1.88 (s, 3H), 1.85 (s, 3H); ^1^C NMR (100 MHz, CDCl$_3$) δ 153.7, 139.9, 137.7, 12.6, 120.8, 119.8, 12.6, 120.8, 119.4, 117.2, 109.9, 97.2, 30.5, 25.8, 21.4, 17.9; ^13^C NMR (100 MHz, CDCl$_3$) δ 154.16, 140.4, 138.5, 131.1, 127.3, 124.7, 124.0, 123.9, 120.5, 119.7, 118.5, 116.1, 109.7, 95.9, 28.5, 24.9, 20.4, 16.7 HRMS (EI+) calcd. for C$_{18}$H$_{19}$NO 265.1467 (M+), found 267.1471.

6.31: MP 126-128°C; IR (thin film) 3524, 3424, 3261, 2919, 2853, 1614, 1227, 1211, 1032, 802; ^1^H NMR (400 MHz, CDCl$_3$) δ 7.85 (br s, 1H), 7.78 (d, J = 1.0 Hz, 1H), 7.76 (d, J = 3.6 Hz, 1H), 7.31 (d, J = 8.2 Hz, 1H), 7.18 (dd, J = 8.4, 1.1 Hz, 1H), 6.76 (d, J = 8.3 Hz, 1H), 5.41 (d-quint, J = 6.9, 1.4 Hz, 1H), 5.11 (br s, 1H), 3.64 (d, J = 7.3 Hz, 2H), 2.54 (s, 3H), 1.94 (s, 3H), 1.82 (d, J = 1.2 Hz, 3H); ^13^C NMR (100 MHz, CDCl$_3$) δ 152.2, 140.4, 138.5, 131.1, 127.3, 124.7, 124.0, 123.9, 120.5, 119.7, 118.5, 116.1, 109.7, 95.9, 28.5, 24.9, 20.4, 16.7 HRMS (EI+) calcd. for C$_{18}$H$_{19}$NO 265.1467 (M+), found 267.1471.

6.29: MP 126-132°C; IR (thin film) 3363, 3276, 2920, 1604, 1431, 1279, 1233; ^1^H NMR (400 MHz, CDCl$_3$) δ 7.23 (d, J = 2.0 Hz, 1H), 7.21 (dd, J = 8.3, 2.1 Hz, 1H), 7.00 (d, J = 9.1 Hz, 2H), 6.87 (d, J = 8.0 Hz, 1H), 6.74 (d, J = 7.8 Hz, 1H), 5.40 (tt, J = 5.9, 1.3 Hz, 1H), 4.18 (br s, 1H), 3.44 (d, J = 7.2 Hz, 2H), 2.32 (s, 3H), 1.83 (s, 3H), 1.82 (s, 3H); ^13^C NMR (100 MHz, CDCl$_3$) δ 153.6, 140.9, 134.8, 131.9, 131.1, 130.7, 128.6, 128.1, 128.0, 127.4, 121.7,
Aniline 6.29: To a stirred solution of 6.28 (196.7 mg, 660.4 µmol) in glacial HOAc (6.0 mL) was added Zn dust (314.2 mg, 4.803 mmol) at rt. After 3 h, the mixture was quenched with sat. aq. NaHCO₃ (20 mL), diluted with EtOAc (100 mL) and washed with H₂O (10 mL) and sat. aq. NaCl (2 x 20 mL). The dried extract (Na₂SO₄) was concentrated in vacuo and purified by chromatography over silica gel, eluting with 0-40% EtOAc / Hexanes to give 6.29 (151.7 mg, 551.0 µmol, 86%) as an off white solid. MP 126-132°C; IR (thin film) 3363, 3276, 2920, 1604, 1431, 1279, 1233; ¹H NMR (400 MHz, CDCl₃) δ 7.23 (d, J=2.0 Hz, 1H), 7.21 (dd, J = 8.3, 2.1 Hz, 1H), 7.00 (d, J = 9.1 Hz, 2H), 6.87 (d, J = 8.0 Hz, 1H), 6.74 (d, J = 7.8 Hz, 1H), 5.40 (tt, J = 5.9, 1.3 Hz, 1H), 4.18 (br s, 1H), 3.44 (d, J = 7.2 Hz, 2H), 2.32 (s, 3H), 1.83 (s, 3H), 1.82 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 153.6, 140.9, 134.8, 131.9, 131.1, 130.7, 128.6, 128.1, 128.0, 128.0, 127.4, 121.7, 115.9, 115.9, 29.8, 25.9, 20.5, 17.9; HRMS (EI+) calcd. for C₁₈H₂₁NO (M+) 267.1623, found 267.1629.

Azide 6.30: To a stirred solution of 6.29 (150.2 mg, 562.1 mmol) and dioxane (2.00 mL) was chilled to -10°C and H₂SO₄ (5.60 mL, 1.98 M) was added. After stirring for 5 min at -10°C, NaN₃ (82.8 mg, 400 µL, 1.20 mmol, 3.00 M) was added via syringe. After 20 min at -10°C, NaN₃ (117.0 mg, 600 µL, 1.80 mmol, 3.01 M) was added to the deep yellow solution and copious
effervescence evolved. After 30 min, the mixture was warmed to rt, and diluted with Et₂O (30 mL). The organic extract was washed with NaHCO₃ (3 x 15 mL) and sat aq. NaCl (2 x 10 mL). The dried extract (Na₂SO₄) was concentrated in vacuo to give **6.30** (114.0 mg, 542.8 µmol, 97%) as a brown oil and used without further purification. IR (thin film) 3419, 2115, 2068, 1608, 1296, 1263, 808; ¹H NMR (400 MHz, CDCl₃) δ 7.25-7.13 (m, 5H), 6.89 (d, J = 7.9 Hz, 1H), 5.41 (tt, J = 7.4, 1.3 Hz, 1H), 5.24 (d, J = 1.9 Hz, 1H), 3.45 (d, J = 7.2 Hz, 2H), 2.40 (s, 3H), 1.84 (s, 3H), 1.83 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 154.0, 135.0, 134.6, 134.3, 133.4, 131.8, 131.1, 130.8, 128.9, 128.6, 126.5, 121.7, 118.7, 115.5, 30.0, 25.8, 20.9, 17.9; HRMS (EI+) calcd. for C₁₈H₁₉N₃O (M+) 293.1528, found 293.1518.

**MRN-IV-53, Carbazole 6.31 and Siamenol 6.1:** To a stirred solution of **6.30** (57.4 mg, 195.6 mmol) and PhMe (1.96 mL) and 2-methyl-2-butene (300 µL) was chilled to -10°C and MeLi (160 µL, 216 µmol, 1.35M in Et₂O) was added. After 5 min, BCl₃ (600 µL, 600 µmol, 1 M in hexanes) was added to the red mixture, and slight effervescence was observed. After stirring for 24 h at -10°C, the mixture was quenched with MeOH (1 mL) at -10°C, and then warmed to rt, The mixture was diluted with CH₂Cl₂ (30 mL) and washed with sat. aq. NH₄Cl (10 mL), H₂O (10 mL) and sat aq. NaCl (2 x 10 mL). The dried extract (Na₂SO₄) was concentrated in vacuo and purified via flash chromatography over silica gel, eluting with 0-20% EtOAc / Hexanes to give sequentially **6.31** (21.1 mg, 79.5 µmol, 41%) and **6.1** (19.2 mg, 72.3 µmol, 37%) as white solids.

**6.1:** MP 140-143°C; IR (thin film) 3406, 3252, 2920, 2852, 1636, 1617, 1465, 1319, 1210, 1014, 802; ¹H NMR (400 MHz, CDCl₃) δ 7.77 (m, 3H), 7.27 (d, J = 8.0 Hz, 1H), 7.17 (d, J=8.0 Hz, 1H), 6.86 (s, 1H), 5.44 (tt, J = 7.2, 1.2 H,
1H, 5.30 (s, 1H), 3.55 (d, $J = 7.2$ Hz, 2H), 2.54 (s, 3H), 1.88 (s, 3H), 1.85 (s, 3H); $^1$H NMR (400 MHz, $d_4$-MeOD) $\delta$ 7.64 (dd, $J = 1.6$, 0.8 Hz, 1H), 7.60 (s, 1H), 7.19 (d, $J = 8.2$ Hz, 1H), 7.04 (dd, $J = 8.1$, 1.0 Hz, 1H), 6.79 (s, 1H), 5.43 (t-sept, $J = 7.3$, 1.4 Hz, 1H), 3.41 (d, $J = 7.3$ Hz, 2H), 2.45 (s, 3H), 1.78 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 153.7, 139.9, 137.7, 134.7, 128.6, 125.7, 123.7, 122.6, 120.8, 119.4, 117.2, 109.9, 97.2, 30.5, 25.8, 21.4, 17.9; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 154.16, 140.4, 138.5, 131.1, 127.3, 124.7, 124.0, 123.9, 120.5, 119.7, 118.5, 116.1, 109.7, 95.9, 28.5, 24.9, 20.4, 16.7 HRMS (EI+) calcd. for C$_{18}$H$_{19}$NO 265.1467 (M+), found 267.1471.

6.31: MP 126-128°C; IR (thin film) 3524, 3424, 3261, 2919, 2853, 1614, 1227, 1032, 802; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.85 (br s, 1H), 7.78 (d, $J = 1.0$ Hz, 1H), 7.76 (d, $J = 3.6$ Hz, 1H), 7.31 (d, $J = 8.2$ Hz, 1H), 7.18 (dd, $J = 8.4$, 1.1 Hz, 1H), 6.76 (d, $J = 8.3$ Hz, 1H), 5.41 (d-quint, $J = 6.9$, 1.4 Hz, 1H), 5.11 (br s, 1H), 3.64 (d, $J = 6.9$ Hz, 2H), 2.54 (s, 3H), 1.94 (s, 3H), 1.82 (d, $J = 1.2$ Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 152.2, 140.4, 137.8, 134.9, 128.8, 125.8, 124.2, 121.5, 119.5, 118.6, 117.4, 110.1, 109.0, 108.3, 25.8, 24.9, 21.5, 18.1; HRMS (EI+) calcd. for C$_{16}$H$_{15}$NO 237.1154 (M+), found 237.1155.

MRN-V-28, Carbazole 6.41a and Carbazole 6.41b: To a stirred solution of 6.35 (453.0 mg, 1.181 mmol) o-dichlorobenzene (2.5 mL) was added PBu$_3$ (903 mg, 1.10 mL, 4.46 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.34 mL, 1.34 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH$_4$Cl (10 mL) and extracted with EtOAc (2 x 50 mL). The organic part was washed with aq. Na$_2$S$_2$O$_3$ (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na$_2$SO$_4$) was concentrated in vacuo to a brown oil of impure cabazoles 6.41a and 6.41b as a 1:1.1 mix via crude $^1$H-NMR. Purification via
flash chromatography over silica gel with 0-40% EtOAc / hexanes to give sequentially cabazoles 6.41a (80.6 mg, 340 µmol, 58%) and 6.41b (77.8 mg, 328 µmol, 56%) as a light brown solid.

6.41a: MP 189-190°C; IR (thin film, cm\(^{-1}\)) 3373, 1624, 1609, 1583, 1473, 1456, 1402, 1407, 1119, 837, 776, 758, 723; \(^1\)H NMR (300 MHz, acetone-\(d_6\)) \(\delta\) 9.99 (br, 1H), 8.31 (br, 1H), 7.88 (s, 1H), 7.26 (d, \(J = 7.8\) Hz, 1H), 7.16 (t, \(J = 7.2\) Hz, 1H), 7.03 (s, 1H), 6.90 (dt, \(J = 6.3, 0.8\) Hz, 1H), 6.16 (ddt, \(J = 16.7, 6.5, 3.5\) Hz, 1H), 5.13 (dq, \(J = 17.1, 1.6\) Hz, 1H), 5.03 (dq, \(J = 10.0, 1.3\) Hz, 1H), 3.57 (d, \(J = 6.6\) Hz, 2H), 2.79 (s, 3H); \(^{13}\)C NMR (100 MHz, acetone-\(d_6\)) \(\delta\) 153.7, 140.3, 140.0, 138.3, 131.3, 123.7, 2123.1, 122.0, 120.0, 119.0, 117.0, 114.0, 108.0, 96.2, 34.7, 19.9; HRMS (EI+) calcd. for C\(_{16}\)H\(_{15}\)NO (M+) 237.1154, found 237.1152.

6.41b: MP 150.157°C, IR (thin film, cm\(^{-1}\)) 3583, 3608, 3407, 3303, 1637, 1609, 1428, 1303, 1226, 1077, 911, 869, 801, 772, 751, 736; \(^1\)H NMR (400 MHz, acetone-\(d_6\)) \(\delta\) 7.88 (s, 1H), 7.25 (d, \(J = 8.0\) Hz, 1H), 7.16 (t, \(J = 7.5\) Hz, 1H), 7.03 (s, 1H) 7.90 (d, \(J = 7.1\), 1H), 6.15 (ddt, \(J = 16.8, 6.5, 3.4\) Hz, 1H), 5.13 (dt, \(J = 17.1, 2.4\) Hz, 1H), 5.03 (dd, \(J = 10.0, 2.0\) Hz, 1H), 3.57 (d, \(J = 6.5, 2H\), 2.88 (s, 3H); \(^{13}\)C NMR (100 MHz, acetone-\(d_6\)) \(\delta\) 153.0, 140.7, 140.2, 136.1, 131.4, 123.8, 122.4, 120.7, 120.1, 117.1, 114.1, 108.3, 108.1, 107.1, 19.9; HRMS (EI+) calcd. for C\(_{16}\)H\(_{15}\)NO (M+) 237.1154, found 237.1143.

MRN-V-93 Carbazole 6.47a and 6.47b: To a stirred solution of 8.40 (482.6 mg, 1.117 mmol) \(o\)-dichlorobenzene (2.5 mL) was added PBu\(_3\) (903 mg, 1.10 mL, 4.46 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.34 mL, 1.34 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH\(_4\)Cl (10 mL) and extracted with EtOAc (2 x 50 mL). The organic part was washed with aq. Na\(_2\)S\(_2\)O\(_3\) (3 x 20
mL, 10% w/v), and sat. \( aq \) NaCl (2 x 10 mL). The dried extract (\( Na_2SO_4 \)) was concentrated \textit{in vacuo} to a brown oil of impure cabazoles 6.47a and 6.47b as a 1:1.2 mix via crude \(^1\)H-NMR. Purification via flash chromatography over silica gel with 0-40% EtOAc / hexanes to give sequentially cabazoles 6.47a (135.1 mg, 472.8 \( \mu \)mol, 85%) and 6.47b (132.0 mg, 461.9 \( \mu \)mol, 82%) as a light brown solid.

**6.47a:** MP 145-146 °C, IR (thin film, cm\(^{-1}\)) 3409, 3251, 1635, 1610, 1473, 1432, 1412, 1312, 1220, 1167, 986, 910, 822, 774; \(^1\)H NMR (400 MHz, acetone-\(d_6\)) \( \delta \) 7.38 (dd, \( J = 8.0, 0.9 \) Hz, 1H), 7.24 (t, \( J = 7.8 \) Hz, 1H), 7.11 (d, \( J = 7.7, 0.8 \) Hz, 1H), 7.03 (s, 1H), 5.47 (tt, \( J = 7.3, 1.4 \) Hz, 1H), 3.50 (d, \( J = 7.3 \) Hz, 2H), 1.80 (s, 3H), 1.77 (d, \( J = 1.1 \) Hz, 3H); \(^1\)C NMR (100 MHz, acetone-\(d_6\)) \( \delta \) 154.9, 141.1, 140.2, 131.1, 126.5, 124.2, 123.8, 122.9, 121.3, 120.6, 119.0, 114.9, 109.0, 96.2, 28.7, 25.0, 17.0; HRMS (EI+) calcd. for \( C_{17}H_{16}NOCl \) (M+) 285.0920, found 285.0923.

**6.47b:** MP 150.157 °C, IR (thin film, cm\(^{-1}\)) 3434, 1610, 1568, 1487, 1436, 1426, 1305, 1180, 942, 801, 760, 726; \(^1\)H NMR (400 MHz, acetone-\(d_6\)) \( \delta \) 8.19 (d, \( J = 8.5 \) Hz, 1H), 7.42 (dd, \( J = 8.0, 0.8 \) Hz, 1H), 7.25 (t, \( J = 7.8 \) Hz, 1H), 7.13 (dd, \( J = 7.7, 0.8 \) Hz, 1H), 6.91 (d, \( J = 8.5 \) Hz, 1H), 5.39 (tt, \( J = 6.9, 1.4 \) Hz, 1H), 3.69 (d, \( J = 6.8 \) Hz, 2H), 1.92 (s, 3H), 1.81 (s, 3H); \(^1\)C NMR (100 MHz, acetone-\(d_6\)) \( \delta \) 153.8, 141.5, 140.9, 131.6, 126.6, 124.4, 122.5, 121.1, 120.3, 119.2, 115.2, 109.4, 109.2, 109.1, 25.0, 23.6, 17.3; HRMS (EI+) calcd. for \( C_{17}H_{16}NOCl \) (M+) 285.0920, found 285.0923.

**MRN-III-56, Phenol 8.10:** To a pressure vessel containing 2.20 (1.294 g, 7.126 mmol) and xylenes (14.0 mL) was added known diene 8.41 Error! Bookmark not defined. (4.831 g, 28.70 mmol) at rt. The mixture was heated at 140°C. After 10 h, the reaction was cooled to 0°C and TBAF (29.0 mL, 29.0
mmol, 1 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH₄Cl (100 mL), diluted with EtOAc (200 mL), washed with H₂O (2 x 50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified via flash chromatography over silica, eluting with 0-35% EtOAc / Hexanes to give the phenol 8.10 (1.928 g) as an impure yellow oil.

MRN-III-53, MRN-III-55, MRN-III-66, Allyl ether 8.28: To a stirred solution of 8.10 (804.2 mg, 2.951 mmol) and dry DMF (15.0 mL) was added NaH (280.4 mg, 7.010 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added allyl bromide (1.82 g, 1.30 mL, 15.0 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (20 mL), diluted with EtOAc (100 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-15% Et₂O / PhMe to give 8.28 (701.3 mg, 2.420 mmol, 82%) as a bright yellow oil.

MRN-III-63, MRN-III-64, MRN-III-65, MRN-VI-76, Phenol 6.33: To a stirred solution of 8.28 (1.425 g, 4.919 mmol) in CH₂Cl₂ (50.0 mL) at -78°C, was added BCl₃ (6.0 mL, 6.0 mmol, 1 M in hexanes) slowly via syringe. After 15 min, the mixture was warmed gradually to rt over 2 h. The mixture was cooled to 0°C, quenched with MeOH (5 mL) and diluted with CH₂Cl₂ (100 mL). The organic part was washed with sat. aq. NH₄Cl (2 x 10 mL) and sat aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a brown oil. Purification via flash chromatography over silica gel with 0-20% EtOAc / PhMe gave pure 6.33 (1.199 g, 4.139 mmol, 84%) as a yellow solid. MP 70-72°C; IR (thin film, cm⁻¹) 3468, 1601, 1505, 1349, 1271, 1125, 899, 872, 853, 828, 756; ¹H NMR (400 MHz, CDCl₃) δ 7.81 (d, J = 8.4 Hz, 1H), 7.45 – 7.43 (m, 2H), 7.12-7.08 (m, 2H), 6.88 (d, J = 8.1 Hz, 1H), 6.06 (ddt, J = 17.6, 9.6, 6.3 Hz, 1H), 5.31 (s, 1H), 5.23 (d, J = 1.0 Hz, 1H), 5.20 (d, J = 3.7, Hz, 1H), 3.46 (d, J = 6.4 Hz, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 154.7, 147.5, 138.3, 137.8, 135.8, 131.9, 129.9, 128.6, 127.7, 127.4, 126.1, 125.6, 117.1,
116.2, 34.9; HRMS (EI+) calcd. for C\textsubscript{15}H\textsubscript{12}NO\textsubscript{3}Cl (M+) 289.0506, found 289.0503.

**MRN-VI-75, Phenol 6.24:** To a stirred solution of 8.29 (1.084 g, 4.027 mmol) in CH\textsubscript{2}Cl\textsubscript{2} (40.0 mL) at -78°C, was added BCl\textsubscript{3} (5.0 mL, 5.0 mmol, 1 M in hexanes) slowly via syringe. After 15 min, the mixture was warmed gradually to rt over 2 h. The mixture was cooled to 0°C, quenched with MeOH (5 mL) and diluted with CH\textsubscript{2}Cl\textsubscript{2} (100 mL). The organic part was washed with sat. aq. NH\textsubscript{4}Cl (2 x 10 mL) and sat aq. NaCl (2 x 10 mL). The dried (Na\textsubscript{2}SO\textsubscript{4}) extract was concentrated in vacuo to give a brown oil. Purification via flash chromatography over silica gel with 20-30% EtOAc / hexanes gave pure 6.24 (935.7 g, 3.475 mmol, 86%) as a yellow solid. MP 70-72°C, IR (thin film, cm\textsuperscript{-1}) 3468, 1601, 1505, 1349, 1271, 1125, 899, 872, 853, 828, 756; \textsuperscript{1}H NMR (400 MHz, CDCl\textsubscript{3}) \textdelta 7.81 (d, J = 8.4 Hz, 1H), 7.53-7.37 (m, 2H), 7.17-7.04 (m, 2H), 6.93-6.84 (m, 1H), 6.06 (ddt, J = 17.6, 9.6, 6.3 Hz, 1H), 5.31 (s, 1H), 5.23 (d, J = 1.0 Hz, 1H), 5.20 (dt, J = 3.7, 1.0 Hz, 1H), 3.46 (d, J = 6.4 Hz, 2H); \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}) \textdelta 154.7, 147.5, 138.3, 137.8, 135.8, 131.9, 129.9, 128.6, 127.7, 127.4, 126.1, 125.6, 117.1, 116.2, 34.9; HRMS (EI+) calcd. for C\textsubscript{15}H\textsubscript{12}NO\textsubscript{3}Cl (M+) 289.0506, found 289.0503.

**MRN-III-95, MRN-IV-36, MR–IV-41, Prenyl benzene 6.45:** To a stirred solution of 6.36 (78.3 mg, 204 µmol) in 2-methyl-2-butene (5.0 mL) was added
Grubbs’ 2nd generation catalyst (3.6 mg, 4.2 µmol). After 24 h, the mixture was eluted past a silica gel / Celite® pad with Et₂O (20 mL), and concentrated in vacuo to an impure orange oil. Purification via flash chromatography over silica gel with 0-10% EtOAc / PhMe gave 6.46 (69.2 mg, 168 µmol, 82%) as a yellow oil. IR (thin film, cm⁻¹) 2957, 2858, 1608, 1524, 1502, 1354, 1277, 1255, 1120, 1096, 941, 905, 940, 809, 780, 758; ¹H NMR (400 MHz, CDCl₃) δ 7.76 (d, J = 7.9 Hz, 1H), 7.24 (d, J = 8.0 Hz, 2H), 7.11 (t, J = 2.0 Hz, 1H), 7.06 (dt, J = 8.3, 2.0 Hz, 1H), 6.86 (dd, J = 8.2, 2.0 Hz, 1H), 5.37 (t, J = 7.2 Hz, 1H), 3.39 (s, J = 6.6 Hz); ¹³C NMR (100 MHz, CDCl₃) δ 153.6, 147.2, 142.9, 136.4, 133.1, 132.6, 132.6, 130.1, 129.2, 128.0, 126.2, 124.2, 122.2, 118.3, 28.6, 25.8, 25.8, 21.4, 18.3, 17.9, -4.0; HRMS (EI+) calcd. for C₂₄H₃₃NO₃Si (M⁺) 411.2230, found 411.2218.

Carbazole 6.50a and 6.50b: To a stirred solution of 6.44 (540 mg, 1.337 mmol) PhMe (2.5 mL) was added PBU₃ (1.14 mg, 1.40 mL, 5.63 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.40 mL, 1.40 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH₄Cl (10 mL) and extracted with EtOAc (2 x 50 mL). The organic part was washed with aq. Na₂S₂O₃ (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na₂SO₄) was concentrated in vacuo to a brown oil of impure cabazoles 6.50a and 6.50b as a 1:1.2 mix via crude ¹H-NMR. Purification via flash chromatography over silica gel with 0-40% EtOAc / hexanes to give sequentially cabazoles 6.50a (81.4 mg, 316 µmol, 47%) and 6.50b (63.7 mg, 247 µmol, 37%) as a light brown solid.

6.50a: MP 154-155°C; IR (thin film, cm⁻¹) 3405, 3052, 1634, 1608, 1582, 1459, 1316, 1225, 1157, 1122, 985, 826, 777, 757, 727; ¹H NMR (400 MHz,
acetone-$d_6$) $\delta$ 7.84 (s, 1H), 7.24 (d, $J = 8.0$ Hz, 1H), 7.13 (t, $J = 7.2$ Hz, 1H), 7.00 (s, 1H), 6.87 (dd, $J = 7.2$, 0.8 Hz, 1H), 5.47 (tt, $J = 7.2$, 1.6 Hz, 1H), 3.48 (d, $J = 7.2$ Hz, 1H), 2.77 (s, 3H), 1.79 (s, 3H), 1.75 (s, 3H); $^{13}$C NMR (100 MHz, acetone-$d_6$) $\delta$ 153.9, 140.0, 140.0, 131.1, 130.8, 124.1, 123.5, 122.6, 122.0, 120.4, 119.9, 116.8, 107.9, 96.1, 28.8, 25.0, 19.9, 17.0; HRMS (EI+) calcd. for C$_{18}$H$_{19}$NO (M+) 265.1467, found 165.1467.

6.50b: MP 150-153°C; IR (thin film, cm$^{-1}$) 3403, 3310, 1622, 1608, 1584, 1428, 1373, 1348, 1312, 1301, 1076, 878, 796, 764, 747, 736; $^1$H NMR (400 MHz, acetone-$d_6$) $\delta$ 7.82 (d, $J = 8.4$ Hz, 1H), 7.30 (d, $J = 0.5$ Hz, 1H), 7.17 (t, $J = 7.4$ Hz, 1H), 6.91 (dt, $J = 7.2$, 0.8 Hz, 1H), 6.84 (d, $J = 8.4$ Hz, 1H), 5.40 (tt, $J = 6.9$, 1.4 Hz, 1H), 3.69 (d, $J = 6.8$ Hz, 2H), 2.78 (s, 3H), 1.85 (d, $J = 0.4$ Hz, 3H), 1.69 (d, $J = 1.2$ Hz, 3H), 1.09 (s, 9H), 0.33 (s, 6H); $^{13}$C NMR (100 MHz, acetone-$d_6$) $\delta$ 152.8, 140.6, 140.3, 131.3, 131.2, 123.8, 122.8, 122.5, 120.3, 120.1, 117.2, 109.2, 108.5, 108.2, 24.9, 23.6, 19.9, 17.2; HRMS (EI+) calcd. for C$_{18}$H$_{19}$NO (M+) 265.1467, found 265.1466.

MRN-IV-35, Silyl ether 6.36: To a stirred solution of 6.24 (116.4 mg, 432.2 µmol) in CH$_2$Cl$_2$ (3.7 mL) was added imid. (37.6 mg, 552 µmol) and TBSCl (148.7 mg, 986.3 µmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH$_2$Cl$_2$ (2 x 10 mL). The organic part was washed with sat aq. NaCl (2 x 5 mL). The dried (Na$_2$SO$_4$) extract was concentrated in vacuo to give a yellow oil. Purification via flash chromatography over silica gel with PhMe gave 6.36 (160.4 mg, 418.6 µmol, 97%) as a bright yellow oil. IR (thin film, cm$^{-1}$) 1609, 1522, 1503, 1473, 1354, 1278, 1256, 909, 846, 826, 782, 734; $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 7.76 (d, $J = 8.0$ Hz, 1H), 7.26-7.18 (m, 2H), 7.13 (d, $J = 2.3$ Hz, 1H), 7.07 (dd, $J = 8.3$, 2.4 Hz, 1H), 6.86 (d, $J = 8.3$ Hz, 1H), 6.02 (ddt, $J = 17.6$, 8.9, 6.5 Hz, 1H), 5.12
(t, J = 1.4 Hz, 1H), 5.08 (dq, J = 7.5, 1.7 Hz, 1H), 3.46 (d, J = 6.4 Hz, 2H), 2.48 (s, 3H), 1.08 (s, 9H), 0.32 (s, 6H); ^13^C NMR (100 MHz, CDCl\textsubscript{3}) δ 153.6, 147.1, 143.0, 136.6, 136.3, 132.6, 131.0, 130.3, 129.8, 128.1, 126.7, 124.2, 118.4, 115.9, 34.4, 35.8, 21.4, 18.3, -4.1; HRMS (EI+) calcd. for C\textsubscript{22}H\textsubscript{29}NO\textsubscript{3}Si (M+) 383.1917, found 383.1919.

**MRN-VI-20, Toluene 6.36:** To a pressure vessel was added 8.31 (891.9 mg, 2.208 mmol), PEPPSI-® (20.5 mg, 30.2 µmol), K\textsubscript{2}CO\textsubscript{3} (992.5 mg, 7.181 mmol), dioxane (5.5 mL), and (BOMe)\textsubscript{3} (370 mg, 410 µL, 2.95 mmol) sequentially. The vessel was sealed, and heated to 100°C. After 18 h, the mixture was eluted through a Celite-® pad with Et\textsubscript{2}O (30 mL) and purified via flash chromatography over silica gel, eluting with 0-15% EtOAc / hexanes to give 6.36 (721.5 mg, 1.881 µmol, 85%) as a yellow oil. IR (thin film, cm\textsuperscript{-1}) 1609, 1522, 1503, 1473, 1354, 1278, 1256, 909, 846, 826, 782, 734; ^1^H NMR (300 MHz, CDCl\textsubscript{3}) δ 7.76 (d, J = 8.0 Hz, 1H), 7.26-7.18 (m, 2H), 7.13 (d, J = 2.3 Hz, 1H), 7.07 (dd, J = 8.3, 2.4 Hz, 1H), 6.86 (d, J = 8.3 Hz, 1H), 6.02 (ddt, J = 17.6, 8.9, 6.5 Hz, 1H), 5.12 (t, J = 1.4 Hz, 1H), 5.08 (dq, J = 7.5, 1.7 Hz, 1H), 3.46 (d, J = 6.4 Hz, 2H), 2.48 (s, 3H), 1.08 (s, 9H), 0.32 (s, 6H); ^13^C NMR (100 MHz, CDCl\textsubscript{3}) δ 153.6, 147.1, 143.0, 136.6, 136.3, 132.6, 131.0, 130.3, 129.8, 128.1, 126.7, 124.2, 118.4, 115.9, 34.4, 35.8, 21.4, 18.3, -4.1; HRMS (EI+) calcd. for C\textsubscript{22}H\textsubscript{29}NO\textsubscript{3}Si (M+) 383.1917, found 383.1919.
MRN-VI-30, Prenyl benzene 8.26: To a stirred solution of 6.33 (801.8 mg, 1.985 mmol) in 2-methyl-2-butene (8.5 mL) was added Grubbs’ 2nd generation catalyst (24.1 mg, 28.4 µmol). After 24 h, the mixture was eluted past a silica gel / Celite-® pad with Et₂O (20 mL), and concentrated in vacuo to an impure orange oil. Purification via flash chromatography over silica gel with 0-10% EtOAc / PhMe gave 8.26 (582.3 mg, 1.348 mmol, 68%) as a yellow oil.

MRN-V-84, Toluene 6.45: To a pressure vessel was added 8.26 (482.2 mg, 1.116 mmol), PEPPSI-® (11.2 mg, 16.5 µmol), K₂CO₃ (563.5 mg, 4.077 mmol), dioxane (5.0 mL), and (BOMe)₃ (189 mg, 210 µL, 1.51 mmol) sequentially. The vessel was sealed, and heated to 100°C. After 18 h, the mixture was eluted through a Celite-® pad with Et₂O (30 mL) and purified via flash chromatography over silica gel, eluting with 0-15% EtOAc / hexanes to give 6.45 (403.7 mg, 932.2 µmol, 88%) as a yellow oil. IR (thin film, cm⁻¹) 2957, 2858, 1608, 1542, 1354, 1277, 1255, 1120, 1096, 941, 905, 940, 809, 780, 758; ¹H NMR (400 MHz, CDCl₃) δ 7.76 (d, J = 7.9 Hz, 1H), 7.48 (d, J = 8.0 Hz, 2H), 7.11 (t, J = 2.0 Hz, 1H), 7.06 (dt, J = 8.3, 2.0 Hz, 1H), 6.86 (dd, J = 8.2, 2.0 Hz, 1H), 5.37 (t, J = 7.2 Hz, 1H), 3.93 (d, J = 7.0 Hz, 2H), 2.48 (s, 3H), 1.80 (s, 3H), 1.74 (s, 3H), 1.09 (s, 9H), 0.33 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 153.6, 147.2, 142.9, 136.4, 133.1, 132.6, 132.6, 130.1, 129.2, 128.0, 126.2, 124.2, 122.2, 118.3, 28.6, 25.8, 25.8, 21.4, 18.3, 17.9, -4.0; HRMS (EI+) calcd. for C₂₄H₃₃NO₃Si (M⁺) 411.2230, found 411.2218.

MRN-IV-76, Carbazole 6.38a and 6.38b: To a stirred solution of 8.30 (540 mg, 1.337 mmol) o-dichlorobenzene (2.5 mL) was added PBu₃ (1.14 mg, 1.40 mL, 5.63 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.40 mL, 1.40 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH₄Cl (10 mL) and extracted with
EtOAc (2 x 50 mL). The organic part was washed with *aq* Na$_2$S$_2$O$_3$ (3 x 20 mL, 10% w/v), and sat. *aq* NaCl (2 x 10 mL). The dried extract (Na$_2$SO$_4$) was concentrated *in vacuo* to a brown oil of impure cabazoles 6.38a and 6.38b as a 1:1.2 mix via crude $^1$H-NMR. Purification via flash chromatography over silica gel with 0-40% EtOAc / hexanes to give sequentially cabazoles 6.38a (81.4 mg, 316 µmol, 47%) and 6.38b (63.7 mg, 247 µmol, 37%) as a light brown solid.

**6.38a**: MP 145-146 °C, IR (thin film, cm$^{-1}$) 3409, 3251, 1635, 1610, 1473, 1432, 1412, 1312, 1220, 1167, 986, 910, 822, 774, 746, 719; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.32 (s, 1H), 7.95 (s, 1H), 7.40 (d, $J$ = 0.8 Hz, 1H), 7.39 (dd, $J$ = 8.0, 0.8 Hz, 1H), 7.24 (t, $J$ = 7.8 Hz, 1H), 7.12 (dd, $J$ = 7.8, 0.9 Hz, 1H), 6.87 (s, 1H), 6.14 (ddt, $J$ = 16.6, 6.6, 3.5 Hz, 1H) 5.13 (ddt, $J$ = 17.1, 2.2 1.6 Hz, 1H), 5.04 (ddt, $J$ = 10.0, 2.2, 1.3 Hz, 1H), 3.64 (d, $J$ = 6.4 Hz, 2H); $^{13}$C NMR (100 MHz, acetone-$d_6$) $\delta$ 154.8, 141.2, 140.5, 137.9, 126.5, 124.4, 123.3, 120.6, 119.9, 119.0, 115.0, 114.2, 109.0, 96.2, 34.6; HRMS (EI+) calcd. for C$_{15}$H$_{12}$NOCl (M$^+$) 257.0607, found 257.0604.

**6.38b**: MP 161-162 °C, IR (thin film, cm$^{-1}$) 3583, 3425, 1609, 1487, 1435, 1426, 1301, 1179, 942, 905, 865, 805, 764, 738, 722; $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.34 (d, $J$ = 8.5 Hz, 1H), 8.12 (br, 1H), 7.40-7.35 (m, 2H), 7.20 (d, $J$ = 0.9 Hz, 1H), 6.83 (d, $J$ = 8.5 Hz, 1H), 6.13 (ddt, $J$ = 16.6, 5.9, 4.5 Hz, 1H), 5.26 (dd, $J$ = 9.7, 1.5 Hz, 1H), 5.22 (dd, $J$ = 1.6, 1.2 Hz, 1H) 5.03 (s, 1H), 3.74 (d, $J$ = 5.9 Hz, 2H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 152.4, 140.7, 140.5, 135.5, 127.8, 124.9, 122.0, 121.3, 120.4, 116.6, 116.4, 109.5, 108.8, 106.3, 29.3; HRMS (EI+) calcd. for C$_{15}$H$_{12}$NOCl (M$^+$) 257.0607, found 257.0616.
**Silyl Ether 8.31:** To a stirred solution of 6.39 (116.4 mg, 432.2 µmol) in CH$_2$Cl$_2$ (3.7 mL) was added imid. (37.6 mg, 552 µmol) and TBSCl (148.7 mg, 986.3 µmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH$_2$Cl$_2$ (2 x 10 mL). The organic part was washed with sat aq. NaCl (2 x 5 mL). The dried (Na$_2$SO$_4$) extract was concentrated *in vacuo* to give a yellow oil. Purification via flash chromatography over silica gel with PhMe gave 8.31 (160.4 mg, 418.6 µmol, 97%) as a bright yellow oil. IR (thin film, cm$^{-1}$) 1639, 1607, 1529, 1352, 1275, 1090, 843, 802, 781; $^1$H NMR (300 MHz, CDCl$_3$) δ 7.80 (d, $J$ = 8.6 Hz, 1H), 7.46 (d, $J$ = 2.0 Hz, 1H), 7.41 (dd, $J$ = 8.6, 2.3 Hz, 1H), 7.14 (d, $J$ = 2.3 Hz, 1H), 7.08 (dd, $J$ = 8.3, 2.4 Hz, 1H), 6.88 (d, $J$ = 8.3 Hz, 1H), 6.02 (ddt, $J$ = 18.8, 6.5, 3.8 Hz, 1H), 5.13 (dq, $J$ = 4.4, 1.8 Hz, 1H) 5.09 (dq, $J$ = 10.6, 1.4 Hz, 1H), 3.45 (d, $J$ = 6.5 Hz, 2H), 1.08 (s, 9H), 0.32 (s, 6H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ 154.2, 147.6, 138.1, 138.0, 136.4, 131.8, 131.4, 129.7, 128.7, 127.6, 126.6, 125.5, 118.6, 116.1, 34.3, 25.8, 18.3, -4.1; HRMS (EI+) calcd. for C$_{21}$H$_{26}$NO$_3$ClSi (M+) 403.1370, found 403.1378.

**Phenol 8.33:** To a pressure vessel containing 2.21 (1.294 g, 7.126 mmol) and xylenes (14.0 mL) was added known diene 8.41 Error! Bookmark not defined. (4.831 g, 28.70 mmol) at rt. The mixture was heated at 140°C. After 10 h, the reaction was cooled to 0°C and TBAF (29.0 mL, 29.0 mmol, 1 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH$_4$Cl (100 mL), diluted with EtOAc (200 mL), washed with H$_2$O (2 x 50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (Na$_2$SO$_4$) extract was concentrated *in vacuo* and purified via flash chromatography over silica, eluting with 0-35% EtOAc / Hexanes to give the phenol 8.33 (1.928 g) as an impure yellow oil.
MRN-VI-87, Allyl Ether 8.34: To a stirred solution of 8.33 (804.2 mg, 2.951 mmol) and dry DMF (15.0 mL) was added NaH (280.4 mg, 7.010 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added allyl bromide (1.82 g, 1.30 mL, 15.0 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (20 mL), diluted with EtOAc (100 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-15% Et₂O / PhMe to give impure 8.34 as a bright yellow oil.

MRN-IV-89, MRN-IV-87, MRN-IV-94, Phenol 6.34: To a stirred solution of impure D (3.502 g, 12.09 mmol) in CH₂Cl₂ (40.0 mL) at -78°C, was added BCl₃ (14.0 mL, 14.0 mmol, 1 M in hexanes) slowly via syringe. After 10 min, the mixture was warmed gradually to rt over 2 h. The mixture was cooled to 0°C, quenched with MeOH (5 mL) and diluted with CH₂Cl₂ (100 mL). The organic part was washed with sat. aq. NH₄Cl (2 x 10 mL) and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a brown oil. Purification via flash chromatography over silica gel with 10-25% EtOAc / hexanes gave pure B (1.262 g, 4.356 mmol, 36%) as a yellow solid. MP 108-111°C, IR (thin film, cm⁻¹) 3279, 1523, 1353, 1233, 1111, 989, 912, 873, 822, 767; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, J = 2.1 Hz, 1H), 7.59 (dd, J = 8.3, 2.1 Hz, 1H), 7.41 (d, J = 8.3 Hz, 1H), 7.12-7.07 (m, 2H), 6.91-6.85 (m, 1H), 6.05 (ddt, J = 17.6, 9.6, 6.3 Hz, 1H), 5.32-5.15 (m, 3H), 3.46 (d, J = 6.4 Hz, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 154.6, 149.5, 1435.8, 134.4, 133.4, 133.0, 132.2, 129.9, 128.7, 127.4, 126.1, 124.1, 117.1, 116.3, 34.9; HRMS (EI+) calcd. for C₂₁H₂₆NO₃ClSi (M+) 403.1370, found 403.1378.

\[
\begin{array}{c}
\text{Cl} \\
\text{NO}_2 \\
\text{OH} \\
\text{6.34} \\
\text{Cl} \\
\text{NO}_2 \\
\text{TBS} \\
\text{8.32}
\end{array}
\]
MRN-IV-95, MRN-IV-97, MRN-V-59 Silyl Ether 8.32: To a stirred solution of 6.34 (677.6 mg, 2.339 mmol) in CH₂Cl₂ (2.5 mL) was added imid. (175.2 mg, 2.573 mmol) and TBSCI (387.8 mg, 2.573 mmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH₂Cl₂ (4 x 50 mL). The organic part was washed with sat aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a yellow oil. Purification via flash chromatography over silica gel with PhMe gave 8.32 (944.0 mg, 2.339 mmol, quant.) as a bright yellow oil. IR (thin film, cm⁻¹) 1607, 1535, 1360, 1267, 1111, 995, 919, 886, 857, 840, 781; ¹H NMR (300 MHz, CDCl₃) δ 7.81 (d, J = 2.1 Hz, 1H), 7.57 (dd, J = 8.3, 2.2 Hz, 1H), 7.40 (d, J = 8.3 Hz, 1H), 7.10 (d, J = 2.4 Hz, 1H), 7.04 (dd, J = 8.3, 2.4 Hz, 1H), 6.86 (d, J = 8.3 Hz, 1H), 5.99 (ddt, J = 16.8, 6.5, 3.8 Hz, 1H), 5.11 (dt, J = 2.8, 1.8 Hz, 1H), 5.06 (dq, J = 11.1, 1.5 Hz, 1H), 3.42 (d, J = 6.3 Hz, 2H), 1.05 (s, 9H), 0.30 (s, 6H); ¹³C NMR (75 MHz, CDCl₃) δ 154.0, 149.5, 136.4, 134.6, 133.3, 133.0, 132.1, 131.4, 129.8, 128.7, 126.7, 124.0, 118.6, 116.1, 34.3, 25.8, 18.3, -4.1; HRMS (EI⁺) calcd. for C₂₁H₂₆NO₃ClSi (M⁺) 403.1371, found 403.1357.

Prenyl benzene 8.35: To a stirred solution of 8.32 (479.7 mg, 1.656 mmol) in 2-methyl-2-butene (10 mL) was added Grubbs' 2nd generation catalyst (20.9 mg, 24.6 µmol). After 24 h, the mixture was eluted past a silica gel / Celite-® pad with Et₂O (30 mL), and concentrate in vacuo to an impure orange oil. Purification via flash chromatography over silica gel with 5-15% EtOAc / hexanes gave 8.35 (460.4 mg, 1.449 mmol, 89%) as a yellow oil. IR (thin film, cm⁻¹) 1606, 1537, 1360, 1266, 1111, 931, 888, 838, 781, 707; ¹H NMR (400 MHz, CDCl₃) δ 7.80 (d, J = 2.1 Hz, 1H), 7.58 (dd, J = 8.3, 2.2 Hz, 1H), 7.41 (d, J = 8.3 Hz, 1H), 7.09 (d, J = 2.4 Hz, 1H), 7.04 (dd, J = 8.2, 2.6 Hz, 1H), 6.86
(d, J = 8.2 Hz, 1H), 5.34 (tq J = 8.6, 1.4 Hz, 1H), 3.37 (d, J = 7.2 Hz, 2H), 1.80 (d, J = 1.2 Hz, 3H), 1.72 (s, 3H), 1.08 (s, 9H), 0.32 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 154.1, 149.6, 134.7, 133.4, 133.2, 132.9, 132.1, 129.2, 128.5, 126.2, 124.0, 121.9, 118.5, 28.5, 25.8, 18.3, 17.8, -4.1; HRMS (EI+) calcd. for C$_{23}$H$_{30}$NO$_3$ClSi (M$^+$) 431.1684, found 431.1662.

**Silyl ether 6.37:** To a stirred solution of 8.36 (677.6 mg, 2.339 mmol) in CH$_2$Cl$_2$ (2.5 mL) was added imid. (175.2 mg, 2.573 mmol) and TBSCl (387.8 mg, 2.573 mmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH$_2$Cl$_2$ (4 x 50 mL). The organic part was washed with sat. aq. NaCl (2 x 10 mL). The dried (Na$_2$SO$_4$) extract was concentrated *in vacuo* to give a yellow oil. Purification via flash chromatography over silica gel with PhMe gave 6.37 (944.0 mg, 2.339 mmol, quant.) as a bright yellow oil. IR (thin film, cm$^{-1}$) 1608, 1531, 1360, 1273, 1123, 917, 841, 821, 801, 781; $^1$H NMR (300 MHz, CDCl$_3$) δ 7.63 (s, 1H), 7.49-7.31 (m, 2H), 7.13 (d, J = 2.4 Hz, 1H), 7.07 (dd, J = 8.2, 2.4 Hz, 1H), 6.86 (d, J = 8.3 Hz, 1H), 5.09 (t, J = 1.5 Hz, 1H), 5.05 (dq J = 7.8, 1.8 Hz, 1H), 3.41 (d, J = 6.6 Hz, 2H), 2.46 (s, 3H), 1.05 (s, 9H), 0.29 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 153.5, 149.3, 138.0, 136.6, 133.2, 132.7, 131.7, 131.0, 129.8, 129.1, 126.7, 124.2, 118.4, 115.9, 32.3, 25.8, 20.8, 18.3, -4.1; HRMS (EI+) calcd. for C$_{22}$H$_{29}$NO$_3$Si (M$^+$) 383.1917, found 383.1914.
MRN-V-61, MRN-V-60, MRN-IV-99, Toluene 6.37: To a pressure vessel was added 8.32 (477.0 mg, 1.181 mmol), PEPPSI-® (27.5 mg, 40.5 µmol), K$_2$CO$_3$ (551.6 mg, 3.991 mmol), dioxane (4.00 mL), and (BOMe)$_3$ (244 mg, 220 µL, 1.94 mmol) sequentially. The vessel was sealed, and heated to 100°C. After 18 h, the mixture was eluted through a Celite-® pad with Et$_2$O (30 mL) and purified via flash chromatography over silica gel, eluting with 0-25% EtOAc / hexanes to give 6.37 (350.0 mg, 912 µmol, 78%) as a yellow oil.  

IR (thin film, cm$^{-1}$) 1608, 1531, 1360, 1273, 1123, 841, 821, 801, 781; $^1$H NMR (300 MHz, CDCl$_3$) δ 7.63 (s, 1H), 7.49-7.31 (m, 2H), 7.13 (d, $J = 2.4$ Hz, 1H), 7.07 (dd, $J = 8.2, 2.4$ Hz, 1H), 6.86 (d, $J = 8.3$ Hz, 1H), 5.09 (t, $J = 1.5$ Hz, 1H), 5.05 (dq $J = 7.8, 1.8$ Hz, 1H), 3.41 (d, $J = 6.6$ Hz, 2H), 2.46 (s, 3H), 1.05 (s, 9H), 0.29 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 153.5, 149.3, 138.0, 136.6, 133.2, 132.7, 131.7, 131.0, 129.8, 129.1, 126.7, 124.2, 118.4, 115.9, 32.3, 25.8, 20.8, 18.3, -4.1; HRMS (EI+) calcd. for C$_{22}$H$_{29}$NO$_3$Si (M+) 383.1917, found 383.1914.

MRN-VI-25, Prenyl Benzene 6.46: To a stirred solution of 8.37 (128.4 mg, 419.7 mmol) in CH$_2$Cl$_2$ (1.00 mL) was added imid. (40.9 mg, 601 µmol) and TBSCl (140.3 mg, 930.9 µmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH$_2$Cl$_2$ (4 x 50 mL). The organic part was washed with sat aq. NaCl (2 x 10 mL). The dried (Na$_2$SO$_4$) extract
was concentrated in vacuo to give a yellow oil. Purification via flash chromatography over silica gel with PhMe gave 6.46 (157.0 mg, 381.0 µmol, 91%) as a bright yellow oil. IR (thin film, cm⁻¹) 1607, 1531, 1360, 1271, 1120, 934, 839, 801, 781, 710; ¹H NMR (300 MHz, CDCl₃) δ 7.60 (s, 1H), 7.48-7.14 (m, 4H), 7.14-6.97 (m, 2H), 6.84 (d, J = 8.1 Hz, 1H), 5.33 (th, J = 7.2, 1.4 Hz, 1H), 3.36 (d, J = 7.2 Hz, 2H), 2.46 (s, 3H), 1.77 (s, 3H), 1.70 (s, 3H), 1.05 (s, 9H), 0.29 (s, 6H); ¹³C NMR (75 MHz, CDCl₃) δ 153.5, 149.3, 137.9, 133.3, 133.1, 132.7, 132.6, 131.7, 129.7, 129.2, 126.2, 124.2, 122.1, 118.3, 28.6, 25.8, 25.7, 20.8, 18.3, 17.8, -4.1; HRMS (EI+) calcd. for C₂₄H₃₃NO₃Si (M⁺) 411.2229, found 411.2223.

MRN-IV-98 Phenol 8.39: To a stirred solution of 8.38 (386.9 mg, 1.437 mmol) in CH₂Cl₂ (40.0 mL) at -78°C, was added BCl₃ (1.60 mL, 1.60 mmol, 1 M in hexanes) slowly via syringe. After 10 min, the mixture was warmed gradually to rt over 2 h. The mixture was cooled to 0°C, quenched with MeOH (1 mL) and diluted with CH₂Cl₂ (50 mL). The organic part was washed with sat. aq. NH₄Cl (2 x 10 mL) and sat aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a brown oil. Purification via flash chromatography over silica gel with 0-10% EtOAc / PhMe gave pure 8.39 (347.6 mg, 1.291 mmol, 90%) as a yellow solid.. MP 74-76°C, IR (thin film, cm⁻¹) 3492, 1638, 1520, 1360, 1274, 1205, 1116, 997, 918, 923, 823, 805, 747, 716; ¹H NMR (300 MHz, CDCl₃) δ 7.62 (dd, J = 8.0, 0.5 Hz, 1H), 7.48 (dd, J = 7.7, 0.6 Hz, 1H), 7.36 (t, J = 7.9 Hz, 1H), 7.03-6.94 (m, 2H), 6.84 (d, J = 8.9 Hz, 1H), 6.05 (ddt, J = 18.1, 9.4, 3.1 Hz, 1H), 5.54 (br, 1H), 5.26-5.08 (m, 2H), 3.45 (t, J = 5.1 Hz, 2H), 2.20 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 153.8, 150.8, 139.6, 136.2, 135.1, 133.7, 130.5, 128.1, 127.9, 127.6, 125.9, 120.9,
116.5, 115.9, 34.6, 20.7; HRMS (El+) calcd. for C_{15}H_{15}NO_3 (M+) 269.1052, found 269.1045.

MRN-V-79, MRN-V-81 Carbazole 6.40a and 6.40b: To a stirred solution of 8.32 (342.4 mg, 847.6 mmol) o-dichlorobenzene (2.0 mL) was added PBu₃ (739 mg, 900 µL, 3.65 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.40 mL, 1.40 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH₄Cl (10 mL) and extracted with EtOAc (2 x 50 mL). The organic part was washed with aq. Na₂S₂O₃ (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na₂SO₄) was concentrated in vacuo to a brown oil of impure cabazoles 6.40a and 6.40b as a 1:1.2 mix via crude ¹H-NMR. Purification via flash chromatography over silica gel with 0-40% EtOAc / hexanes gave sequentially cabazoles 6.40a (73.9 mg, 287 µmol, 68%) and 6.40b (66.3 mg, 257 µmol, 61%) as a light brown solid.

6.40a: MP: 148-151°C; IR (thin film, cm⁻¹) 3409, 1639, 1608, 1219, 1066, 917, 811, 739; ¹H NMR (400 MHz, acetone-d₆) δ 10.13 (s, 1H), 8.48 (s, 1H), 7.94 (d, J = 8.3 Hz, 1H), 7.80 (s, 1H), 7.43 (d, J = 1.9 Hz, 1H), 7.11 (dd, J = 8.3, 1.9 Hz, 1H), 7.02 (s, 1H), 5.12 (ddt, J = 16.7, 6.6, 3.4 Hz, 1H), 5.11 (dt, J = 7.1, 1.7 Hz, 1H), 5.03 (dt, J = 10.1, 2.2, 1H), 3.53 (d, J = 6.6 Hz, 2H); ¹³C NMR (75 MHz, CDCl₃) δ 153.8, 140.0, 136.9, 130.2, 122.1, 121.5, 120.1, 119.9, 118.7, 116.9, 116.6, 110.3, 97.6, 35.7; HRMS (El+) calcd. for C_{15}H_{12}NOCl (M+) 257.0607, found 257.0603.

6.40b: MP: 153-155°C; IR (thin film, cm⁻¹) 3425, 3359, 1607, 915, 802, 795; ¹H NMR (400 MHz, acetone-d₆) δ 10.18 (s, 1H), 8.43 (s, 1H), 7.93 (d, J = 8.2 Hz, 1H), 7.80 (d, J = 8.4 Hz, 1H), 7.44 (d, J = 1.9 Hz, 1H), 7.12 (dd, J = 8.3,
1.9 Hz, 1H), 6.87 (d, J = 8.4 Hz, 1H), 6.08 (ddt, J = 17.0, 10.1, 6.1 Hz, 1H), 5.11 (dq, J = 17.1, 1.8 Hz, 1H), 4.99 (dq, J = 10.7, 1.5 Hz, 1H), 3.71 (dt, J = 6.1, 1.5 Hz, 1H); ^13^C NMR (100 MHz, CDCl\textsubscript{3}) δ 153.9, 141.2, 140.8, 135.9, 128.9, 122.9, 120.0, 118.9, 118.6, 115.7, 114.2, 110.3, 109.1, 107.6, 29.7; HRMS (EI+) calcd. for C\textsubscript{15}H\textsubscript{12}NOCl (M+) 257.0607, found 257.0600.

MRN-V-27, Carbazole 6.49\textsuperscript{a} and 6.49\textsuperscript{b}: To a stirred solution of 8.35 (194.6 mg, 455 mmol) o-dichlorobenzene (1.0 mL) was added PBu\textsubscript{3} (365 mg, 450 µL, 1.81 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (1.00 mL, 1.00 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH\textsubscript{4}Cl (10 mL) and extracted with EtOAc (2 x 20 mL). The organic part was washed with aq. Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3} (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na\textsubscript{2}SO\textsubscript{4}) was concentrated \textit{in vacuo} to a brown oil of impure cabazoles 6.49\textsuperscript{a} and 6.49\textsuperscript{b} as a 1:1.2 mix via crude \textsuperscript{1}H-NMR. Purification via flash chromatography over silica gel with 5-15% EtOAc / PhMe gave sequentially cabazoles 6.49\textsuperscript{a} (29.2 mg, 113 µmol, 50%) and 6.49\textsuperscript{b} (24.0 mg, 93.1 µmol, 41%) as a light brown solid.

\textbf{6.49\textsuperscript{a}}: MP 142-144°C, IR (thin film, cm\textsuperscript{-1}) 3408, 1636, 1607, 1065, 889, 846, 810, 727; \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) δ 7.85 (d, J = 8.3 Hz, 1H), 7.80 (s, 1H), 7.73 (s, 1H), 7.29 (t, J = 1.8 Hz, 1H), 7.18 (dd, J = 8.2, 1.8 Hz, 1H), 6.82 (s, 1H), 5.50-5.32 (m, 2H), 3.53 (d, J = 7.1 Hz, 2H), 1.86 (s, 3H), 1.83 (s, 3H); \textsuperscript{13}C NMR (75 MHz, CDCl\textsubscript{3}) δ 154.1, 140.0, 139.8, 135.1, 130.1, 122.3, 122.2, 120.9, 120.3, 120.1, 119.9, 116.7, 110.4, 97.5, 30.4, 25.9, 17.9; HRMS (Cl+) calcd. for C\textsubscript{17}H\textsubscript{16}NOCl (M+) 285.0920, found 285.0912.
6.49b: MP 165-166°C, IR (thin film, cm\(^{-1}\)) 3426, 3350, 1608, 1423, 1341, 1320, 1304, 1289, 1221, 1065, 905, 857, 798; \(^1\)H NMR (400 MHz, acetone-\(d_6\)) \(\delta\) 10.11 (s, 1H), 8.38 (s, 1H), 7.94 (d, \(J = 8.2\) Hz, 1H), 7.77 (d, \(J = 8.3\) Hz, 1H), 7.46 (s, 1H), 7.12 (dd, \(J = 8.3, 1.8\) Hz, 1H), 6.86 (d, \(J = 8.3\) Hz, 1H), 5.39 (t, \(J = 5.6\) Hz, 1H), 3.66 (d, \(J = 6.4\) Hz, 2H), 1.85 (s, 3H), 1.70 (s, 3H); \(^{13}\)C NMR (100 MHz, acetone-\(d_6\)) \(\delta\) 153.6, 141.1, 140.9, 131.5, 128.9, 122.9, 122.5, 119.9, 118.8, 118.1, 115.8, 110.4, 109.7, 109.2, 24.9, 23.6, 17.2; HRMS (EI+) calcd. for C\(_{17}\)H\(_{16}\)NOCl (M+) 285.0920, found 285.0913.

MRN-V-31, Prenyl benzene 8.40: To a stirred solution of 8.30 (3.784 g, 9.367 mmol) in 2-methyl-2-butene (40.0 mL) was added Grubbs’ 2\(^{nd}\) generation catalyst (253.0 mg, 298 µmol). After 24 h, the mixture was eluted past a silica gel / Celite-® pad with Et\(_2\)O (40 mL), and concentrated \textit{in vacuo} to an impure orange oil. Purification via flash chromatography over silica gel with 5-15% EtOAc / hexanes gave 8.40 (3.30 g, 7.64 mmol, 82%) as a yellow oil. IR (thin film, cm\(^{-1}\)) 1607, 1534, 1500, 1362, 1276, 1255, 928, 869, 839, 780, 759; \(^1\)H NMR (300 MHz, CDCl\(_3\)) \(\delta\) 7.69 (dd, \(J = 8.0, 1.3\) Hz, 1H), 7.68 (dd, \(J = 8.2, 1.2\) Hz, 1H), 7.42 (t, \(J = 8.1\) Hz, 1H), 7.03 (d, \(J = 2.3\) Hz, 1H), 6.99 (dd, \(J = 8.2, 2.3\) Hz, 1H), 6.84 (d, \(J = 8.2\) Hz, 1H), 5.33 (tq, \(J = 7.2, 1.4\) Hz, 1H), 3.34 (d, \(J = 7.1\) Hz, 2H), 1.76 (s, 3H), 1.68 (s, 3H), 1.05, (s, 3H), 0.30 (s, 6H); \(^{13}\)C NMR (75 MHz, CDCl\(_3\)) \(\delta\) 153.9, 151.6, 135.9, 134.8, 133.3, 132.9, 132.4, 130.1, 129.0, 128.3, 127.2, 126.0, 121.9, 121.7, 118.0, 28.5, 25.8, 18.3, 17.8, -4.1; HRMS (EI+) calcd. for C\(_{23}\)H\(_{30}\)NO\(_3\)SiCl (M+) 431.1683, found 431.1693.
Prenyl Benzene 6.44: To a stirred solution of 6.35 (479.7 mg, 1.656 mmol) in 2-methyl-2-butene (10 mL) was added Grubbs' 2nd generation catalyst (20.9 mg, 24.6 µmol). After 24 h, the mixture was eluted past a silica gel / Celite-® pad with Et₂O (30 mL), and concentrated in vacuo to an impure orange oil. Purification via flash chromatography over silica gel with 5-15% EtOAc / hexanes gave 6.44 (460.4 mg, 1.449 mmol, 89%) as a yellow oil. IR (thin film, cm⁻¹) 1608, 1531, 1501, 1471, 1361, 1274, 1255, 1118, 931, 871, 840, 804, 781, 751; ¹H NMR (300 MHz, CDCl₃) δ 7.61 (d, J = 8.0 Hz, 1H), 7.47 (d, J = 7.3 Hz, 1H), 7.35 (t, J = 7.9 Hz, 1H), 6.96 (d, J = 2.3 Hz, 1H), 6.91 (dd, J = 8.2, 2.0 Hz, 1H), 6.84 (d, J = 8.2 Hz, 1H), 5.33 (tq, J = 7.2, 1.3 Hz, 1H), 3.35 (dt J = 5.7 Hz, 2H), 2.18 (s, 3H), 1.76 (s, 3H), 1.68, (s, 3H), 1.06 (s, 9H), 0.30 (s, 6H); ¹³C NMR (75 MHz, CDCl₃) δ 153.2, 150.9, 139.5, 135.4, 133.4, 133.0, 132.4, 129.8, 128.2, 127.3, 126.8, 122.2, 120.8, 118.2, 28.5, 5.8, 20.8, 18.3, 17.8, -4.1; HRMS (EI⁺) calcd. for C₂₄H₃₃NO₃Si (M⁺) 411.2230, found 411.2208.

MRN-V-92, Toluene 6.44: To a pressure vessel was added 8.40 (454.7 mg, 1.052 mmol), PEPPSI-® (9.3 mg, 14 µmol), K₂CO₃ (448.8 mg, 3.247 mmol), dioxane (2.50 mL), and (BOMe)₃ (180.4 mg, 1.437 mmol) sequentially. The vessel was sealed, and heated to 100°C. After 18 h, the mixture was eluted through a Celite-® pad with Et₂O (30 mL) and purified via flash chromatography over silica gel, eluting with 0-25% EtOAc / hexanes to give 6.44 (407.7 mg, 932.2 µmol, 88%) as a yellow oil. IR (thin film, cm⁻¹) 1608,
MRN-V-26, Silyl ether 6.35: To a stirred solution of 8.39 (347.6 g, 1.291 mmol) in CH₂Cl₂ (1.5 mL) was added imid. (128.5 mg, 1.887 mmol) and TBSCI (289.6 mg, 1.921 mmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH₂Cl₂ (2 x 10 mL). The organic part was washed with sat aq. NaCl (2 x 5 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a yellow oil. Purification via flash chromatography over silica gel with 70% PhMe / hexanes gave 6.35 (458.0 mg, 1.190 mmol, 92%) as a bright yellow oil, IR (thin film, cm⁻¹) 1609, 1530, 1361, 1255, 1121, 941, 841, 804, 749, 700; ¹H NMR (400 MHz, CDCl₃) δ 7.63 (d, J = 8.0 Hz, 1H), 7.48 (d, J = 7.1 Hz, 1H), 7.36 (t, J = 7.9 Hz, 1H), 7.05 (d, J = 2.2 Hz, 1H), 6.99 (dd, J = 8.2, 2.2 Hz, 1H), 6.93 (d, J = 8.2 Hz, 1H), 6.05 (ddt, J = 16.6, 6.3, 3.8 Hz, 1H), 5.17-5.03 (m, 2H), 3.58-3.38 (m, 2H), 2.22 (s, 3H), 1.12, (s, 9H), 0.35 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 153.2, 150.9, 139.5, 136.8, 135.2, 133.5, 130.8, 130.6, 128.4, 127.5, 127.3, 120.8, 118.4, 115.8, 34.2, 25.9, 25.7, 20.7, 18.3, -4.1; HRMS (EI⁺) calcd. for C₂₂H₂₉NO₅Si (M⁺) 383.1917, found 383.1923.
MRN-V-24, MRN-V-30, Silyl ether 8.30: To a stirred solution of 6.32 (3.167 g, 11.05 mmol) in CH$_2$Cl$_2$ (14.0 mL) was added imid. (900.0 mg, 13.32 mmol) and TBSCl (1.966 g, 13.04 mmol) sequentially. After 2 h, the mixture was quickly added to an ice slurry, and extracted with CH$_2$Cl$_2$ (2 × 50 mL). The organic part was washed with sat aq. NaCl (2 × 10 mL). The dried (Na$_2$SO$_4$) extract was concentrated in vacuo to give a yellow oil. Purification via flash chromatography over silica gel with 50-100% PhMe / hexanes gave 8.30 (3.784 g, 9.360 mmol, 85%) as a bright yellow oil. IR (thin film, cm$^{-1}$) 1608, 1537, 1503, 1362, 1275, 1247, 1126, 938, 920, 861, 841, 822, 803, 782, 759, 741, 719; $^1$H NMR (400 MHz, CDCl$_3$) δ 7.70 (d, $J$ = 8.1 Hz, 1H), 7.41 (t, $J$ = 7.9 Hz, 1H), 7.09 (s, 1H), 7.04 (dd, $J$ = 8.3, 2.3 Hz, 1H), 6.91 (d, $J$ = 8.2 Hz, 1H), 6.02 (ddt, $J$ = 16.9, 6.3, 3.8 Hz, 1H), 5.17-5.03 (m, 2H), 3.46 (d, $J$ = 5.2 Hz, 2H), 1.09 (s, 9H), 0.33 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 153.9, 151.6, 136.6, 136.0, 134.7, 133.0, 130.9, 130.8, 128.5, 127.7, 126.2, 121.8, 118.2, 115.9, 34.1, 25.8, 18.3, -4.1; HRMS (EI+) calcd. for C$_{21}$H$_{26}$NO$_3$ClSi (M+) 403.1371, found 403.1367.

MRN-IV-70, MRN-V-29 Phenol 6.32: To a stirred solution of 8.40 (4.360 g, 15.21 mmol) in CH$_2$Cl$_2$ (50.0 mL) at -°C, was added BCl$_3$ (16.0 mL, 16.0 mmol, 1 M in hexanes) slowly via syringe. After 15 min, the mixture was warmed gradually to rt over 2 h. The mixture was cooled to 0°C, quenched with MeOH (5 mL) and diluted with CH$_2$Cl$_2$ (100 mL). The organic part was
washed with sat. aq. NH₄Cl (2 x 10 mL) and sat aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo to give a brown oil. Purification via flash chromatography over silica gel with 0-20% EtOAc / PhMe gave pure 6.32 (3.167 g, 11.05 mmol, 73%) as a yellow solid. MP 92-94°C, IR (thin film, cm⁻¹) 3500, 1610, 1531, 1361, 1274, 1124, 919, 821, 804, 760, 739; ¹H NMR (400 MHz, CDCl₃) δ 7.71 (d, J = 8.1 Hz, 1H), 7.43 (t, J = 8.2 Hz, 1H), 7.09-7.02 (m, 2H), 6.89 (d, J = 7.6 Hz, 1H), 6.05 (ddt, J = 12.3, 7.7, 1.7 Hz, 1H), 5.38 (br, 1H), 5.27-5.16 (m, 2H), 3.45 (d, J = 6.2 Hz, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 154.5, 151.5, 136.0, 135.9, 134.5, 133.8, 130.9, 128.7, 128.4, 126.1, 125.7, 121.8, 116.9, 115.9, 34.7; HRMS (EI+) calcd. for C₁₅H₁₂NO₃Cl (M⁺) 289.0506, found 289.0510.

MRN-IV-77, MRN-III-53, MRN-III-55, MRN-III-66, Allyl ether 8.28: To a stirred solution of 8.39 (804.2 mg, 2.951 mmol) and dry DMF (15.0 mL) was added NaH (280.4 mg, 7.010 mmol, 60% dispersion in mineral oil) at 0°C. To this dark red solution was added allyl bromide (1.82 g, 1.30 mL, 15.0 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH₄Cl (20 mL), diluted with EtOAc (100 mL), washed with H₂O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na₂SO₄) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with 0-15% Et₂O / PhMe to give 8.28 (701.3 mg, 2.420 mmol, 82%) as a bright yellow oil. IR (thin film, cm⁻¹) 1611, 1529, 1515, 1360, 1241, 997, 929, 832, 799, 750; ¹H NMR (400 MHz, CDCl₃) δ 7.64 (dd, J = 8.0, 0.5 Hz, 1H), 7.49 (d, J = 7.6 Hz, 1H), 7.36 (t, J = 7.8 Hz, 1H), 7.15 (d, J = 8.8 Hz, 2H), 7.02 (d, J = 8.8 Hz, 2H), 6.11 (ddt, J = 17.2, 10.5, 5.2 Hz, 1H), 5.47 (dq, J = 17.2, 1.6 Hz, 1H), 5.33 (dq, J = 10.5, 1.4 Hz, 1H), 4.59 (dt, J = 5.3, 1.5 Hz, 2H), 2.19 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 158.4, 150.9, 139.6, 134.9, 133.6, 133.3, 129.7, 128.2, 127.7, 120.8,
HRMS (CI+) calcd. for C\textsubscript{16}H\textsubscript{16}NO\textsubscript{3} (M+H) 270.1130, found 270.1128.

MRN-V-23 Phenol 8.9: To a pressure vessel containing 2.19 (1.294 g, 7.126 mmol) and xylenes (14.0 mL) was added known diene 8.41 Error! Bookmark not defined. (4.831 g, 28.70 mmol) at rt. The mixture was heated at 140°C. After 10 h, the reaction was cooled to 0°C and TBAF (29.0 mL, 29.0 mmol, 1 M in THF) was added. After 15 min, the brown mixture was quenched with sat. aq. NH\textsubscript{4}Cl (100 mL), diluted with EtOAc (200 mL), washed with H\textsubscript{2}O (2 x 50 mL), and sat. aq. NaCl (2 x 50 mL). The dried (Na\textsubscript{2}SO\textsubscript{4}) extract was concentrated in vacuo and purified via flash chromatography over silica gel, eluting with 0-35% EtOAc / Hexanes to give the phenol 8.9 (1.928 g) as an impure yellow oil.

MRN-IV-67, MRN-4-73, MRN-V-25, MRN-VI-65, Allyl ether 6.32: To a stirred solution of impure 8.9 (4.850 g, 16.81 mmol) and dry DMF (60.0 mL) was added NaH (1.463 g, 33.62 mmol, 60% dispersion in mineral oil) at 0°C. To this dark green solution was added allyl iodide (2.24 g, 1.60 mL, 18.49 mmol). After 10 min, the yellow solution was quenched with sat. aq. NH\textsubscript{4}Cl (20 mL), diluted with EtOAc (100 mL), washed with H\textsubscript{2}O (10 mL), and sat. aq. NaCl (2 x 10 mL). The dried (Na\textsubscript{2}SO\textsubscript{4}) extract was concentrated in vacuo and purified by flash chromatography over silica gel, eluting with PhMe to give 6.32 (4.36 mg, 15.21 mmol, 90%) as a bright yellow oil. IR (thin film, cm\textsuperscript{-1}) 1610, 1533, 1362, 1179, 1028, 930, 832, 804, 759; \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}) \textsuperscript{δ} 7.71 (dd, J = 7.8, 0.9 Hz, 2H), 7.45 (d, J = 7.7 Hz, 1H), 7.42 (d, J = 7.7 Hz, 1H), 7.20 (d, J = 8.9 Hz, 2H), 7.00 (d, J = 8.9 Hz, 2H), 6.11 (ddt, J = 17.2, 10.5, 5.2 Hz, 1H), 5.47 (dq, J = 17.2, 1.6 Hz, 1H), 5.34 (dq, J = 10.5, 1.4 Hz, 1H), 4.60 (dt, J = 5.3, 1.5 Hz, 2H); \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}) \textsuperscript{δ} 158.9, 151.6,
136.0, 134.3, 133.2, 133.1, 130.1, 128.8, 126.1, 121.9, 112.9, 114.7, 68.8; HRMS (EI+) calcd. for C\textsubscript{15}H\textsubscript{12}NO\textsubscript{3}Cl (M+) 289.0506 found 289.0511.

MRN-V-78, MRN-V-80, Carbazole 6.43a and 6.43b: To a stirred solution of 6.37 (758.7 mg, 1.978 mmol) o-dichlorobenzene (2.5 mL) was added PBu\textsubscript{3} (1.64 g, 2.00 µL, 8.12 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (2.30 mL, 2.30 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH\textsubscript{4}Cl (10 mL) and extracted with EtOAc (2 x 40 mL). The organic part was washed with aq. Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3} (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na\textsubscript{2}SO\textsubscript{4}) was concentrated in vacuo to a brown oil of impure cabazoles 6.43a and 6.43b as a 1:1.3 mix via crude \textsuperscript{1}H-NMR. Purification via flash chromatography over silica gel with 5-15% EtOAc / PhMe gave sequentially cabazoles 6.43a (190.3 mg, 801.9 µmol, 81%) and 6.43b (164.2 mg, 692 µmol, 70%) as a light brown solid, MP 162-165°C, IR (thin film, cm\textsuperscript{-1}) 3410, 3251, 1616, 1435, 1313, 1219, 1130, 1029, 913, 810, 726; \textsuperscript{1}H NMR (300 MHz, acetone-\textsubscript{d}\textsubscript{6}) δ 9.84 (s, 1H), 8.28 (s, 1H), 7.81 (d, J = 7.9 Hz, 1H), 7.73 (s, 1H), 7.20 (t, J = 0.7 Hz, 1H), 7.00-6.88 (m, 2H), 6.12 (ddt, J = 16.7, 6.6, 3.4 Hz, 1H), 5.11 (dq, J = 17.1, 1.6 Hz, 1H), 5.01 (ddt, J = 10.0, 2.3, 1.3 Hz, 1H), 3.52 (d, J = 6.6 Hz, 2H), 2.45 (s, 3H); \textsuperscript{13}C NMR (75 MHz, acetone-\textsubscript{d}\textsubscript{6}) δ 153.8, 140.5, 140.2, 138.2, 133.4, 121.4, 120.4, 119.9, 118.9, 118.6, 116.4, 114.0, 110.5, 96.4, 34.5, 21.1; HRMS (EI+) calcd. for C\textsubscript{16}H\textsubscript{15}NO (M+) 237.1154 found 237.1151.

MRN-V-78 Carbazole 6.43b: MP 128-130°C, IR (thin film, cm\textsuperscript{-1}) 3403, 3299, 1605, 1421, 1312, 1231, 1111, 1079, 910, 856, 791; \textsuperscript{1}H NMR (400 MHz, acetone-\textsubscript{d}\textsubscript{6}) δ 8.71 (s, 1H), 7.77 (d, J = 8.2 Hz, 1H), 7.37 (d, J = 8.2 Hz, 1H),
7.32 (s, 1H), 7.10 (d, J = 2.3 Hz, 1H), 7.03 (dd, J = 8.2, 2.3 Hz, 1H), 6.93 (d, J = 8.2 Hz, 1H), 6.03 (ddt, J = 16.8, 6.6, 3.5 Hz, 1H), 5.10 (dq, J = 17.1, 1.7 Hz, 1H), 5.02 (ddt, J = 10.0, 2.1, 1.3 Hz, 1H), 3.44 (d, J = 6.4 Hz, 2H), 2.47 (s, 3H); 13C NMR (100 MHz, CDCl₃) δ 155.1, 147.5, 143.1, 136.8, 135.8, 132.2, 129.5, 128.7, 128.2, 126.8, 126.7, 123.9, 115.1, 114.9, 33.8, 20.3; HRMS (EI+) calcd. for C₁₆H₁₅NO (M+) 237.1154 found 237.1148.

Carbazole 6.51a and 6.51b: To a stirred solution of 6.46 (758.7 mg, 1.978 mmol) o-dichlorobenzene (2.5 mL) was added PBu₃ (1.64 g, 2.00 µL, 8.12 mmol) at rt and heated to 100°C. After 10 h, the mixture was cooled to 0°C, and TBAF (2.30 mL, 2.30 mmol, 1 M in THF) was added. After 15 min, the reaction was quenched with sat. aq. NH₄Cl (10 mL) and extracted with EtOAc (2 x 40 mL). The organic part was washed with aq. Na₂S₂O₃ (3 x 20 mL, 10% w/v), and sat. aq NaCl (2 x 10 mL). The dried extract (Na₂SO₄) was concentrated in vacuo to a brown oil of impure cabazoles 6.51a and 6.51b as a 1:1.3 mix via crude ¹H-NMR. Purification via flash chromatography over silica gel with 5-15% EtOAc / PhMe gave sequentially cabazoles 6.51a (190.3 mg, 801.9 µmol, 81%) and 6.51b (164.2 mg, 692 µmol, 70%) as a light brown solid.

Carbazole 6.51a: MP 171-173°C; IR (thin film, cm⁻¹) 3505, 1618, 1473, 1436, 1342, 1217, 1150, 808; ¹H NMR (300 MHz, acetone-d₆) δ 9.82 (s, 1H), 8.21 (s, 1H), 7.80 (d, J = 7.9 Hz, 1H), 7.72 (s, 1H), 7.19 (dd, J = 1.4, 0.6 Hz, 1H), 6.94 (s, 1H), 6.91 (dd, J = 1.4, 0.6 Hz, 1H), 5.46 (dp, J = 7.3, 1.4 Hz, 1H), 3.46 (d, J = 7.3 Hz, 2H), 1.78 (d, J = 0.7 Hz, 3H), 1.75 (d, J = 1.1 Hz, 3H); 13C NMR (75 MHz, acetone-d₆) δ 153.9, 140.5, 139.9, 133.2, 130.7, 124.0, 121.4,
120.4, 119.9, 119.9, 118.5, 116.3, 110.5, 96.4, 28.6, 25.1, 21.0, 16.9; HRMS (EI+) calcd. for C_{18}H_{19}NO (M+) 265.1467 found 265.1458

**Carbazole 6.51b:** MP 165-167°C IR (thin film, cm\(^{-1}\)) 3459, 1615, 1376, 1440, 1424, 1226, 1098, 864, 801, 743; \(^1H\) NMR (300 MHz, acetone-\(d_6\)) \(\delta\) 9.78 (s, 1H), 8.21 (s, 1H), 7.81 (d, \(J = 7.9\) Hz, 1H), 7.69 (d, \(J = 8.3\) Hz, 1H), 7.25 (s, 1H), 6.94 (d, \(J = 7.8\) Hz, 1H), 6.79 (d, \(J = 8.3\) Hz, 1H), 5.40 (t, \(J = 6.9\) Hz, 1H), 3.66 (d, \(J = 6.8\) Hz, 2H), 2.45 (s, 3H), 1.85 (s, 3H), 1.68 (s, 3H); \(^{13}C\) NMR (75 MHz, acetone-\(d_6\)) \(\delta\) 152.9, 140.7, 140.6, 133.4, 131.2, 122.8, 121.9, 120.1, 118.6, 117.5, 116.6, 110.7, 109.4, 108.4, 24.9, 23.7, 21.1, 17.2; HRMS (EI+) calcd. for C_{18}H_{19}NO (M+) 265.1467 found 265.1461.
8.3 References


2 Sigma-Aldrich Catalog # 106,046.


4 Sigma-Aldrich Catalog # C4753.

5 Purchased from EMD, GR ACS grade, used without further purification

6 Purchased from Aldrich Chemical Company

7 Purchased from TCI

8 Plates purchased from EMD (Silica Gel 60 F254)

9 TLC analysis was performed on silica gel with 50% EtOAc-hexanes as the eluent and visualization with UV lamp. The toluene starting material has Rf = 0.64, the enamine has Rf = 0.39 (yellow streak due to hydrolysis to aldehyde), and the DMF and DMF-DMA has baseline smear.

10 Solution prepared w/v

11 The solution (approx. 180 mL) contained an equal amount of DMF and enamine 2 by crude 1H-NMR.

12 Prepared w/v

13 Isolated oil has a small amount of impurities ( <1%, seen in 1H-NMR spectra), however, and analytically pure sample can be achieved via flash chromatography over silica gel eluting with PhMe, then recrystallizing over 2% Et2O / hexanes to give a yellow solid.


15 Sigma-Aldrich Catalog # 579,823.

16 Sigma-Aldrich Catalog # C58,800.


20 To a stirred solution of i-Pr2NH (1.42 g, 1.97 mL, 14.1 mmol) in THF (7.78 mL) at -78°C was added dropwise n-BuLi (5.59 mL, 13.2 mmol, 2.4 M in hexanes). After 10 min a white precipitate appeared and the solution was warmed to 0°C. After 5 min, the solution was recooled to -78°C and ready for use.

21 Diazophosphonate was measured via tarred syringe.

22 pH 7 buffer was made double strength.

23 **MRN-X-64:** Each component of the reaction (*i.e.* acetylene, diene mix, and biphenyl) have been separately resubmitted to the reaction conditions (200°C, neat, dark) for 30 min, and 3 h. From this decomposition study, only the diene shows considerable transformation into other products (mostly, anisole and methyl cyclohexanylenolether).

24 CEM Discover S-class

Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

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Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

Appendix

NMR Spectrographic Data
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Aryl Acetylene Substituent Effects:
The Synthesis and Application of Biaryls

Appendix

X-Ray Crystallographic Information
X-ray Crystal Structure Determination. X-ray diffraction intensity data were collected with a Bruker Smart Apex CCD diffractometer using MoKa – radiation (0.71073 Å). Crystallographic data and some details of data collections and refinements for the investigated structures are given in Tables A1-A16. The structures were solved using direct methods, completed by subsequent difference Fourier syntheses, and refined by full matrix least-squares procedures on $F^2$. The non-hydrogen atoms in all structures were refined with anisotropic thermal parameters. Highly disordered solvent molecules were treated by SQUEEZE (Van der Sluis, P. & Spek, A. L. (1990) Acta Cryst. Sect. A, A46, 194-201). All software and scattering factor sources are contained in the SHELXTL (5.10) program package (G. Sheldrick, Bruker XRD, Madison, WI).
Table 1. Crystal data and structure refinement for rc48.

<table>
<thead>
<tr>
<th>Identification code</th>
<th>rc48</th>
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<tbody>
<tr>
<td>Empirical formula</td>
<td>C16 H13 Cl N4 O2</td>
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<tr>
<td>Formula weight</td>
<td>328.75</td>
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<tr>
<td>Temperature</td>
<td>173(2) K</td>
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</table>
Wavelength 0.71073 Å
Crystal system Monoclinic
Space group C2/c
Unit cell dimensions
\[ a = 30.931(6) \text{ Å} \quad a = 90°. \]
\[ b = 7.4285(13) \text{ Å} \quad b = 113.436(2)°. \]
\[ c = 14.506(3) \text{ Å} \quad g = 90°. \]
Volume \( 3058.1(9) \text{ Å}^3 \)
Z 8
Density (calculated) 1.428 Mg/m³
Absorption coefficient 0.265 mm⁻¹
F(000) 1360
Crystal size 0.27 x 0.22 x 0.07 mm³
Theta range for data collection 1.44 to 27.00°.
Index ranges -39 ≤ h ≤ 38, -9 ≤ k ≤ 5, -18 ≤ l ≤ 18
Reflections collected 9853
Independent reflections 3342 [R(int) = 0.0404]
Completeness to theta = 27.00° 99.8 %
Absorption correction Semi-empirical from equivalents
Max. and min. transmission 0.9817 and 0.9319
Refinement method Full-matrix least-squares on F²
Data / restraints / parameters 3342 / 0 / 260
Goodness-of-fit on F² 1.001
Final R indices [I > 2σ(I)] R1 = 0.0505, wR2 = 0.1203
R indices (all data) R1 = 0.0709, wR2 = 0.1331
 Largest diff. peak and hole 0.489 and -0.324 e Å⁻³
Table 1. Crystal data and structure refinement for rc47.

<table>
<thead>
<tr>
<th>Identification code</th>
<th>rc47</th>
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<td>Formula weight</td>
<td>356.80</td>
</tr>
<tr>
<td>Temperature</td>
<td>173(2) K</td>
</tr>
<tr>
<td>Property</td>
<td>Value</td>
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<td>----------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Wavelength</td>
<td>0.71073 Å</td>
</tr>
<tr>
<td>Crystal system</td>
<td>Monoclinic</td>
</tr>
<tr>
<td>Space group</td>
<td>P2(1)/c</td>
</tr>
<tr>
<td>Unit cell dimensions</td>
<td>a = 15.8541(16) Å a = 90°. b = 7.1382(7) Å b = 114.406(2)°. c = 16.7066(17) Å g = 90°.</td>
</tr>
<tr>
<td>Volume</td>
<td>1721.7(3) Å³</td>
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<tr>
<td>Z</td>
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<tr>
<td>Density (calculated)</td>
<td>1.376 Mg/m³</td>
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<tr>
<td>Absorption coefficient</td>
<td>0.243 mm⁻¹</td>
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<tr>
<td>F(000)</td>
<td>744</td>
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<td>Crystal size</td>
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<td>Theta range for data collection</td>
<td>2.46 to 27.00°.</td>
</tr>
<tr>
<td>Index ranges</td>
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<td>Independent reflections</td>
<td>3747 [R(int) = 0.0321]</td>
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<td>Completeness to theta = 27.00°</td>
<td>99.9 %</td>
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<td>Absorption correction</td>
<td>Semi-empirical from equivalents</td>
</tr>
<tr>
<td>Max. and min. transmission</td>
<td>0.9577 and 0.9135</td>
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<tr>
<td>Refinement method</td>
<td>Full-matrix least-squares on F²</td>
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<tr>
<td>Data / restraints / parameters</td>
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<tr>
<td>Goodness-of-fit on F²</td>
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<tr>
<td>Final R indices [I&gt;2sigma(I)]</td>
<td>R1 = 0.0438, wR2 = 0.1219</td>
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<tr>
<td>R indices (all data)</td>
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<td>Largest diff. peak and hole</td>
<td>0.783 and -0.293 e.Å⁻³</td>
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Table 1. Crystal data and structure refinement for rc45a.

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<td>C19 H17 Cl N2 O3</td>
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<tr>
<td>Formula weight</td>
<td>356.80</td>
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</tbody>
</table>
Temperature: 173(2) K
Wavelength: 0.71073 Å
Crystal system: Orthorhombic
Space group: Pca2(1)
Unit cell dimensions:
- \( a = 13.6753(18) \, \text{Å} \) \( a = 90^\circ \)
- \( b = 8.3473(11) \, \text{Å} \) \( b = 90^\circ \)
- \( c = 15.493(2) \, \text{Å} \) \( g = 90^\circ \)
Volume: 1768.5(4) Å³
Z: 4
Density (calculated): 1.340 Mg/m³
Absorption coefficient: 0.236 mm⁻¹
F(000): 744
Crystal size: 0.22 x 0.14 x 0.06 mm³
Theta range for data collection: 2.44 to 27.00°.
Index ranges:
- \(-12 \leq h \leq 17, -10 \leq k \leq 10, -19 \leq l \leq 16\)
Reflections collected: 9680
Independent reflections: 3413 [R(int) = 0.0443]
Completeness to theta = 27.00°: 100.0%
Absorption correction: Semi-empirical from equivalents
Max. and min. transmission: 0.9860 and 0.9499
Refinement method: Full-matrix least-squares on F²
Data / restraints / parameters: 3413 / 9 / 244
Goodness-of-fit on F²: 1.027
Final R indices [I>2σ(I)]: R1 = 0.0541, wR2 = 0.1323
R indices (all data): R1 = 0.0766, wR2 = 0.1484
Absolute structure parameter: 0.22(14)
Largest diff. peak and hole: 0.253 and -0.209 e.Å⁻³
Table 1. Crystal data and structure refinement for rc46.

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<td>Temperature</td>
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<tr>
<td>Wavelength</td>
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<tr>
<td>Crystal system</td>
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<td>Unit cell dimensions</td>
<td>a = 7.1538(6) Å a= 78.9380(10)°.</td>
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<td>b = 8.3848(7) Å b = 87.6670(10)°.</td>
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<td>c = 15.2827(13) Å g = 75.9210(10)°.</td>
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<td>Density (calculated)</td>
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